

IDT Assembler Software Reference Guide Volume 2

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About This Manual



Notes

This manual provides a reference for all real hardware (non-synthetic) assembler instructions. A sister publication of this manual provides an introduction and design overview as well as more detailed descriptions for the following IDT product families:

- ◆ IDT79RC30xx family of 32-bit RISC controllers
- IDT79RC323xx family of 32-bit enhanced MIPS-2 embedded devices
- IDT79RC4xxx 64-BIT RISCONTROLLER family of high-performance 64-bit CPUs
- IDT79RC5000 family of MIPS-4 ISA compatible CPU devices

Summary of Contents

Chapter 1, "CPU Instructions Basics," presents an overview and broad classification of the CPU instruction set of all IDT microprocessors and RISControllers.

Chapter 2, "CPU Instructions Reference," is the detailed reference material for each of the CPU instructions in alphabetical order. Each new instruction starts on a new page and the instruction mnemonic is easily locatable at the top of the page in large bold letters.

Chapter 3, "CPU instructions Encoding," explains the format and encoding of all of the CPU instructions.

Chapter 4, **"FPU Instructions Basics,"** is similar to Chapter 1 except that it deals with the FPU (hardware floating point unit) instructions.

Chapter 5, "FPU Instructions Reference," is similar to Chapter 2 except that it deals with the FPU (hardware floating point unit) instructions.

Chapter 6, "FPU instructions Encoding," is similar to Chapter 3 except that it deals with the FPU (hardware floating point unit) instructions.







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Notes

Introduction

This chapter describes the instruction set architecture (ISA) for the central processing unit (CPU) in the MIPS IV architecture. The CPU architecture defines the non-privileged instructions that execute in user mode. It does not define privileged instructions providing processor control executed by the implementation-specific System Control Processor. Instructions for the floating-point unit (FPU) are described in Chapters 4, 5 and 6.

CPU Instructions Basics

The original MIPS I CPU ISA has been extended in a backward-compatible fashion three times. The ISA extensions are inclusive as the diagram illustrates; each new architecture level (or version) includes the former levels. The description of an architectural feature includes the architecture level in which the feature is (first) defined or extended. The feature is also available in all later (higher) levels of the architecture.

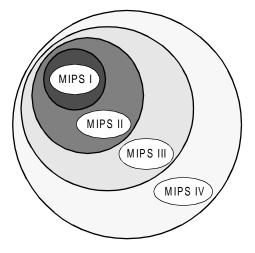


Figure 1.1 MIPS Architecture Extensions

The practical result is that a processor implementing MIPS IV is also able to run MIPS I, MIPS II, or MIPS III user-mode binary programs without change.

It should be noted that there may not always be a one-to-one relationship between an IDT microprocessor or RISController and a MIPS ISA level. Some IDT parts adhere strictly to a MIPS ISA level, some implement a specific MIPS ISA level and also implement additional special instructions (for example, in the case of RC4640, RC4650), while yet others implement a combination of different MIPS ISA levels and also additional special instructions (for example, in the case of RC32364).

The CPU instruction set is first summarized by functional group. In Chapter 2 each instruction is described separately in alphabetical order. Chapter 3 describes the organization of the individual instruction descriptions and the notation used in them (including FPU instructions). It concludes with the CPU instruction formats and opcode encoding tables.

Functional Instruction Groups

CPU instructions are divided into the following functional groups:

- Load and Store
- Arithmetic Logic Unit
- Jump and Branch
- Miscellaneous
- Coprocessor



Load and Store Instructions

Load and store instructions transfer data between the memory system and the general register sets in the CPU and the coprocessors. There are separate instructions for different purposes: transferring various sized fields, treating loaded data as signed or unsigned integers, accessing unaligned fields, selecting the addressing mode, and providing atomic memory update (read-modify-write).

Regardless of byte ordering (big- or little-endian), the address of a halfword, word, or doubleword is the smallest byte address among the bytes forming the object. For big-endian ordering this is the most-significant byte; for a little-endian ordering this is the least-significant byte.

Except for the few specialized instructions listed in Table 1.4, loads and stores must access naturally aligned objects. An attempt to load or store an object at an address that is not an even multiple of the size of the object will cause an Address Error exception.

Load and store operations have been added in each revision of the architecture:

- MIPS II
 - ⁻ 64-bit coprocessor transfers¹
 - ⁻ atomic update
- MIPS III
 - ⁻ 64-bit CPU transfers
 - ⁻ unsigned word load for CPU
- MIPS IV
 - register + register addressing mode for FPU

Table 1.1 and Table 1.2 tabulate the supported load and store operations and indicate the MIPS architecture level at which each operation was first supported. The instructions themselves are listed in the following sections.

	Load Signed		Coprocessor (except 0)		
Data Size			Store	Load	Store
byte	I	I	I		
halfword	I	I	Ι		
word	I	III	Ι	I	Ι
doubleword			III		II
unaligned word	I		Ι		
unaligned doubleword	III		III		
linked word (atomic modify)	II		II		
linked doubleword (atomic modify)	III		III		

Table 1.1 Load/Store Operations Using Register + Offset Addressing Mode

	floating-point co	floating-point coprocessor only		
Data Size	Load	Store		
word	IV	IV		
doubleword	IV	IV		

 Table 1.2 Load/Store Operations Using Register + Register Addressing Mode

^{1.} Even though the RISCore32300 implements MIPS II, double word accesses will signal a trap.



Delayed Loads

The MIPS I architecture defines delayed loads; an instruction scheduling restriction requires that an instruction immediately following a load into register *Rn* cannot use *Rn* as a source register. The time between the load instruction and the time the data is available is the "load delay slot". If no useful instruction can be put into the load delay slot, then a null operation (assembler mnemonic NOP) must be inserted.

In MIPS II, this instruction scheduling restriction is removed. Programs will execute correctly when the loaded data is used by the instruction following the load, but this may require extra real cycles. Most processors cannot actually load data quickly enough for immediate use and the processor will be forced to wait until the data is available. Scheduling load delay slots is desirable for performance reasons even when it is not necessary for correctness.

CPU Loads and Stores

There are instructions to transfer different amounts of data: bytes, halfwords, words, and doublewords. Signed and unsigned integers of different sizes are supported by loads that either sign-extend or zero-extend the data loaded into the register.

Mnemonic	Description	Defined in
LB	Load Byte	I
LBU	Load Byte Unsigned	I
SB	Store Byte	I
LH	Load Halfword	I
LHU	Load Halfword Unsigned	I
SH	Store Halfword	I
LW	Load Word	I
LWU	Load Word Unsigned	III
SW	Store Word	I
LD	Load Doubleword	III
SD	Store Doubleword	III

Table 1.3 Normal CPU Load/Store Instructions

Unaligned words and doublewords can be loaded or stored in only two instructions by using a pair of special instructions. The load instructions read the left-side or right-side bytes (left or right side of register) from an aligned word and merge them into the correct bytes of the destination register. MIPS I, though it prohibits other use of loaded data in the load delay slot, permits LWL and LWR instructions targeting the same destination register to be executed sequentially. Store instructions select the correct bytes from a source register and update only those bytes in an aligned memory word (or doubleword).

Mnemonic	Description	Defined in
LWL	Load Word Left	I
LWR	Load Word Right	I
SWL	Store Word Left	Ι
SWR	Store Word Right	_
LDL	Load Doubleword Left	=
LDR	Load Doubleword Right	=
SDL	Store Doubleword Left	=
SDR	Store Doubleword Right	=

Table 1.4 Unaligned CPU Load/Store Instructions



Atomic Update Loads and Stores

There are paired instructions, Load Linked and Store Conditional, that can be used to perform atomic read-modify-write of word and doubleword cached memory locations. These instructions are used in carefully coded sequences to provide one of several synchronization primitives, including test-and-set, bit-level locks, semaphores, and sequencers/event counts. The individual instruction descriptions describe how to use them.

Mnemonic	Description	Defined in
LL	Load Linked Word	=
SC	Store Conditional Word	II
LLD	Load Linked Doubleword	III
SCD	Store Conditional Doubleword	III

Table 1.5 Atomic Update CPU Load/Store Instructions

Coprocessor Load and Store Instructions

These loads and stores are coprocessor instructions, however it seems more useful to summarize all load and store instructions in one place instead of listing them in the coprocessor instructions functional group.

If a particular coprocessor is not enabled, loads and stores to that processor cannot execute and will cause a Coprocessor Unusable exception. Enabling a coprocessor is a privileged operation provided by the System Control Coprocessor.

Mnemonic	Description	Defined in
LWCz	Load Word to Coprocessor-z	-
SWCz	Store Word from Coprocessor-z	I
LDCz	Load Doubleword to Coprocessor-z	II
SDCz	Store Doubleword from Coprocessor-z	I

Table 1.6 Coprocessor Load/Store Instructions

Description	Defined in
Load Word Indexed to Floating Point	IV
Store Word Indexed from Floating Point	IV
Load Doubleword Indexed to Floating Point	IV
Store Doubleword Indexed from Floating Point	IV
	Load Word Indexed to Floating Point Store Word Indexed from Floating Point Load Doubleword Indexed to Floating Point

Table 1.7 PFU Load/Store Instructions Using Register + Register Addressing

Computational Instructions

Computational instructions perform arithmetic, logical, shift, multiply, and divide operations on values in registers. Two's complement arithmetic is performed on integers represented in two's complement notation. There are signed versions of add, subtract, multiply, and divide. There are add and subtract operations, called "unsigned," that are actually modulo arithmetic without overflow detection. There are unsigned versions of multiply and divide. There is a full complement of shift and logical operations.

MIPS I provides 32-bit integers and 32-bit arithmetic. MIPS III adds 64-bit integers and provides separate arithmetic and shift instructions for 64-bit operands. Logical operations are not sensitive to the width of the register.

Arithmetic Logic Unit

Some arithmetic and logical instructions operate on one operand, from a register and the other from a 16-bit immediate value in the instruction word. The immediate operand is treated as signed for the arithmetic and compare instructions, and treated as logical (zero-extended to register length) for the logical instructions.



Mnemonic	Description	Defined in
ADDI	Add Immediate Word	I
ADDIU	Add Immediate Unsigned Word	I
SLTI	Set on Less Than Immediate	I
SLTIU	Set on Less Than Immediate Unsigned	I
ANDI	And Immediate	I
ORI	Or Immediate	I
XORI	Exclusive Or Immediate	I
LUI	Load Upper Immediate	I
DADDI	Doubleword Add Immediate	III
DADDIU	Doubleword Add Immediate Unsigned	III

Table 1.8 ALU Instructions With an Immediate Operand

Mnemonic	Description	Defined in
ADD	Add Word	I
ADDU	Add Unsigned Word	I
SUB	Subtract Word	I
SUBU	Subtract Unsigned Word	I
DADD	Doubleword Add	III
DADDU	Doubleword Add Unsigned	III
DSUB	Doubleword Subtract	III
DSUBU	Doubleword Subtract Unsigned	III
SLT	Set on Less Than	I
SLTU	Set on Less Than Unsigned	I
AND	And	I
OR	Or	I
XOR	Exclusive Or	I
NOR	Nor	I

Table 1.9 Operand ALU Instructions

Shift Instructions

There are shift instructions that take the shift amount from a 5-bit field in the instruction word and shift instructions that take a shift amount from the low-order bits of a general register. The instructions with a fixed shift amount are limited to a 5-bit shift count, so there are separate instructions for doubleword shifts of 0-31 bits and 32-63 bits.

Mnemonic	Description	Defined in
SLL	Shift Word Left Logical	I
SRL	Shift Word Right Logical	I
SRA	Shift Word Right Arithmetic	I
SLLV	Shift Word Left Logical Variable	I
SRLV	Shift Word Right Logical Variable	I
SRAV	Shift Word Right Arithmetic Variable	I
DSLL	Doubleword Shift Left Logical	III
DSRL	Doubleword Shift Right Logical	III



bleword Shift Right Arithmetic bleword Shift Left Logical + 32 bleword Shift Right Logical + 32	
bleword Shift Right Logical + 32	
0 0	III
bleword Shift Right Arithmetic + 32	III
bleword Shift Left Logical Variable	III
bleword Shift Right Logical Variable	III
bleword Shift Right Arithmetic Variable	
	bleword Shift Right Logical Variable

Multiply and Divide Instructions

Multiply produces a full-width product twice the width of the input operands: the low half is placed in LO and the high half is placed in HI. Integer divides produce both a quotient in LO and a remainder in HI. These results are accessed by instructions that transfer data between these special purpose registers and the general registers.

The RC4650 adds the MAD or MADU instruction (multiply-accumulate or multiply-accumulate unsigned, with HI and LO as the accumulator) to the base MIPS-III ISA. The MAD or MADU instruction uses the HI and LO registers as a 64-bit accumulator. This process allows these instructions to compatibly operate in 32-bit processors.

The RC4650 also adds MUL, a 3-operand $32x32 \rightarrow 32$ multiply instruction that eliminates the need to explicitly move the multiply result from the LO register back to a general register.

Note: After executing the MUL instruction, the HI and LO registers are undefined.

Mnemonic	Description	Defined in
MAD	Multiply/Add	IDT extension
MADU	Multiply/Add Unsigned	IDT extension
MUL	Multiply	IDT extension
MULT	Multiply Word	MIPS I
MULTU	Multiply Unsigned Word	MIPS I
DIV	Divide Word	I
DIVU	Divide Unsigned Word	I
DMULT	Doubleword Multiply	III
DMULTU	Doubleword Multiply Unsigned	III
DDIV	Doubleword Divide	III
DDIVU	Doubleword Divide Unsigned	III
MFHI	Move From HI	I
MTHI	Move To HI	I
MFLO	Move From LO	I
MTLO	Move To LO	

Table 1.11 Multiply/Divide Instructions

Jump and Branch Instructions

The architecture defines PC-relative conditional branches, a PC-region unconditional jump, an absolute (register) unconditional jump, and a similar set of procedure calls that record a return link address in a general register. For convenience this discussion refers to them all as branches.



All branches have an architectural delay of one instruction. When a branch is taken, the instruction immediately following the branch instruction, in the branch delay slot, is executed before the branch to the target instruction takes place. Conditional branches come in two versions that treat the instruction in the delay slot differently when the branch is not taken and execution falls through. The "branch" instructions execute the instruction in the delay slot, but the "branch likely" instructions do not (they are said to nullify it).

By convention, if an exception or interrupt prevents the completion of an instruction occupying a branch delay slot, the instruction stream is continued by re-executing the branch instruction. To permit this, branches must be restartable; procedure calls may not use the register in which the return link is stored (usually register *3*1) to determine the branch target address.

Mnemonic	Description	Defined in
J	Jump	I
JAL	Jump and Link	I

Table 1.12 Jump Instructions Jumping Within a 256 Megabyte Region

Mnemonic	Description	Defined in
JR	Jump Register	Ι
JALR	Jump and Link Register	I

Table 1.13 Jump Instructions to Absolute Address

Mnemonic	Description	Defined in
BEQ	Branch on Equal	I
BNE	Branch on Not Equal	I
BLEZ	Branch on Less Than or Equal to Zero	I
BGTZ	Branch on Greater Than Zero	I
BEQL	Branch on Equal Likely	II
BNEL	Branch on Not Equal Likely	II
BLEZL	Branch on Less Than or Equal to Zero Likely	II
BGTZL	Branch on Greater Than Zero Likely	II

Table 1.14 PC-Relative Conditional Branch Instructions, Comparing 2 Registers

Mnemonic	Description	Defined in
BLTZ	Branch on Less Than Zero	I
BGEZ	Branch on Greater Than or Equal to Zero	I
BLTZAL	Branch on Less Than Zero and Link	I
BGEZAL	Branch on Greater Than or Equal to Zero and Link	Ι
BLTZL	Branch on Less Than Zero Likely	I
BGEZL	Branch on Greater Than or Equal to Zero Likely	II
BLTZALL	Branch on Less Than Zero and Link Likely	II
BGEZALL	Branch on Greater Than or Equal to Zero and Link Likely	I

Table 1.15 PC-Relative Conditional Branch Instructions, Comparing Against Zero

Miscellaneous Instructions

Exception Instructions

Exception instructions have as their sole purpose causing an exception that will transfer control to a software exception handler in the kernel. System call and breakpoint instructions cause exceptions unconditionally. The trap instructions cause exceptions conditionally based upon the result of a comparison.

Mnemonic	Description	Defined in
SYSCALL	System Call	-
BREAK	Breakpoint	I
Table 1.16 System Call and Breakpoint Instructions		

 Mnemonic
 Description
 Defined in

 TGE
 Trap if Greater Than or Equal
 II

 TGEU
 Trap if Greater Than or Equal Unsigned
 II

IGEO		11
TLT	Trap if Less Than	Π
TLTU	Trap if Less Than Unsigned	II
TEQ	Trap if Equal	II
TNE	Trap if Not Equal	Π

 Table 1.17 Trap-on-Condition Instructions, Comparing Two Registers

Mnemonic	Description	Defined in
TGEI	Trap if Greater Than or Equal Immediate	
TGEIU	Trap if Greater Than or Equal Unsigned Immediate	II
TLTI	Trap if Less Than Immediate	II
TLTIU	Trap if Less Than Unsigned Immediate	II
TEQI	Trap if Equal Immediate	II
TNEI	Trap if Not Equal Immediate	II

 Table 1.18 Trap-on-Condition Instructions, Comparing an Immediate

Serialization Instructions

The order in which memory accesses from load and store instruction appears **outside** the processor executing them, such as in a multiprocessor system, is not specified by the architecture. The SYNC instruction creates a point in the executing instruction stream at which the relative order of some loads and stores is known. Loads and stores executed before the SYNC are completed before loads and stores after the SYNC can start.

Mnemonic	Description	Defined in
SYNC	Synchronize Shared Memory	II

Table 1.19 Serialization Instructions

Conditional Move Instructions

Instructions were added in MIPS IV to conditionally move one CPU general register to another, based on the value in a third general register.

Mnemonic	Description	Defined in
MOVN	Move Conditional on Not Zero	IV
MOVZ	Move Conditional on Zero	IV
	Table 1 00 ODU Osmalitismal Marca lusaturatisma	

Table 1.20 CPU Conditional Move Instructions

Prefetch Instructions

There are two prefetch advisory instructions: one with register+offset addressing (PREF) and the other with register+register addressing (PREFX). These instructions advise that memory is likely to be used in a particular way in the near future and should be prefetched into the cache. The PREFX instruction using register+register addressing mode is coded in the FPU opcode space, along with the other operations using register+register addressing. The RC32364 implements PREF instruction.

Mnemonic	Description	Defined in
PREF	Prefetch Indexed	IV

Table 1.21 Prefetch Using Register + Offset Address Mode

Mnemonic	Description	Defined in
PREFX	Prefetch Indexed	IV

Table 1.22 Prefetch Using Register + Register Address Mode

Coprocessor Instructions

Coprocessors are alternate execution units, with register files separate from the CPU. The MIPS architecture provides an abstraction for up to 4 coprocessor units, numbered 0 to 3. Each architecture level defines some of these coprocessors, as shown in Table 1.23.

Coprocessor 0 is always used for system control and coprocessor 1 is used for the floating-point unit. Other coprocessors are architecturally valid, but do not have a reserved use. Some coprocessors are not defined and their opcodes are either reserved or used for other purposes.

MIPS Architecture Level				
coprocessor	I	11	111	IV
0	Sys Control	Sys Control	Sys Control	Sys Control
1	FPU	FPU	FPU	FPU
2	unused	unused	unused	unused
3	unused	unused	not defined	FPU (COP 1X)

Table 1.23 Coprocessor Definition and Use in the MIPS Architecture

The coprocessors may have two register sets—coprocessor general registers and coprocessor control registers—each set containing up to thirty two registers. Coprocessor computational instructions may alter registers in either set.

System control for all MIPS processors is implemented as coprocessor 0 (CP0), the System Control Coprocessor. It provides the processor control, memory management, and exception handling functions. The CP0 instructions are specific to each CPU and are documented with the CPU-specific information.

If a system includes a floating-point unit, it is implemented as coprocessor 1 (CP1). In MIPS IV, the FPU also uses the computation opcode space for coprocessor unit 3, renamed COP1X. The FPU instructions are documented in Chapters 4, 5 and 6.

The coprocessor instructions are divided into these two main groups:

- Load and store instructions that are reserved in the main opcode space.
- Coprocessor-specific operations that are defined entirely by the coprocessor.



Coprocessor Load and Store Instructions

Load and store instructions are not defined for CP0; the move to/from coprocessor instructions are the only way to write and read the CP0 registers. The loads and stores for coprocessors are summarized on page 1-1.

Coprocessor Operations

There are up to four coprocessors and the instructions are shown generically for coprocessor-*z*. Within the operation main opcode, the coprocessor has further coprocessor-specific instructions encoded.

Mnemonic	Description	Defined in
COPz	Coprocessor-z Operation	I

Table 1.24 Coprocessor Operation Instructions

Memory Access Types

MIPS processors provide a few *memory access types* that are characteristic ways to use physical memory and caches to perform a memory access. The memory access type is specified as a cache coherence algorithm (CCA) in the CP0 descriptions of a virtual address. The access type used for a location is associated with the virtual address, not the physical address or the instruction making the reference. Implementations without multiprocessor (MP) support provide uncached and cached accesses. Implementations with MP support provide uncached, cached noncoherent and cached coherent accesses. The memory access types use the memory hierarchy as follows:

Uncached

Physical memory is used to resolve the access. Each reference causes a read or write to physical memory. Caches are neither examined nor modified.

Cached Noncoherent

Physical memory and the caches of the processor performing the access are used to resolve the access. Other caches are neither examined nor modified.

Cached Coherent

Physical memory and all caches in the system containing a coherent copy of the physical location are used to resolve the access. A copy of a location is coherent (noncoherent) if the copy was placed in the cache by a cached coherent (cached noncoherent) access. Caches containing a coherent copy of the location are examined and/or modified to keep the contents of the location coherent. It is unpredictable whether caches holding a noncoherent copy of the location are examined and/or modified to cherent access.

Cached

For early 32-bit processors without MP support, cached is equivalent to cached noncoherent. If an instruction description mentions the cached noncoherent access type, the comment applies equally to the cached access type in a processor that has the cached access type.

For processors with MP support, cached is a collective term, e.g. "cached memory" or "cached access", that includes both cached noncoherent and cached coherent. Such a collective use does not imply that cached is an access type, it means that the statement applies equally to cached noncoherent and cached coherent access types.

Mixing References with Different Access Types

It is possible to have more than one virtual location simultaneously mapped to the same physical location. The memory access type that is used for virtual mappings may be different.

For all accesses to virtual locations with the **same** memory access type, a processor executing load and store instructions must observe the effect of those instructions to a physical location in the order that they occur in the instruction stream (such as program order).



If a processor executes a load or store using one access type to a physical location, the behavior of a subsequent load or store to the same location, using a different memory access type, is undefined unless a privileged instruction sequence is executed between the two accesses. Each implementation has a privileged implementation-specific mechanism that must be used to change the access type being used to access a location.

The 64-bit RISController family allows physical memory to be described simultaneously with different access characteristics, such as write-back and write-through. The caches are physically tagged, and provide sufficient state bites, to ensure memory coherency in a uniprocessor system.

The memory access type of a location affects the behavior of I-fetch, load, store, and prefetch operations to the location. In addition, memory access types affect some instruction descriptions. Load linked (LL, LLD) and store conditional (SC, SCD) have defined operation only for locations with cached memory access type. SYNC affects only load and stores made to locations with uncached or cached coherent memory access types.

Cache Coherence Algorithms and Access Types

The memory access types are specified by implementation-specific cache coherence algorithms (CCAs) in TLB entries. Slightly different cache coherence algorithms such as "cached coherent, update on write" and "cached coherent, exclusive on write" can map to the same memory access type, in this case they both map to cached coherent.

To map to the same access type, the fundamental mechanism of both CCAs must be the same. When it affects the operation of the instruction, the instructions are described in terms of the memory access types. The load and store operations in a processor proceeds according to the specific CCA of the reference, however, and the pseudocode for load and store common functions in the section "Load and Store Memory Functions" on page 1-18 use the CCA value rather than the corresponding memory access type.

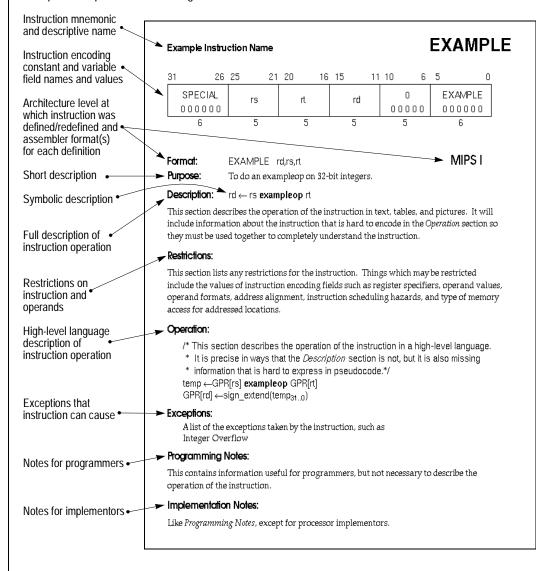
Implementation-Specific Access Types

An implementation may provide memory access types other than uncached, cached noncoherent, or cached coherent. Implementation-specific documentation will define the properties of the new access types and their effect on all memory-related operations.



Instruction Descriptions

The CPU instructions are described in alphabetic order. Each description contains several sections that contain specific information about the instruction. The content of the section is described in detail below. An example description is shown in Figure 1.2.





Instruction Mnemonic and Name

The instruction mnemonic and name are printed as page headings for each page in the instruction description.

Instruction Encoding Picture

The instruction word encoding is shown in pictorial form at the top of the instruction description. This picture shows the values of all constant fields and the opcode names for opcode fields in upper-case. It labels all variable fields with lower-case names that are used in the instruction description. Fields that contain zeroes but are not named are unused fields that are required to be zero. A summary of the instruction formats and a definition of the terms used to describe the contents can be found in **CPU Instruction Formats**.



Format

The assembler formats for the instruction and the architecture level at which the instruction was originally defined are shown. If the instruction definition was later extended, the architecture levels at which it was extended and the assembler formats for the extended definition are shown in order of extension. The MIPS architecture levels are inclusive; higher architecture levels include all instructions in previous levels. Extensions to instructions are backwards compatible. The original assembler formats are valid for the extended architecture.

The assembler format is shown with literal parts of the assembler instruction in upper-case characters. The variable parts, the operands, are shown as the lower-case names of the appropriate fields in the instruction encoding picture. The architecture level at which the instruction was first defined, e.g. "MIPS I", is shown at the right side of the page.

There can be more than one assembler format per architecture level. This is sometimes an alternate form of the instruction. Floating-point operations on formatted data show an assembly format with the actual assembler mnemonic for each valid value of the "fmt" field. For example the ADD.fmt instruction shows ADD.S and ADD.D.

The assembler format lines sometimes have comments to the right in parentheses to help explain variations in the formats. The comments are not a part of the assembler format.

Purpose

This section provides a short statement on the purpose of the instruction.

Description

If a one-line symbolic description of the instruction is feasible, it will appear immediately to the right of the *Description* heading. The main purpose is to show how fields in the instruction are used in the arithmetic or logical operation.

The body of the section is a description of the operation of the instruction in text, tables, and figures. This description complements the high-level language description in the *Operation* section.

This section uses acronyms for register descriptions. "GPR *rt*" is CPU General Purpose Register specified by the instruction field *rt*. "FPR *fs*" is the Floating Point Operand Register specified by the instruction field *fs*. "CP1 register *fd*" is the coprocessor 1 General Register specified by the instruction field *fd*. "FCSR" is the floating-point control and status register.

Restrictions

This section documents the restrictions on the instruction. Most restrictions fall into one of the following six categories:

- The valid values for instruction fields (see floating-point ADD.fmt).
- The alignment requirements for memory addresses (see LW).
- The valid values of operands (see DADD).
- The valid operand formats (see floating-point ADD.fmt).
- The order of instructions necessary to guarantee correct execution.
- The valid memory access types (see LL/SC).

These ordering constraints avoid pipeline hazards for which some processors do not have hardware interlocks (see MUL).

Operation

This section describes the operation of the instruction as pseudocode in a high-level language notation resembling Pascal. The purpose of this section is to describe the operation of the instruction clearly in a form with less ambiguity than prose. This formal description complements the *Description* section; it is not complete in itself because many of the restrictions are either difficult to include in the pseudocode or omitted for readability.

There will be separate *Operation* sections for 32-bit and 64-bit processors if the operation is different. This is usually necessary because the path to memory is a different size on these processors.

See "Operation Section Notation and Functions" on page 1-15 for more information on the formal notation.



Exceptions

This section lists the exceptions that can be caused by **operation** of the instruction. It omits exceptions that can be caused by instruction fetch, e.g. TLB Refill. It omits exceptions that can be caused by asynchronous external events, e.g. Interrupt. Although the Bus Error exception may be caused by the operation of a load or store instruction this section does not list Bus Error for load and store instructions because the relationship between load and store instructions and external error indications, like Bus Error, are implementation dependent.

Reserved Instruction is listed for every instruction not in MIPS I because the instruction will cause this exception on a MIPS I processor. To execute a MIPS II, MIPS III, or MIPS IV instruction, the processor must both support the architecture level and have it enabled. The mechanism to do this is implementation specific.

The mechanism used to signal a floating-point unit (FPU) exception is implementation specific. Some implementations use the exception named "Floating Point". Others use external interrupts (the Interrupt exception). This section lists Floating Point to represent all such mechanisms. The specific FPU traps are listed, indented, under the Floating Point entry.

An instruction may cause implementation-dependent exceptions that are not present in the *Exceptions* section.

Programming and Implementation Notes

These sections contain material that is useful for programmers and implementors respectively but that is not necessary to describe the instruction and does not belong in the description sections.

Operation Section Notation and Functions

In an instruction description, the *Operation* section describes the operation performed by each instruction using a high-level language notation. The contents of the *Operation* section are described here. The special symbols and functions used are documented here.

Pseudocode Language

Each of the high-level language statements is executed in sequential order (as modified by conditional and loop constructs).

Pseudocode Symbols

Special symbols used in the notation are described in Table 1.25.

Symbol	Meaning
	Assignment.
=, ≠	Tests for equality and inequality.
	Bit string concatenation.
х ^у	A <i>y</i> -bit string formed by <i>y</i> copies of the single-bit value <i>x</i> .
x _{yz}	Selection of bits <i>y</i> through <i>z</i> of bit string <i>x</i> . Little-endian bit notation (rightmost bit is 0) is used. If <i>y</i> is less than <i>z</i> , this expression is an empty (zero length) bit string.
+, -	2's complement or floating-point arithmetic: addition, subtraction.
*, ¥	2's complement or floating-point multiplication (both used for either).
div	2's complement integer division.
mod	2's complement modulo.
1	Floating-point division.
<	2's complement less than comparison.
nor	Bit-wise logical NOR.
xor	Bit-wise logical XOR.
and	Bit-wise logical AND.
or	Bit-wise logical OR.
	Table 1.25 Symbols in Instruction Operation Statements (Page 1 of 2)



Symbol	Meaning
GPRLEN	The length in bits (32 or 64), of the CPU General Purpose Registers.
GPR[x]	CPU General Purpose Register x. The content of GPR[0] is always zero.
FPR[x]	Floating-Point operand register x.
FCC[cc]	Floating-Point condition code cc. FCC[0] has the same value as COC[1].
FGR[x]	Floating-Point (Coprocessor unit1), general register x.
CPR[z,x]	Coprocessor unit z, general register x.
CCR[z,x]	Coprocessor unit z, control register x.
COC[z]	Coprocessor unit z condition signal.
BigEndianMem	Endian mode as configured at chip reset (0 \rightarrow Little, 1 \rightarrow Big). Specifies the endianness of the memory interface (see LoadMemory and StoreMemory), and the endianness of Kernel and Supervisor mode execution.
ReverseEndian	Signal to reverse the endianness of load and store instructions. This feature is available in User mode only, and is effected by setting the RE bit of the Status register. Thus, ReverseEndian may be computed as (SR _{RE} and User mode).
BigEndianCPU	The endianness for load and store instructions (0 \rightarrow Little, 1 \rightarrow Big). In User mode, this endianness may be switched by setting the RE bit in the Status Register. Thus, BigEndianCPU may be computed as (BigEndianMem XOR ReverseEndian).
LLbit	Bit of virtual state used to specify operation for instructions that provide atomic read-modify-write. It is set when a linked load occurs. It is tested and cleared by the conditional store. It is cleared, during other CPU operation, when a store to the location would no longer be atomic. In particular, it is cleared by exception return instructions.
l:, l+n:, l-n:	This occurs as a prefix to operation description lines and functions as a label. It indicates the instruct tion time during which the effects of the pseudocode lines appears to occur (i.e. when the pseudocode is "executed"). Unless otherwise indicated, all effects of the current instruction appear to occur during the instruction time of the current instruction. No label is equivalent to a time label of "I:". Sometimes effects of an instruction appear to occur either earlier or later – during the instruction time of another instruction. When that happens, the instruction operation is written in sections labelled with the instruction time, relative to the current instruction I, in which the effect of that pseudocode appears to occur. For example, an instruction may have a result that is not available until after the next instruction. Such an instruction will have the portion of the instruction operation description that writes the result register in a section labelled "I+1:".
	the same time" as the effect of pseudocode statements labelled "I:" for the following instruction. Within one pseudocode sequence the effects of the statements takes place in order. However, between sequences of statements for different instructions that occur "at the same time", there is no order defined. Programs must not depend on a particular order of evaluation between such sections.
PC	The Program Counter value. During the instruction time of an instruction this is the address of the instruction word. The address of the instruction that occurs during the next instruction time is determined by assigning a value to PC during an instruction time. If no value is assigned to PC during ar instruction time by any pseudocode statement, it is automatically incremented by 4 before the next instruction time. A taken branch assigns the target address to PC during the instruction time of the instruction in the branch delay slot.
PSIZE	The SIZE, number of bits, of Physical address in an implementation.



Pseudocode Functions

There are several functions used in the pseudocode descriptions. These are used either to make the pseudocode more readable, to abstract implementation specific behavior, or both. The functions are defined in this section.

Coprocessor General Register Access Functions

Defined coprocessors, except for CPO, have instructions to exchange words and doublewords between coprocessor general registers and the rest of the system. What a coprocessor does with a word or doubleword supplied to it and how a coprocessor supplies a word or doubleword is defined by the coprocessor itself. This behavior is abstracted into the following functions:

COP_LW (z, rt, memword	()
Z:	The coprocessor unit number.
rt:	Coprocessor general register specifier.
memword:	A 32-bit word value supplied to the coprocessor.
This is the action taken by	coprocessor z when supplied with a word from memory during a load word
	oprocessor specific. The typical action would be to store the contents of
<i>memword</i> in coprocessor	
· · · · · · · · · · · · · · · · · · ·	
COP_LD (z, rt, memdoub	
Z:	The coprocessor unit number.
rt:	Coprocessor general register specifier.
memdouble:	64-bit doubleword value supplied to the coprocessor.
	coprocessor z when supplied with a doubleword from memory during a load
doubleword operation. Th	e action is coprocessor specific. The typical action would be to store the
contents of <i>memdouble</i> in	coprocessor general register rt.
dataword " COP_SW (z, r	t)
Z:	The coprocessor unit number.
rt:	Coprocessor general register specifier.
dataword:	32-bit word value.
	ken by coprocessor z to supply a word of data during a store word operation.
	specific. The typical action would be to supply the contents of the low-order
word in coprocessor gene	
datadouble [–] COP_SD (z,	
Z:	The coprocessor unit number.
rt:	Coprocessor general register specifier.
datadouble:	64-bit doubleword value.
	ten by coprocessor z to supply a doubleword of data during a store doubleword
	oprocessor specific. The typical action would be to supply the contents of the
doubleword in coprocesso	or general register <i>rt</i> .
Tab	le 1.26 Coprocessor General Register Access Functions



Load and Store Memory Functions

Regardless of byte ordering (big- or little-endian), the address of a halfword, word, or doubleword is the smallest byte address among the bytes forming the object. For big-endian ordering this is the most-significant byte; for a little-endian ordering this is the least-significant byte.

In the operation description pseudocode for load and store operations, the functions shown below are used to summarize the handling of virtual addresses and accessing physical memory. The size of the data item to be loaded or stored is passed in the *AccessLength* field.

The valid constant names and values are shown in Table 1.27. The bytes within the addressed unit of memory (word for 32-bit processors or doubleword for 64-bit processors) can be determined directly from the AccessLength and the two or three low-order bits of the address.

(pAddr, CCA) "Address"	Translation (vAddr, IorD, LorS)
pAddr:	Physical Address.
CCA:	Cache Coherence Algorithm: the method used to access caches and memory
	and resolve the reference.
vAddr:	Virtual Address.
lorD:	Indicates whether access is for INSTRUCTION or DATA.
LorS:	Indicates whether access is for LOAD or STORE.
Translate a virtual addre	ess to a physical address and a cache coherence algorithm describing the

Translate a virtual address to a physical address and a cache coherence algorithm describing the mechanism used to resolve the memory reference.

Given the virtual address *vAddr*, and whether the reference is to Instructions or Data (*lorD*), find the corresponding physical address (*pAddr*) and the cache coherence algorithm (*CCA*) used to resolve the reference. If the virtual address is in one of the unmapped address spaces the physical address and *CCA* are determined directly by the virtual address. If the virtual address is in one of the mapped address spaces then the TLB is used to determine the physical address and access type; if the required translation is not present in the TLB or the desired access is not permitted the function fails and an exception is taken.

MemElem LoadMemory (CCA, AccessLength, pAddr, vAddr, lorD)

Memelem:	Data is returned in a fixed width with a natural alignment. The width is the	
	same size as the CPU general purpose register, 32 or 64 bits, aligned on a	
	32 or 64-bit boundary respectively.	
CCA:	Cache Coherence Algorithm: the method used to access caches and memory	
	and resolve the reference.	
AccessLength:	Length, in bytes, of access.	
pAddr:	Physical Address.	
vAddr:	Virtual Address.	
lorD:	Indicates whether access is for Instructions or Data.	

Load a value from memory.

Uses the cache and main memory as specified in the Cache Coherence Algorithm (*CCA*) and the sort of access (*lorD*) to find the contents of *AccessLength* memory bytes starting at physical location *pAddr*. The data is returned in the fixed width naturally-aligned memory element (MemElem). The low-order two (or three) bits of the address and the *AccessLength* indicate which of the bytes within *MemElem* needs to be given to the processor. If the memory access type of the reference is uncached then only the referenced bytes are read from memory and valid within the memory element. If the access type is cached, and the data is not present in cache, an implementation specific size and alignment block of memory is read and loaded into the cache to satisfy a load reference. At a minimum, the block is the entire memory element.

CCA.	ssLength, MemElem, pA		athad used to access	cachoc and mar
CCA:	Cache Coherence Algo and resolve the referen		emou used to access	caches and mem
AccessLength:	Length, in bytes, of acc			
MemElem:	Data in the width and al size as the CPU genera byte boundary. For a pa stored must be valid.	ignment of a al purpose r	egister, 4 or 8 bytes,	aligned on a 4 or
pAddr:	Physical Address.			
vAddr:	Virtual Address.			
Store a value to memory. The specified data is store nain memory) as specified				
or an aligned, fixed-width rocessors), though only t wo (or three) bits of <i>pAdd</i>	he bytes that will actually Ir and the <i>AccessLength</i> f	be stored to ield indicate	o memory need to be as which of the bytes	valid. The low-ord
ata should actually be sto	orea; only these bytes in	memory will	be changed.	
Prefetch (CCA, pAddr, vA CCA:	ddr, DATA, hint) Cache Coherence Algo and resolve the referen		ethod used to access	caches and mem
pAddr:	physical Address.			
vAddr:	Virtual Address.			
DATA:	Indicates that access is			
hint:	nint that indicates the h			
rofotch data from momor			of the data.	
Prefetch data from memor Prefetch is an advisory ins nay increase performance tate.	y. truction for which an imp	lementation	specific action is tak	
Prefetch is an advisory ins hay increase performance tate.	y. truction for which an imp	lementation	specific action is tak	
Prefetch is an advisory ins hay increase performance tate.	y. truction for which an imple but must not change the essLength Name	lementation meaning of	specific action is tak the program or alter a	
Prefetch is an advisory ins hay increase performance tate.	y. truction for which an implet but must not change the essLength Name	lementation meaning of Value	specific action is tak the program or alter a Meaning	
Prefetch is an advisory ins hay increase performance tate. Acc DOUBLE	y. truction for which an imple but must not change the essLength Name EWORD YTE	lementation meaning of Value 7	specific action is tak the program or alter a Meaning 8 bytes (64 bits)	
Prefetch is an advisory instay increase performance tate.	y. truction for which an imple but must not change the essLength Name EWORD YTE YTE	lementation meaning of Value 7 6	specific action is tak the program or alter a Meaning 8 bytes (64 bits) 7 bytes (56 bits)	
Prefetch is an advisory instay increase performance tate. Acc DOUBLE SEPTIB'	y. truction for which an imple but must not change the essLength Name EWORD YTE YTE	lementation meaning of Value 7 6 5	specific action is tak the program or alter a Meaning 8 bytes (64 bits) 7 bytes (56 bits) 6 bytes (48 bits)	
Prefetch is an advisory instay increase performance tate. DOUBLE SEPTIBY SEXTIBY QUINTIE	y. truction for which an imple but must not change the essLength Name WORD YTE YTE BYTE	lementation meaning of Value 7 6 5 4	specific action is tak the program or alter a Meaning 8 bytes (64 bits) 7 bytes (56 bits) 6 bytes (48 bits) 5 bytes (40 bits)	
Prefetch is an advisory instate hay increase performance tate. DOUBLE SEPTIB' SEXTIB' QUINTIE WORD	y. truction for which an imple but must not change the essLength Name EWORD YTE YTE BYTE BYTE	lementation meaning of Value 7 6 5 4 3	specific action is tak the program or alter a Meaning 8 bytes (64 bits) 7 bytes (56 bits) 6 bytes (48 bits) 5 bytes (40 bits) 4 bytes (32 bits)	
Prefetch is an advisory instay increase performance tate. Acc DOUBLE SEPTIBY SEXTIBY QUINTIE WORD TRIPLEE	y. truction for which an imple but must not change the essLength Name EWORD YTE YTE BYTE BYTE	Value 7 6 5 4 3 2	specific action is tak the program or alter a Meaning 8 bytes (64 bits) 7 bytes (56 bits) 6 bytes (48 bits) 5 bytes (40 bits) 4 bytes (32 bits) 3 bytes (24 bits)	



Access Functions for Floating-Point Registers

The details of the relationship between CP1 general registers and floating-point operand registers is encapsulated in the functions included in this section. See Valid Operands for FP Instructions in the Chapter Titled "FPU Instruction Set" for more information.

This function returns the current logical width, in bits, of the CP1 general registers. All 32-bit processors will return "32". 64-bit processors will return "32" when in 32-bit-CP1-register emulation mode and "64" when in native 64-bit mode.

The following pseudocode referring to the $Status_{FR}$ bit is valid for all existing MIPS 64-bit processors at the time of this writing, however this is a privileged processor-specific mechanism and it may be different in some future processor.

```
SizeFGR() -- current size, in bits, of the CP1 general registers

size "SizeFGR()

if 32_bit_processor then

size "32

else

/* 64-bit processor */

if Status<sub>FR</sub> = 1 then

size "64

else

size "32

endif

endif
```

This pseudocode specifies how the unformatted contents loaded or moved-to CP1 registers are interpreted to form a formatted value. If an FPR contains a value in some format, rather than unformatted contents from a load (uninterpreted), it is valid to interpret the value in that format, but not to interpret it in a different format.

```
ValueFPR() -- Get a formatted value from an FPR.
value ValueFPR (fpr, fmt)
                                       /* get a formatted value from an FPR */
     if SizeFGR() = 64 then
          case fmt of
               S. W:
                    value FGR[fpr]31..0
              D, L:
                    value FGR[fpr]
          endcase
     elseif fpr<sub>0</sub> = 0 then
                                       /* fpr is valid (even), 32-bit wide FGRs */
          case fmt of
               S, W:
                   value FGR[fpr]
              D, L:
                    value FGR[fpr+1] || FGR[fpr]
          endcase
     else
                                       /* undefined for odd 32-bit FGRs */
          UndefinedResult
     endif
```

This pseudocode specifies the way that a binary encoding representing a formatted value is stored into CP1 registers by a computational or move operation. This binary representation is visible to store or movefrom instructions. Once an FPR contains a value via StoreFPR(), it is not valid to interpret the value with ValueFPR() in a different format.

StoreFPR() -- store a formatted value into an FPR. StoreFPR(fpr, fmt, value): /* place a formatted value into an FPR */ if SizeFGR() = 64 then /* 64-bit wide FGRs */ case fmt of S, W: FGR[fpr] " undefined³² || value D, L: FGR[fpr] value endcase elseif $fpr_0 = 0$ then /* fpr is valid (even), 32-bit wide FGRs */ case fmt of S, W: FGR[fpr+1] undefined³² FGR[fpr] value D, L: FGR[fpr+1] value_{63.32} FGR[fpr] value_{31.0} endcase else /* undefined for odd 32-bit FGRs */ UndefinedResult endif **Miscellaneous Functions** SyncOperation(stype) Type of load/store ordering to perform. stype: order loads and stores to synchronize shared memory. Perform the action necessary to make the effects of groups synchronizable loads and stores indicated by stype occur in the same order for all processors. SignalException(Exception) Exception The exception condition that exists. Signal an exception condition. This will result in an exception that aborts the instruction. The instruction operation pseudocode will never see a return from this function call. UndefinedResult() This function indicates that the result of the operation is undefined. NullifyCurrentInstruction() Nullify the current instruction. This occurs during the instruction time for some instruction and that instruction is not executed further. This appears for branch-likely instructions during the execution of the instruction in the delay slot and it kills the instruction in the delay slot. CoprocessorOperation (z, cop_fun) Coprocessor unit number Ζ Coprocessor function from function field of instruction cop_fun Perform the specified Coprocessor operation.



Individual CPU Instruction Descriptions

The user-mode CPU instructions are described in alphabetic order. See "Instruction Descriptions" on page 1-13 for a description of the information in each instruction description.









CPU Instruction Reference

Notes

This chapter contains the detailed reference material for each of the CPU instructions in alphabetical order. Each new instruction starts on a new page and the instruction mnemonic is easily locatable at the top of the page in large bold letters.



31 26 2	25 21	20 16	15 11	10 6	5 0
SPECIAL	rs	rt	rd	0	ADD
000000	10	i.	i u	00000	100000
6	5	5	5	5	6
Format: Al	DD rd, rs, rt				MIPS I

Purpose:

To add 32-bit integers. If overflow occurs, then trap.

a.p.....

Description: $rd \leftarrow rs + rt$

The 32-bit word value in GPR *rt* is added to the 32-bit value in GPR *rs* to produce a 32-bit result. If the addition results in 32-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 32-bit result is placed into GPR *rd*.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif temp ← GPR[rs] + GPR[rt] if (32_bit_arithmetic_overflow) then

SignalException(IntegerOverflow)

```
else
```

 $GPR[rd] \leftarrow sign_extend(temp_{31..0})$ endif

Exceptions:

Integer Overflow

Programming Notes:

ADDU performs the same arithmetic operation but, does not trap on overflow.



31	26	25 21	20 16	15 0	
	ADDI 0 0 1 0 0 0	rs	rt	immediate	
	6	5	5	16	
For	mat:	ADDI rt, rs, im	MIPS I		
Pur	Purpose: To add a constant to a 32-bit integer. If overflow occurs, then trap.				

Description: $rt \leftarrow rs + immediate$

The 16-bit signed *immediate* is added to the 32-bit value in GPR *rs* to produce a 32-bit result. If the addition results in 32-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 32-bit result is placed into GPR *rt*.

Restrictions:

On 64-bit processors, if GPR *rs* does not contain a sign-extended 32-bit value (bits 63..31 equal), then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rs])) then UndefinedResult() endif temp ← GPR[rs] + sign_extend(immediate) if (32_bit_arithmetic_overflow) then

SignalException(IntegerOverflow)

```
else
```

 $GPR[rt] \leftarrow sign_extend(temp_{31..0})$ endif

Exceptions:

Integer Overflow

Programming Notes:

ADDIU performs the same arithmetic operation but, does not trap on overflow.



31	26	25 21	20 16	15 0
	ADDIU 0 0 1 0 0 1	rs	rt	immediate
	6	5	5	16
Format: ADDIU rt, rs, immediate		nmediate	MIPS I	

Purpose: To add a constant to a 32-bit integer.

Description: $rt \leftarrow rs + immediate$

The 16-bit signed *immediate* is added to the 32-bit value in GPR *rs* and the 32-bit arithmetic result is placed into GPR *rt*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if GPR *rs* does not contain a sign-extended 32-bit value (bits 63..31 equal), then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rs])) then UndefinedResult() endif temp \leftarrow GPR[rs] + sign_extend(immediate) GPR[rt] \leftarrow sign_extend(temp_{31..0})

Exceptions:

None

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	ADDU 1 0 0 0 0 1
6	5	5	5	5	6
Format:	ADDU rd, rs, rt				MIPS I

Purpose: To add 32-bit integers.

Description: $rd \leftarrow rs + rt$

The 32-bit word value in GPR *rt* is added to the 32-bit value in GPR *rs* and the 32-bit arithmetic result is placed into GPR *rd*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

Operation:

```
if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif
temp \leftarrow GPR[rs] + GPR[rt]
GPR[rd] \leftarrow sign_extend(temp<sub>31.0</sub>)
```

Exceptions:

None

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.



31	26	25	21	20		16	15		11	10	6	5		0
SPE 0 0 0	CIAL 0 0 0		rs		rt			rd		0 0 0 0 0 0			AND 1 0 0 1 0 0	
	6		5		5	•		5		5			6	
Format: AND rd, rs, rt												MIPS I		
Purpose:		To do a bitwise logical AND.												

Description: $rd \leftarrow rs AND rt$

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical AND operation. The result is placed into GPR *rd*.

Restrictions:

None

Operation:

 $GPR[rd] \leftarrow GPR[rs]$ and GPR[rt]

Exceptions:

None



And Immediate

31	26	25	21	20		16	15 0	1	
ANDI 0 0 1 1 (rs			rt		immediate		
6		5			5		16	-	
Format:	Format:ANDI rt, rs, immediateMIPS I								
Purpose:		To do a bitv	vise l	ogical	AND	with	a constant.		
Description: $rt \leftarrow rs AND$ immediate									
The 16-bit <i>immediate</i> is zero-extended to the left and combined with the contents of GPR <i>rs</i> in a bitwise logical AND operation. The result is placed into GPR <i>rt</i> .									

Restrictions:

None

Operation:

GPR[rt] ← zero_extend(immediate) and GPR[rs]

Exceptions:

None



				Branch on Equ	ual			
31	26	25 21	20 1	16 15	0			
	BEQ 0 0 0 1 0 0	rs	rt	offset				
	6	5	5	16				
Format:		BEQ rs, rt, offs	set	MIPS I				
Purpose:		To compare GPRs then do a PC-relative conditional branch.						

Description: if (rs = rt) then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are equal, branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow (GPR[rs] = GPR[rt])

I+1: if condition then

 $\mathsf{PC} \gets \mathsf{PC} + \mathsf{tgt_offset}$ endif

Exceptions:

None

Programming Notes:

31	26	25 21	20 16	15 0
	BEQL 0 1 0 1 0 0	rs	rt	offset
	6	5	5	16
Fo	rmat:	BEQL rs, rt, of	fset	MIPS II
Purpose: To compare GPRs the branch is taken				relative conditional branch; execute the delay slot only

Description: if (rs = rt) then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are equal, branch to the target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow (GPR[rs] = GPR[rt])

```
I+1: if condition then
```

 $PC \leftarrow PC + tgt_offset$

```
else
```

NullifyCurrentInstruction()

endif

Exceptions:

Reserved Instruction

Programming Notes:



Branch on Greater Than or Equal to Zero 26 25 21 20 0 31 16 15 offset REGIMM BGEZ rs $0\ 0\ 0\ 0\ 1$ 00001 5 5 16 6 **MIPS I** Format: BGEZ rs, offset Purpose: To test a GPR then do a PC-relative conditional branch.

Description: if $(rs \ge 0)$ then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow GPR[rs] \ge 0^{GPRLEN}

```
I+1: if condition then
```

```
PC \leftarrow PC + tgt_offset
```

endif

Exceptions:

None

Programming Notes:



Branch on Greater Than or Equal to Zero and Link

31	26	25 21	20 16	15	0
	REGIMM 0 0 0 0 0 1	rs	BGEZAL 1 0 0 0 1	offset	
	6	5	5	16	
For	mat:	BGEZAL rs,	offset		MIPS I
Pur	pose:	To test a GPF			
-					

Description: if $(rs \ge 0)$ then procedure_call

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution would continue after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow GPR[rs] $\ge 0^{GPRLEN}$ GPR[31] \leftarrow PC + 8 I+1: if condition then PC \leftarrow PC + tgt_offset

endif

Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to more distant addresses.



Branch on Greater Than or Equal to Zero and Link Likely

31	26	25	21	20	16	15 0			
	REGIMM 0 0 0 0 0 1	r	S	BGEZALI 1 0 0 1 1	L	offset			
	6		5	5		16			
Format: BGEZALL rs, offset						MIPS II			
Purpose:		To test a GPR then do a PC-relative conditional procedure call; execute the delay slot only if the branch is taken.							

Description: if $(rs \ge 0)$ then procedure_call_likely

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution would continue after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

```
I: tgt_offset \leftarrow sign_extend(offset || 0^2)

condition \leftarrow GPR[rs] \ge 0^{GPRLEN}

GPR[31] \leftarrow PC + 8

I+1: if condition then

PC \leftarrow PC + tgt_offset

else

NullifyCurrentInstruction()

endif
```

Exceptions:

Reserved Instruction

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to more distant addresses.



Branch on Greater Than or Equal to Zero Likely

31	l	26	25	21	20	16	15 0			
	REGIMM 0 0 0 0 0 1		rs		BGEZL 0 0 0 1 1		offset			
	6		5		5		16			
Format: BGEZL rs, offset						MIPS II				
Purpose:			To test a GPR then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.							

Description: if $(rs \ge 0)$ then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than or equal to zero (sign bit is 0), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

```
I: tgt_offset \leftarrow sign_extend(offset || 0<sup>2</sup>)
condition \leftarrow GPR[rs] \ge 0<sup>GPRLEN</sup>
I+1: if condition then
```

```
PC \leftarrow PC + tgt_offset
```

```
else
```

```
NullifyCurrentInstruction()
```

```
endif
```

Exceptions:

Reserved Instruction

Programming Notes:



Branch on Greater Than Zero 0 26 25 21 20 16 15 31 offset BGTZ 0 rs 00000 000111 6 5 5 16 **MIPS I** Format: BGTZ rs, offset Purpose: To test a GPR then do a PC-relative conditional branch.

Description: if (rs > 0) then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than zero (sign bit is 0 but value not zero), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow GPR[rs] > 0^{GPRLEN}

```
I+1: if condition then
```

 $PC \leftarrow PC + tgt_offset$

endif

Exceptions:

None

Programming Notes:



31	26	25 21	20 16	15 0			
	BGTZL 0 1 0 1 1 1	rs	0 0 0 0 0 0	offset			
	6	5	5	16			
Format:		BGTZL rs, offs	et	MIPS II			
Purpose:		To test a GPR then do a PC-relative conditional branch; execute the delay slot onl branch is taken.					

Description: if (rs > 0) then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are greater than zero (sign bit is 0 but value not zero), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

```
I: tgt_offset \leftarrow sign_extend(offset || 0<sup>2</sup>)
condition \leftarrow GPR[rs] > 0<sup>GPRLEN</sup>
I+1: if condition then
```

```
PC ← PC + tgt_offset
else
NullifyCurrentInstruction()
endif
```

Exceptions:

Reserved Instruction

Programming Notes:



31	26	25 21	20 16	15	0
	BLEZ 0 0 0 1 1 0	rs	0 0 0 0 0 0	offset	
	6	5	5	16	
	rmat: rpose:	BLEZ rs, offset To test a GPR t	ative conditional branch.	MIPS I	
De	scription:	if (rs \leq 0) then b	ranch		

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than or equal to zero (sign bit is 1 or value is zero), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow GPR[rs] \leq 0^{GPRLEN}

```
I+1: if condition then
```

 $PC \leftarrow PC + tgt_offset$

endif

Exceptions:

None

Programming Notes:

RENESAS BLEZL

Branch on Less Than or Equal to Zero Likely

3	1 2	26	25 21	20	16	15 0				
	BLEZL 0 1 0 1 1 0		rs	00000)	offset				
	6		5	5		16				
F	ormat:	MIPS II								
Purpose:			To test a GPR then do a PC-relative conditional branch; execute the delay slot only if the branch is taken.							

Description: if $(rs \le 0)$ then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than or equal to zero (sign bit is 1 or value is zero), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

```
I: tgt_offset \leftarrow sign_extend(offset || 0<sup>2</sup>)
condition \leftarrow GPR[rs] \leq 0<sup>GPRLEN</sup>
I+1: if condition then
```

```
PC ← PC + tgt_offset
else
NullifyCurrentInstruction()
endif
```

Exceptions:

Reserved Instruction

Programming Notes:



31	26	25 21	20 16	15	0
	REGIMM 0 0 0 0 0 1	rs	BLTZ 0 0 0 0 0	offset	
	6	5	5	16	
Format: Purpose:		BLTZ rs, offset To test a GPR th		N tive conditional branch.	NPS I

Description: if (rs < 0) then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow GPR[rs] < 0^{GPRLEN}

```
I+1: if condition then
```

```
\mathsf{PC} \gets \mathsf{PC} + \mathsf{tgt\_offset} endif
```

orran

Exceptions:

None

Programming Notes:



				Dranch on Less man Zero And Link	
31	26	25 21	20 16	15 0	
	EGIMM 0 0 0 0 1	rs	BLTZAL 1 0 0 0 0	offset	
	6	5	5	16	,
Format: Purpose		BLTZAL rs, off To test a GPR th		MIPS I tive conditional procedure call.	
Descrip	tion:	if $(rs < 0)$ then p	ocedure call		

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch (**not** the branch itself), where execution would continue after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch, in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

I: $tgt_offset \leftarrow sign_extend(offset || 0^2)$ $condition \leftarrow GPR[rs] < 0^{GPRLEN}$ $GPR[31] \leftarrow PC + 8$ I+1: if condition then $PC \leftarrow PC + tgt_offset$ endif

Exceptions:

None

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to more distant addresses.

RENESAS

Branch on Less Than Zero And Link Likely

	31	26	25 21	20 16	15 0
	REGIMM 0 0 0 0 0 1		rs	BLTZALL 1 0 0 1 0	offset
	6		5	5	16
Format: Purpose:			BLTZALL rs, c To test a GPR t only if the brand	hen do a PC-relati	MIPS II ve conditional procedure call; execute the delay slot

Description: if (rs < 0) then procedure_call_likely

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch (**not** the branch itself), where execution would continue after a procedure call.

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch, in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

Operation:

I: tgt_offset ← sign_extend(offset || 0²) condition ← GPR[rs] < 0^{GPRLEN} GPR[31] ← PC + 8 I+1: if condition then

```
PC \leftarrow PC + tgt_offset
```

```
else
```

NullifyCurrentInstruction() endif

Exceptions:

Reserved Instruction

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to more distant addresses.



31	26	25 21	20 16	15 0
	REGIMM 0 0 0 0 0 1	rs	BLTZL 0 0 0 1 0	offset
	6	5	5	16
Fo	rmat:	BLTZ rs, offset		MIPS II
Purpose:		To test a GPR th branch is taken.	en do a PC-relat	ive conditional branch; execute the delay slot only if the

Description: if (rs < 0) then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* are less than zero (sign bit is 1), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

```
I: tgt_offset ← sign_extend(offset || 0<sup>2</sup>)
condition ← GPR[rs] < 0<sup>GPRLEN</sup>
I+1: if condition then
```

```
PC ← PC + tgt_offset
else
NullifyCurrentInstruction()
endif
```

Exceptions:

Reserved Instruction

Programming Notes:



31	26	25 21	20 16	15	0
	BNE 0 0 0 1 0 1	rs	rt	offset	
	6	5	5	16	
Format: BNE rs, rt, offset			et		MIPS I
Purpose:		To compare GP	Rs then do a PC	-relative conditional branch.	

Description: if $(rs \neq rt)$ then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are not equal, branch to the effective target address after the instruction in the delay slot is executed.

Restrictions:

None

Operation:

I: tgt_offset \leftarrow sign_extend(offset || 0²) condition \leftarrow (GPR[rs] \neq GPR[rt])

- I+1: if condition then
 - $\mathsf{PC} \gets \mathsf{PC} + \mathsf{tgt_offset}$ endif

Exceptions:

None

Programming Notes:

31	26	25	21 20)	16	15 0
	BNEL 0 1 0 1 0 1	rs		rt		offset
	6	5		5		16
For	mat:	BNEL rs, rt,	offset			MIPS II
Pur	pose:	To compare if the branch			PC-	relative conditional branch; execute the delay slot only

Description: if $(rs \neq rt)$ then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the contents of GPR *rs* and GPR *rt* are not equal, branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

Restrictions:

None

Operation:

```
I: tgt_offset ← sign_extend(offset || 0<sup>2</sup>)
condition ← (GPR[rs] ≠ GPR[rt])
I+1: if condition then
```

```
PC ← PC + tgt_offset
else
NullifyCurrentInstruction()
endif
```

Exceptions:

Reserved Instruction

Programming Notes:



31	26	25	650
SPE 0 0 0	CIAL 0 0 0	code	BREAK 0 0 1 1 0 1
6		20	6
Format:	BREAK		MIPS I

Purpose: To cause a Breakpoint exception.

Description:

A breakpoint exception occurs, immediately and unconditionally transferring control to the exception handler.

The *code* field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

Restrictions:

None

Operation:

SignalException(Breakpoint)

Exceptions:

Breakpoint

CACHE op, offset(base)

CACHE

31 26	25 21	20 16	15 0
CACHE 101111	base	ор	offset
6	5	5	16

Format: CACHE op, offset(base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The virtual address is translated to a physical address, and the 5-bit sub-opcode specifies a cache operation for that address.

If CP0 is not usable (User or Supervisor mode) the CP0 enable bit in the *Status* register is clear, and a coprocessor unusable exception is taken. The operation of this instruction on any operation/cache combination not listed below is undefined. The operation of this instruction on uncached addresses is also undefined.

The 64-bit RISController family uses only the tag comparisons, not the valid bits, to choose which data it supplies to the instruction unit. This makes it important that the tags of the A and B sets are never the same.

The Index operation uses part of the virtual address to specify a cache block and set access as shown in Table 2.28

64-bit RISController- Family Processor	Set Selection	Block Selection
RC4640/RC4650	VAddr ₁₂	115
RC4700	VAddr ₁₃	125
RC5000	VAddr ₁₄	135

Table 2.28 64-bit RISController Family Primary Cache Indexing

Index Load Tag also uses vAddr_{4..3} to select the doubleword for reading parity. When the CE bit of the Status register is set, Hit WriteBack, Hit WriteBack Invalidate, Index WriteBack Invalidate, and Fill also use vAddr_{4.3} to select the doubleword that has its parity modified. This operation is performed unconditionally.

The Hit operation accesses the specified cache as normal data references, and performs the specified operation if the cache block contains valid data with the specified physical address (a hit). If both sets are invalid or contain different addresses (a miss), no operation is performed.

Write back from a primary cache goes to memory. The address to be written is specified by the cache tag and not the translated physical address.

For Index operations (where the physical address is used to index the cache but need not match the cache tag), unmapped addresses may be used to avoid exceptions.

This operation will never cause Virtual Coherency exceptions.

Bits 17..16 of the instruction specify the cache as follows:

Code	Name	Cache	
0	I	Primary instruction	
1	D	Primary data	
2	NA	Undefined	
3	SC	Secondary Cache (RV5000)	

Bits 20..18 (this value is listed under the Code column) of the instruction specify the operation as follows:

Code	Caches	Name	Operation	
0	1	Index Invalidate	Set the cache state of the cache block to Invalid. Index_Invalidate_I writes the physical address of the cache op into the tag when it clears the valid bit, which is different from the RC4000.	
0	D	Index WriteBack Invalidate	Examine the cache state and W bit of the primary data cache block at the index specified by the virtual address. If the state is not Invalid and the W bit is set, then write back the block to memory. The address to write is taken from the primary cache tag. Set cache state of primary cache block to Invalid.	
0	SC	Cache Clear	Generate a valid clear sequence to flush the entire cache in one o tion.	
1	I, D	Index Load Tag	g Read the tag for the cache block at the specified index and place the TagLo CP0 registers, ignoring parity errors. Also load the dat bits into the ECC register.	
1	SC	Index Load Tag	Read the secondary cache for the specified index and places it into the TagLo CPO register.	
2	I, D	Index Store Tag	Write the tag for the cache block at the specified index from the TagLo and TagHi CP0 registers.	
2	SC	Index Store Tag	Write the secondary cache for the specified index from the physical address generated by the CACHE instruction.	
3	D	Create Dirty Exclusive	This operation is used to avoid loading data needlessly from memory when writing new contents into an entire cache block. If the cache block does not contain the specified address, and the block is dirty, write it back to the memory. In all cases, set the cache block tag to the specified physical address, set the cache state to Dirty Exclusive.	
4	I, D	Hit Invalidate	If the cache block contains the specified address, mark the cache block invalid.	
5	D	<i>Hit WriteBack</i> Invalidate	If the cache block contains the specified address, write back the data if i is dirty, and mark the cache block invalid.	
5	1	Fill	Fill the primary instruction cache block from memory. If the CE bit of the Status register is set, the contents of the ECC register is used instead o the computed parity bits for addressed doubleword when written to the instruction cache.	
5	SC	Cache Page Invalidate	Flush 128 lines of the cache in one operation with the tag value from the TagLo CPO register. The index for the cache page invalidate must be page aligned. Interrupts are deferred until a cache page invalidate instruction completes (up to 512 processor clocks for a SysClock ratio o 4).	

RENESAS

CACHE



Code	Caches	Name	Operation
6	D	Hit WriteBack	If the cache block contains the specified address, and the W bit is set, write back the data to memory and clear the W bit.
6	-	Hit WriteBack	If the cache block contains the specified address, write back the data unconditionally.

Operation:

T: vAddr ← ((offset₁₅)⁴⁸ || offset_{15..0}) + GPR[base]
 (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
 CacheOp (op, vAddr, pAddr)

Exceptions:

Coprocessor unusable exception

31	26	25 21	20 16	15 11	10 0
	COP1 010001	CF 0 0 0 1 0	rt	fs	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	6	5	5	5	11
For	mat:	CFC1 rt, fs			MIPS I
Pur	pose:	To copy a word	from an FPU cor	trol register to a	GPR.

Description: $rt \leftarrow FP_Control[fs]$

Copy the 32-bit word from FP (coprocessor 1) control register *fs* into GPR *rt*, sign-extending it if the GPR is 64 bits.

Restrictions:

There are only a couple control registers defined for the floating-point unit. The result is not defined if *fs* specifies a register that does not exist.

For MIPS I, MIPS II, and MIPS III, the contents of GPR *rt* are undefined for the instruction immediately following CFC1.

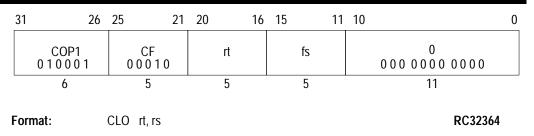
Operatio	n:	MIPS I - III
	temp GPR[rt]	

Operation:

n:MIPS IVtemp \leftarrow FCR[fs]GPR[rt] \leftarrow sign_extend(temp)

Exceptions:

Coprocessor Unusable



Description:

The RC32364 adds this new instruction. The content of general register rs is scanned from most significant bit to least significant bit, the number of leading ones is written into general register rt. If no bits were cleared in general register rs, i.e. rs=0xfffffff, the content of general register rt is 32.

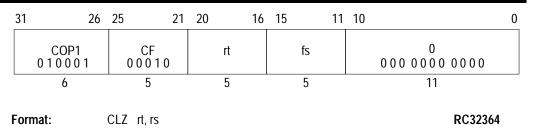
Operation:

T: rt <-- Leading_ones(rs)

Exceptions:

None

Programming Notes: This is an IDT proprietary extension.



Description:

The RC32364 adds this new instruction. The content of general register rs is scanned from most significant bit to least significant bit, the number of leading zeros is written into general register rt. If no bits were set in general register rs, i.e. rs=0x0, the content of general register rt is 32.

Operation:

T: rt <-- Leading_zeros(rs)

Exceptions:

None

Programming Notes: This is an IDT proprietary extension.

		Coprocessor Operation
31 2	6 25	0
COPz 0 1 0 0 z z	cop_	fun
6	26)
Format:	COP0 cop_fun COP1 cop_fun COP2 cop_fun COP3 cop_fun	MIPS I
Purpose:	To execute a coprocessor instruction.	

Description:

The coprocessor operation specified by *cop_fun* is performed by coprocessor unit *zz*. Details of coprocessor operations must be found in the specification for each coprocessor.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3. The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

See specification for the specific coprocessor being programmed.

Operation:

CoprocessorOperation (z, cop_fun)

Exceptions:

Reserved Instruction Coprocessor Unusable Coprocessor interrupt or Floating-Point Exception (CP1 only for some processors)

31	26	25 21	20 16	15 11	10 0
	COP1 0 1 0 0 0 1	CT 00110	rt	fs	0 000 0000 0000
	6	5	5	5	11
	rmat: rpose:	CTC1 rt, fs To copy a word	from a GPR to a	n FPU control re	MIPS I

Description: $FP_Control[fs] \leftarrow rt$

Copy the low word from GPR rt into FP (coprocessor 1) control register fs.

Writing to control register 31, the *Floating-Point Control and Status Register* or FCSR, causes the appropriate exception if any cause bit and its corresponding enable bit are both set. The register will be written before the exception occurs.

Restrictions:

There are only a couple control registers defined for the floating-point unit. The result is not defined if *fs* specifies a register that does not exist.

For MIPS I, MIPS II, and MIPS III, the contents of floating-point control register *fs* are undefined for the instruction immediately following CTC1.

Operatio	n:	MIPS I - III
	FCR[fs]	$ \leftarrow \text{GPR[rt]}_{310} \\ \leftarrow \text{temp} \\ \leftarrow \text{FCR[31]}_{23} $
Operatio	n:	MIPS IV
	FCR[fs]	
Exceptio	ns:	
Res	rocessor L erved Instr ting-Point Unimplen Invalid Op Division-t Inexact Overflow Underflov	ruction nented Operation peration py-zero



31	26	25 21	20 16	15 11	10 6	5 0
	SPECIAL	rs	rt	rd	0	DADD
	000000	15			00000	101100
	6	5	5	5	5	6
For	mat:	DADD rd, rs, r				MIPS III
Purpose: To add 64-bit integers. If overflow occurs, then trap.						

Description: $rd \leftarrow rs + rt$

The 64-bit doubleword value in GPR *rt* is added to the 64-bit value in GPR *rs* to produce a 64-bit result. If the addition results in 64-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 64-bit result is placed into GPR *rd*.

Restrictions:

None

Operation: 64-bit processors

else

 $GPR[rd] \leftarrow temp$

endif

Exceptions:

Integer Overflow Reserved Instruction

Programming Notes:

DADDU performs the same arithmetic operation but, does not trap on overflow.



31	26	25 21	20		16	15 0
	DADDI 1 0 0 0	rs		rt		immediate
	6	5		5		16
Format:DADDI rt, rs, immediateNPurpose:To add a constant to a 64-bit integer. If overflow occurs, then trap.				MIPS III ger. If overflow occurs, then trap.		
Descrip	otion:	$rt \leftarrow rs + imme$	diate			
The 16-bit signed <i>immediate</i> is added to the 64-bit value in GPR <i>rs</i> to produce a 64-bit result. If the addition results in 64-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 64-bit result is placed into GPR <i>rt</i> .						

Restrictions:

None

Operation: 64-bit processors

temp ← GPR[rs] + sign_extend(immediate) if (64_bit_arithmetic_overflow) then SignalException(IntegerOverflow)

else

 $GPR[rt] \leftarrow temp$

endif

Exceptions:

Integer Overflow Reserved Instruction

Programming Notes:

DADDIU performs the same arithmetic operation but, does not trap on overflow.



31	26	25 21	20 16	15 0	
	DADDIU 0 1 1 0 0 1	rs	rt	immediate	
	6	5	5	16	
Format:DADDIUrt, rs, immediatePurpose:To add a constant to a 64-bit integer				eger.	

Description: $rt \leftarrow rs + immediate$

The 16-bit signed *immediate* is added to the 64-bit value in GPR *rs* and the 64-bit arithmetic result is placed into GPR *rt*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

None

Operation: 64-bit processors

 $GPR[rt] \leftarrow GPR[rs] + sign_extend(immediate)$

Exceptions:

Reserved Instruction

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 64-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.



31 26	25 21	20 16	15 11	10 6	5	0
SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	DADDU 1 0 1 1 0 1	
6	5	5	5	5	6	
Format:	DADDU rd, rs,				MIPS III	

Purpose: To add 64-bit integers.

Description: $rd \leftarrow rs + rt$

The 64-bit doubleword value in GPR *rt* is added to the 64-bit value in GPR *rs* and the 64-bit arithmetic result is placed into GPR *rd*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

None

Operation: 64-bit processors $GPR[rd] \leftarrow GPR[rs] + GPR[rt]$

Exceptions:

Reserved Instruction

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 64-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.



31	26	25 21	20 16	15	6	5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	$\begin{smallmatrix}&&0\\0&0&0&0&0&0&0&0\\\end{smallmatrix}$		DDIV 0 1 1 1 1 0	
	6	5	5	10		6	
Format:DDIVrs, rtPurpose:To divide 64-bit signed integers.					MIPS III		
Description: (LO, HI) \leftarrow rs / rt							

The 64-bit doubleword in GPR *rs* is divided by the 64-bit doubleword in GPR *rt*, treating both operands as signed values. The 64-bit quotient is placed into special register *LO* and the 64-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

If the divisor in GPR rt is zero, the arithmetic result value is undefined.

I-2:, I-1:	LO, HI	\leftarrow undefined
l:	LO	\leftarrow GPR[rs] div GPR[rt]
	HI	\leftarrow GPR[rs] mod GPR[rt]

Exceptions:

Reserved Instruction

Programming Notes:

See the Programming Notes for the DIV instruction.



31 2	5 25 2	21 20	16 1	5	6	5	0
SPECIAL 0 0 0 0 0 0	rs	rt		$\begin{smallmatrix}&&0\\0&0&0&0&0&0&0&0\end{smallmatrix}$		DDIVU 0 1 1 1 1 1	
6	5	5		10		6	
Format: Purpose:	DDIVU rs, rt To divide 64-I		integers.			MIPS III	

Description: (LO, HI) \leftarrow rs / rt

The 64-bit doubleword in GPR *rs* is divided by the 64-bit doubleword in GPR *rt*, treating both operands as unsigned values. The 64-bit quotient is placed into special register *LO* and the 64-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

If the divisor in GPR rt is zero, the arithmetic result value is undefined.

Operation: 64-bit processors

I-2:, I-1:	LO, HI	\leftarrow undefined
l:	LO	\leftarrow (0 GPR[rs]) div (0 GPR[rt])
	HI	\leftarrow (0 GPR[rs]) mod (0 GPR[rt])

Exceptions:

Reserved instruction

Programming Notes:

See the Programming Notes for the DIV instruction.

31	26	25 21	20 16	15	6 5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	$\begin{smallmatrix}&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&$	DIV 0 1 1 0 1	0
	6	5	5	10	6	,
Format:DIV rs, rtPurpose:To divide 32-bit signed integers.			signed integers.		MIPS I	
_		(a				

Description: $(LO, HI) \leftarrow rs / rt$

The 32-bit word value in GPR *rs* is divided by the 32-bit value in GPR *rt*, treating both operands as signed values. The 32-bit quotient is placed into special register *LO* and the 32-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

If the divisor in GPR *rt* is zero, the arithmetic result value is undefined.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif

I-2:, I-1:	LO, HI	\leftarrow undefined
l:	q	$\leftarrow GPR[rs]_{310} div GPR[rt]_{310}$
	LO	\leftarrow sign_extend(q _{31.0})
	r	\leftarrow GPR[rs] _{31.0} mod GPR[rt] _{31.0}
	HI	\leftarrow sign_extend(r _{31.0})

Exceptions:

None

Programming Notes:

In some processors the integer divide operation may proceed asynchronously and allow other CPU instructions to execute before it is complete. An attempt to read *LO* or *HI* before the results are written will wait (interlock) until the results are ready. Asynchronous execution does not affect the program result, but offers an opportunity for performance improvement by scheduling the divide so that other instructions can execute in parallel.

No arithmetic exception occurs under any circumstances. If divide-by-zero or overflow conditions should be detected and some action taken, then the divide instruction is typically followed by additional instructions to check for a zero divisor and/or for overflow. If the divide is asynchronous then the zero-divisor check can execute in parallel with the divide. The action taken on either divide-by-zero or overflow is either a convention within the program itself or more typically, the system software; one possibility is to take a BREAK exception with a code field value to signal the problem to the system software.

As an example, the C programming language in a UNIX environment expects division by zero to either terminate the program or execute a program-specified signal handler. C does not expect overflow to cause any exceptional condition. If the C compiler uses a divide instruction, it also emits code to test for a zero divisor and execute a BREAK instruction to inform the operating system if one is detected.

	31 26	25 21	20 16	15	6 5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	DIV 0 1 1 0	-
	6	5	5	10	6	
Format: DIVU rs, rt				MIPS	S I	
l	Purpose:	rpose: To divide 32-bit unsigned integers.				

Description: (LO, HI) \leftarrow rs / rt

The 32-bit word value in GPR *rs* is divided by the 32-bit value in GPR *rt*, treating both operands as unsigned values. The 32-bit quotient is placed into special register *LO* and the 32-bit remainder is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them, like this one, by two or more other instructions.

If the divisor in GPR rt is zero, the arithmetic result is undefined.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif

I-2:, I-1:	LO, HI	\leftarrow undefined	
l:	q	$\leftarrow (0 \parallel \text{GPR}[\text{rs}]_{310}) \text{ div } (0 \parallel \text{GPR}[\text{rt}]_{310})$	
	LO	\leftarrow sign_extend(q ₃₁₀)	
	r	$\leftarrow (0 \parallel GPR[rs]_{310}) \bmod (0 \parallel GPR[rt]_{310})$	
	HI	\leftarrow sign_extend(r _{31.0})	

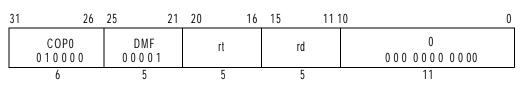
Exceptions:

None

Exceptions:

See the programming Notes for the DIV instruction.





Format:

DMFCO rt, rd

RC5000

Description:

The contents of coprocessor register rd of the CP0 are loaded into general register rt.

This operation is defined in kernel mode regardless of the setting of the Status.KX bit. Execution of this instruction with in supervisor mode with Status.SX = 0 or in user mode with UX = 0, causes a reserved instruction exception. All 64-bits of the general register destination are written from the coprocessor register source. The operation of DMFC0 on a 32-bit coprocessor 0 register is undefined.

Operation:

T: data \leftarrow CPR[0,rd]

T+1: GPR[rt] \leftarrow data

Exceptions:

Coprocessor unusable exception

Reserved instruction exception for supervisor mode with Status.SX = 0 or user mode with Status.UX =

0.

31	26	25 21	20 16	15 11 1	0 0
	COP0 010000	DMT 00101	rt	rd	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	6	5	5	5	11
_					DOF000

Format:

DMTC0 rt, rd

RC5000

Description:

The contents of general register *rt* are loaded into coprocessor register *rd* of the CP0.

This operation is defined in kernel mode regardless of the setting of the Status.KX bit. Execution of this instruction with in supervisor mode with Status.SX = 0 or in user mode with UX = 0, causes a reserved instruction exception.

All 64-bits of the coprocessor 0 register are written from the general register source. The operation of DMTC0 on a 32-bit coprocessor 0 register is undefined.

Because the state of the virtual address translation system may be altered by this instruction, the operation of load instructions and store instructions immediately prior to and after this instruction are undefined.

Operation:

T: data \leftarrow GPR[rt] T+1: CPR[0,rd] \leftarrow data

Exceptions:

Reserved instruction exception for supervisor mode with Status.SX = 0 or user mode with Status.UX = 0.

31	26	25 21	20 16	15	11 10	0
	COP1 010001	DMF 0 0 0 0 1	rt	fs	0000	0 0 0 0 0 0 00
	6	5	5	5		11
	mat: pose:	DMFC1 rt, fs To copy a doub	eword from an F	PR to a GPR	<u>.</u>	MIPS III
D						

Description: $rt \leftarrow fs$

The doubleword contents of FPR fs are placed into GPR rt.

If the coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR *fs* is held in an even/odd register pair. The low word is taken from the even register *fs* and the high word is from fs+1.

Restrictions:

If *fs* does not specify an FPR that can contain a doubleword, the result is undefined; see the Chapter titled "FPU Instruction Set" for information on FP registers, etc..

For MIPS III, the contents of GPR rt are undefined for the instruction immediately following DMFC1.

Operation: MIPS I - III	
I: if SizeFGR() = 64 then data ← FGR[fs]	/* 64-bit wide FGRs */
elseif fs ₀ = 0 then data ← FGR[fs+1] FGR[fs]	/* valid specifier, 32-bit wide FGRs */
else UndefinedResult() endif I+1: GPR[rt] ← data	/* undefined for odd 32-bit FGRs */
Operation: MIPS IV	
if SizeFGR() = 64 then data ← FGR[fs]	/* 64-bit wide FGRs */
elseif fs ₀ = 0 then data ← FGR[fs+1] FGR[fs]	/* valid specifier, 32-bit wide FGRs */
else UndefinedResult() endif GPR[rt] ← data	/* undefined for odd 32-bit FGRs */
Exceptions:	
Reserved Instruction Coprocessor Unusable	

31	26	25 21	20 16	15 1 ⁻	1 10	0
	COP1 010001	DMT 0 0 1 0 1	rt	fs	0 000 0000 0000	
	6	5	5	5	11	
	rmat: rpose:	DMTC1 rt, fs To copy a doub	leword from a G	PR to an FPR.	MIPS III	
		c 1				

Description: $fs \leftarrow rt$

The doubleword contents of GPR rt are placed into FPR fs.

If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR *fs* is held in an even/odd register pair. The low word is placed in the even register *fs* and the high word is placed in *fs*+1.

Restrictions:

If *fs* does not specify an FPR that can contain a doubleword, the result is undefined; see the Chapter Titled "FPU Instruction Set" for information about FP registers, etc.

For MIPS III, the contents of FPR *fs* are undefined for the instruction immediately following DMTC1.

Operation: MIPS I - III	
I: data ← GPR[rt]	
I+1: if SizeFGR() = 64 then	/* 64-bit wide FGRs */
FGR[fs] ← data	
elseif $fs_0 = 0$ then	/* valid specifier, 32-bit wide FGRs */
$FGR[fs+1] \leftarrow data_{6332}$	
$FGR[fs] \leftarrow data_{31.0}$	
else	/* undefined result for odd 32-bit FGRs */
UndefinedResult()	
endif	
Operation: MIPS IV	
data ← GPR[rt]	
if SizeFGR() = 64 then	/* 64-bit wide FGRs */
FGR[fs] ← data	
elseif fs ₀ = 0 then	/* valid specifier, 32-bit wide FGRs */
$FGR[fs+1] \leftarrow data_{6332}$	
$FGR[fs] \leftarrow data_{310}$	
else	/* undefined result for odd 32-bit FGRs */
UndefinedResult()	
endif	
Eventions	
Exceptions:	
Reserved Instruction	
Coprocessor Unusable	



31	26	25 21	20 16	15	6	5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	0 00 0000 0000		DMULT 0 1 1 1 0 0	
	6	5	5	10		6	
	ormat: irpose:	DMULT rs, rt To multiply 64-b	it signed integer	S.		MIPS III	
De	escription:	(LO, HI) \leftarrow rs \times	rt				

The 64-bit doubleword value in GPR *rt* is multiplied by the 64-bit value in GPR *rs*, treating both operands as signed values, to produce a 128-bit result. The low-order 64-bit doubleword of the result is placed into special register *LO*, and the high-order 64-bit doubleword is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

Operation:	64-	bit processors
I-2:, I-1:	LO, HI	\leftarrow undefined
l:	prod	\leftarrow GPR[rs] * GPR[rt]
	LO	$\leftarrow prod_{630}$
	ΗI	$\leftarrow \text{prod}_{12764}$

Exceptions:

Reserved Instruction

Programming Notes:

In some processors the integer multiply operation may proceed asynchronously and allow other CPU instructions to execute before it is complete. An attempt to read *LO* or *HI* before the results are written will wait (interlock) until the results are ready. Asynchronous execution does not affect the program result, but offers an opportunity for performance improvement by scheduling the multiply so that other instructions can execute in parallel.

Programs that require overflow detection must check for it explicitly.



3	26	25 21	20 16	15	6	5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	0 00 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		DMULTU 0 1 1 1 0 1	
	6	5	5	10		6	
	ormat: urpose:	DMULTU rs, rt To multiply 64-b		jers.		MIPS III	
D	escription:	(LO, HI) \leftarrow rs \times	rt				

The 64-bit doubleword value in GPR *rt* is multiplied by the 64-bit value in GPR *rs*, treating both operands as unsigned values, to produce a 128-bit result. The low-order 64-bit doubleword of the result is placed into special register *LO*, and the high-order 64-bit doubleword is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

Operation:	64-b	it processors
I-2:, I-1: I:	LO, HI prod	← undefined ← (0 GPR[rs]) * (0 GPR[rt])
	LO HI	$\leftarrow \operatorname{prod}_{630}$ $\leftarrow \operatorname{prod}_{12764}$

Exceptions:



31	26	25	21	20	16	15		11	10		6	5		0
SPECI. 0 0 0 0 0		000	0) 0 0		rt		rd			sa		1	DSLL 1 1 0 0 0	
6			5		5		5			5			6	
Format:		DSLL	rd, rt, sa										MIPS III	
Purpose:		To left s	hift a do	ublewo	rd by a fi	ked ar	nount -	—0	to 31	bits.				

Description: $rd \leftarrow rt \ll sa$

The 64-bit doubleword contents of GPR *rt* are shifted left, inserting zeros into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 0 to 31 is specified by *sa*.

Restrictions:

None

Operation: 64-bit processors

```
s \leftarrow 0 \parallel sa
```

```
\mathsf{GPR}[\mathsf{rd}] \leftarrow \mathsf{GPR}[\mathsf{rt}]_{(63-s)..0} \parallel 0^{s}
```

Exceptions:



31	26	25 2 ⁻	20 16	15 11	10 6	5 0
	PECIAL 0000	0 0 0 0 0 0	rt	rd	sa	DSLL32 1 1 1 1 0 0
	6	5	5	5	5	6
Format	:	DSLL32 rd, rt	, sa			MIPS III
Purpos	e:	To left shift a d	oubleword by a fi	xed amount — 3	32 to 63 bits.	

•

Description: $rd \leftarrow rt \ll (sa+32)$

The 64-bit doubleword contents of GPR *rt* are shifted left, inserting zeros into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 32 to 63 is specified by *sa*+32.

Restrictions:

None

 Operation:
 64-bit processors

 s
 ← 1 || sa
 /* 32+sa */

 GPR[rd] ← GPR[rt]_{(63-s)..0} || 0^s

Exceptions:



31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	DSLLV 0 1 0 1 0 0
6	5	5	5	5	6
Format:	DSLLV rd, rt, r				MIPS III
Purpose:	To left shift a do	ubleword by a va	ariable number o	f bits.	

Description: $rd \leftarrow rt \ll rs$

The 64-bit doubleword contents of GPR *rt* are shifted left, inserting zeros into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 0 to 63 is specified by the low-order six bits in GPR *rs*.

Restrictions:

None

```
\mathsf{GPR}[\mathsf{rd}] \leftarrow \mathsf{GPR}[\mathsf{rt}]_{(63-s)..0} \parallel 0^s
```

Exceptions:



31	26	25 21	20 16	15 11	10 6	5 0			
SPECIAL 0 0 0 0 0 0 0		0 0 0 0 0 0	rt	rd	sa	DSRA 1 1 1 0 1 1			
6		5	5	5	5	6			
	rmat:	DSRA rd, rt, s				MIPS III			
Purpose:		To arithmetic right shift a doubleword by a fixed amount — 0 to 31 bits.							

Description: $rd \leftarrow rt >> sa$ (arithmetic)

The 64-bit doubleword contents of GPR *rt* are shifted right, duplicating the sign bit (63) into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 0 to 31 is specified by *sa*.

Restrictions:

None

Operation: 64-bit processors

```
s \leftarrow 0 \parallel sa
```

```
GPR[rd] \leftarrow (GPR[rt]_{63})^{s} \parallel GPR[rt]_{63..s}
```

Exceptions:



31	26	25 21	20 16	5 15 11	10 6	5 0		
SPE0 0 0 0 0		00000	rt	rd	sa	DSRA32 111111		
6		5	5	5	5	6		
Format:DSRA32rd, rt, saPurpose:To arithmetic right shift a doubleword by a fixed amount — 3						MIPS III		
Description:		$rd \leftarrow rt >> (sa+32)$ (arithmetic)						

The doubleword contents of GPR *rt* are shifted right, duplicating the sign bit (63) into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 32 to 63 is specified by *sa*+32.

Restrictions:

None

Exceptions:



31	26	25 21	20 16	15 11	10 6	5	0
	SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	DSRAV 0 1 0 1 1 1	
	6	5	5	5	5	6	
For	rmat:	DSRAV rd, rt, r	S			MIPS III	

Purpose:

To arithmetic right shift a doubleword by a variable number of bits.

Description:

 $rd \leftarrow rt >> rs$ (arithmetic)

The doubleword contents of GPR rt are shifted right, duplicating the sign bit (63) into the emptied bits; the result is placed in GPR rd. The bit shift count in the range 0 to 63 is specified by the low-order six bits in GPR rs.

Restrictions:

None

Operation: 64-bit processors

> $\leftarrow \mathsf{GPR}[\mathsf{rs}]_{5..0}$ S $GPR[rd] \leftarrow (GPR[rt]_{63})^{s} || GPR[rt]_{63..s}$

Exceptions:



31	26	25 21	20 16	15 11	10 6	5 0
	SPECIAL 0 0 0 0 0 0 0	00000	rt	rd	sa	DSRL 1 1 1 0 1 0
6 5		5	5	5	5	6
For	mat:	DSRL rd, rt, s	а			MIPS III
Pur	pose:	To logical right	shift a doublewor	d by a fixed amo	ount — 0 to 31 b	its.

Description: $rd \leftarrow rt >> sa$ (logical)

The doubleword contents of GPR *rt* are shifted right, inserting zeros into the emptied bits; the result is placed in GPR *rd*. The bit shift count in the range 0 to 31 is specified by *sa*.

Restrictions:

None

Operation:64-bit processorss $\leftarrow 0 \parallel sa$

```
S \leftarrow O \parallel Sa
GPR[rd] \leftarrow O^{S} \parallel GPR[rt]_{63..S}
```

Exceptions:



3	1 26	25 21	20 16	15 11	10 6	5 0
	SPECIAL 0 0 0 0 0 0	00000	rt	rd	sa	DSRL32 1 1 1 1 1 0
	6	5	5	5	5	6
Format:DSRL32rd, rt, saPurpose:To logical right shift a doubleword				d by a fixed amo	ount — 32 to 63	MIPS III bits.

Description: $rd \leftarrow rt >> (sa+32)$ (logical)

The 64-bit doubleword contents of GPR rt are shifted right, inserting zeros into the emptied bits; the result is placed in GPR rd. The bit shift count in the range 32 to 63 is specified by sa+32.

Restrictions:

None

Exceptions:



31 26	25 21	20 16	15 11	10 6	5	0
SPECIAL 0 0 0 0 0 0	rs	rt	rd	00000	DSRLV 0 1 0 1 1 0	
6	5	5	5	5	6	
Formati	DSDIV rd rt	rc				

To logical right shift a doubleword by a variable number of bits.

Format: DSRLV rd, rt, rs MIPS III

```
Purpose:
```

Description:

 $\mathsf{rd} \gets \mathsf{rt} \mathrel{>>} \mathsf{rs}$ (logical)

The 64-bit doubleword contents of GPR rt are shifted right, inserting zeros into the emptied bits; the result is placed in GPR rd. The bit shift count in the range 0 to 63 is specified by the low-order six bits in GPR rs.

Restrictions:

None

Operation: 64-bit processors

```
\leftarrow \mathsf{GPR}[\mathsf{rs}]_{5..0}
S
GPR[rd] \leftarrow 0^{S} \parallel GPR[rt]_{63..S}
```

Exceptions:



31	26	25 21	20 16	15 11	l 10 6	5 0	,
	SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	DSUB 1 0 1 1 1 0	
	6	5	5	5	5	6	
Forr	nat:	DSUB rd, rs, rt				MIPS III	
Purp	oose:	To subtract 64-b	oit integers; trap	if overflow.			

Description: $rd \leftarrow rs - rt$

The 64-bit doubleword value in GPR *rt* is subtracted from the 64-bit value in GPR *rs* to produce a 64-bit result. If the subtraction results in 64-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 64-bit result is placed into GPR *rd*.

Restrictions:

None

Operation: 64-bit processors

else

 $GPR[rd] \leftarrow temp$

endif

Exceptions:

Integer Overflow Reserved Instruction

Programming Notes:

DSUBU performs the same arithmetic operation but, does not trap on overflow.



31	26	25 21	20 16	15 11	10 6	5 0
	SPECIAL	rs	rt	rd	00000	DSUBU 101111
<u> </u>	6	5	5	5	5	6
Format: DSUBU rd, rs, rt						MIPS III
Purpose:		To subtract 64-b				

Description: $rd \leftarrow rs - rt$

The 64-bit doubleword value in GPR *rt* is subtracted from the 64-bit value in GPR *rs* and the 64-bit arithmetic result is placed into GPR *rd*.

No Integer Overflow exception occurs under any circumstances.

Restrictions:

None

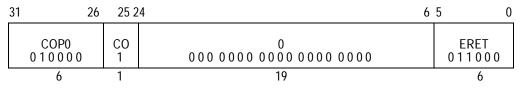
Operation: 64-bit processors $GPR[rd] \leftarrow GPR[rs] - GPR[rt]$

Exceptions:

Reserved Instruction

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 64-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.



Format: ERET

Description:

ERET is the RC4650 instruction for returning from an interrupt, exception, or error trap. Unlike a branch or jump instruction, ERET does not execute the next instruction.

ERET must not itself be placed in a branch delay slot.

If the processor is servicing an error trap ($SR_2 = 1$), then load the PC from the *ErrorEPC* and clear the *ERL* bit of the *Status* register (SR_2). Otherwise ($SR_2 = 0$), load the PC from the *EPC*, and clear the *EXL* bit of the *Status* register (SR_1).

An ERET executed between a LL and SC also causes the SC to fail.

Operation:

Exceptions:

Coprocessor unusable exception

 31
 26
 25
 0

 31
 26
 25
 0

 0
 0
 0
 10

 6
 26
 26

 MIPS I

Purpose:

Description:

This is a PC-region branch (not PC-relative); the effective target address is in the "current" 256 MB aligned region. The low 28 bits of the target address is the *instr_index* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction in the delay slot (**not** the branch itself).

To branch within the current 256 MB aligned region.

Jump to the effective target address. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

None

Operation:

I:

I+1: $PC \leftarrow PC_{GPRLEN..28} \parallel instr_index \parallel 0^2$

Exceptions:

None

Programming Notes:

Forming the branch target address by catenating PC and index bits rather than adding a signed offset to the PC is an advantage if all program code addresses fit into a 256 MB region aligned on a 256 MB boundary. It allows a branch to anywhere in the region from anywhere in the region which a signed relative offset would not allow.

This definition creates the boundary case where the branch instruction is in the last word of a 256 MB region and can therefore only branch to the following 256 MB region containing the branch delay slot

Purpose: To procedure call within the current 256 MB aligned region.

Description:

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, where execution would continue after a procedure call.

This is a PC-region branch (not PC-relative); the effective target address is in the "current" 256 MB aligned region. The low 28 bits of the target address is the *instr_index* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction in the delay slot (**not** the branch itself).

Jump to the effective target address. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

None

Operation:

I: GPR[31] \leftarrow PC + 8 I+1: PC \leftarrow PC_{GPRLEN.28} || instr_index || 0²

Exceptions:

None

Programming Notes:

Forming the branch target address by catenating PC and index bits rather than adding a signed offset to the PC is an advantage if all program code addresses fit into a 256 MB region aligned on a 256 MB boundary. It allows a branch to anywhere in the region from anywhere in the region which a signed relative offset would not allow.

This definition creates the boundary case where the branch instruction is in the last word of a 256 MB region and can therefore only branch to the following 256 MB region containing the branch delay slot.

	31 26	25 21	20 16	15 1 ⁻	1 10 6	5 0
	SPECIAL 0 0 0 0 0 0 0	rs	00000	rd	00000	JALR 0 0 1 0 0 1
	6	5	5	5	5	6
Format:		JALR rs JALR rd, rs	(rd = 31 im	plied)		MIPS I
	Purpose:	To procedure ca	all to an instructio	on address in a	register.	

Description: $rd \leftarrow return_addr, PC \leftarrow rs$

Place the return address link in GPR *rd*. The return link is the address of the second instruction following the branch, where execution would continue after a procedure call.

Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

Register specifiers *rs* and *rd* must not be equal, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

The effective target address in GPR *rs* must be naturally aligned. If either of the two least-significant bits are not -zero, then an Address Error exception occurs, not for the jump instruction, but when the branch target is subsequently fetched as an instruction.

Operation:

```
I: temp \leftarrow GPR[rs]
GPR[rd] \leftarrow PC + 8
I+1: PC \leftarrow temp
```

Exceptions:

None

Programming Notes:

This is the only branch-and-link instruction that can select a register for the return link; all other link instructions use GPR 31 The default register for *GPR rd*, if omitted in the assembly language instruction, is GPR 31.

31		26	25	21 20)	65	0
	SPECIAL 0 0 0 0 0 0 0		rs		000 0000 0000 0000	JR 0 0 1 0 0	00
	6		5		15	6	
Format: JR rs		rs			MIPS	I	
Pur	pose:	To	branch to a	n instruc	tion address in a register.		

Description: $PC \leftarrow rs$

Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

The effective target address in GPR *rs* must be naturally aligned. If either of the two least-significant bits are not -zero, then an Address Error exception occurs, not for the jump instruction, but when the branch target is subsequently fetched as an instruction.

Operation:

I: temp \leftarrow GPR[rs] I+1: PC \leftarrow temp

Exceptions:

None

Load Byte 26 25 16 15 0 31 21 20 offset LB base rt 100000 6 5 5 16 Format: LB rt, offset(base) **MIPS I** Purpose: To load a byte from memory as a signed value. Description: rt ← memory[base+offset]

The contents of the 8-bit byte at the memory location specified by the effective address are fetched, sign-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

None

Operation: 32-bit processors

 $vAddr \leftarrow sign_extend(offset) + GPR[base]$ (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD) pAddr \leftarrow pAddr_{(PSIZE-1)...2} || (pAddr_{1..0} xor ReverseEndian²) memword \leftarrow LoadMemory (uncached, BYTE, pAddr, vAddr, DATA) byte \leftarrow vAddr_{1..0} xor BigEndianCPU² GPR[rt] \leftarrow sign_extend(memword_{7+8*byte..8*byte})

Operation: 64-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..3}} \parallel (\mathsf{pAddr}_{2..0} \, \mathsf{xor} \, \mathsf{ReverseEndian}^3) \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \, (\mathsf{uncached}, \, \mathsf{BYTE}, \, \mathsf{pAddr}, \, \mathsf{vAddr}, \, \mathsf{DATA}) \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \, \mathsf{xor} \, \mathsf{BigEndianCPU}^3 \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{sign_extend}(\mathsf{memdouble}_{7+8^*\mathsf{byte}..8^*\mathsf{byte}}) \end{array}$

Exceptions:

TLB Refill, TLB Invalid Address Error

31	26	25	21	20	16	15 0		
	BU 1 0 0	bas	e		rt	offset		
6		5		5		16		
Format: Purpose	:	LBU rt, o To load a	•	,	mory as a	MIPS I In unsigned value.		
Descript	ion:	$rt \leftarrow men$	nory[ba	ase+offs	set]			
The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR <i>rt</i> . The 16-bit signed <i>offset</i> is added to the contents of GPR <i>base</i> to form the effective address.								

Restrictions:

None

Operation: 32-bit processors

vAddr ← sign_extend(offset) + GPR[base] (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE - 1 ... 2} || (pAddr_{1..0} xor ReverseEndian²) memword ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA) byte ← vAddr_{1..0} xor BigEndianCPU² GPR[rt] ← zero_extend(memword_{7+8* byte..8* byte})

Operation: 64-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..3}} \parallel (\mathsf{pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3) \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{BYTE}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^3 \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{zero_extend} (\mathsf{memdouble}_{7+8^* \ \mathsf{byte..8^*} \ \mathsf{byte}}) \end{array}$

Exceptions:

TLB Refill, TLB Invalid Address Error

Load Doubleword

31	26	25 21	20 16	15	0
	LD 1 1 0 1 1 1	base	rt	offset	
	6	5	5	16	
Format:LD rt, offset(base)Purpose:To load a doubleword				nory.	MIPS III
Description:		rt ← memory[ba			

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If any of the three least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

64-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{if} \ (\mathsf{vAddr}_{2..0}) \neq 0^3 \ \mathsf{then} \ \mathsf{SignalException}(\mathsf{AddressError}) \ \mathsf{endif} \\ (\mathsf{pAddr}, \ \mathsf{uncached}) \leftarrow \ \mathsf{AddressTranslation} \ (\mathsf{vAddr}, \ \mathsf{DATA}, \ \mathsf{LOAD}) \\ \mathsf{memdouble} \leftarrow \ \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{DOUBLEWORD}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \ \mathsf{memdouble} \end{array}$

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

31 26	25 2	1 20	16	15	0
LDCz 1 1 0 1 z z	base	rt		offset	
6	5	5		16	
Format:	LDC1 rt, offse LDC2 rt, of		e)	MIPS II	
Purpose:	To load a doub	pleword from	n mem	ory to a coprocessor general register.	

Description: rt ← memory[base+offset]

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and made available to coprocessor unit zz. The 16-bit signed offset is added to the contents of GPR base to form the effective address.

The manner in which each coprocessor uses the data is defined by the individual coprocessor specifications. The usual operation would place the data into coprocessor general register rt.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3. The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

This instruction is not available for coprocessor 0, the System Control coprocessor, and the opcode may be used for other instructions.

The effective address must be naturally aligned. If any of the three least-significant bits of the effective address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the offset field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

vAddr \leftarrow sign extend(offset) + GPR[base]

if $(vAddr_{2,0}) \neq 0^3$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) memdouble ← LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) COP_LD (z, rt, memdouble)

Operation:

64-bit processors

vAddr ← sign_extend(offset) + GPR[base]

if $(vAddr_{2,0}) \neq 0^3$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) memdouble ← LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) COP LD (z, rt, memdouble)

Exceptions:

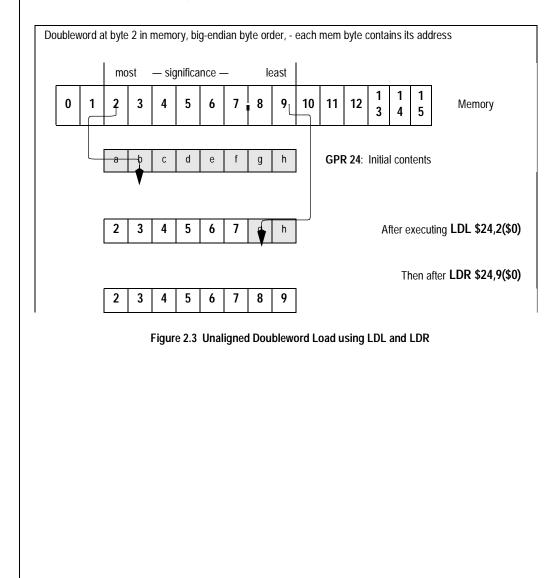
TLB Refill, TLB Invalid Bus Error Address Error **Reserved Instruction** Coprocessor Unusable

Load Doubleword Left 0 31 26 25 21 20 16 15 offset LDL base rt 011010 5 5 16 6 Format: LDL rt, offset(base) MIPS III Purpose: To load the most-significant part of a doubleword from an unaligned memory address.

Description: $rt \leftarrow rt MERGE memory[base+offset]$

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the most-significant of eight consecutive bytes forming a doubleword in memory (*DW*) starting at an arbitrary byte boundary. A part of *DW*, the most-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. This part of *DW* is loaded appropriately into the most-significant (left) part of GPR *rt* leaving the remainder of GPR *rt* unchanged.

The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, six bytes, is contained in the aligned doubleword containing the most-significant byte at 2. First, LDL loads these six bytes into the left part of the destination register and leaves the remainder of the destination unchanged. Next, the complementary LDR loads the remainder of the unaligned doubleword.



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr_{2.0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.

Memory contents and byte offsets $(vAddr_{20})$									Initial contents of								
mo	st	-	signifi	cance	-	I	east		Destination Register								
0	1	2	3	4	5	6	7	¨ big-	mo	most – significance –					I	least	
Ι	J	K	L	М	Ν	0	Ρ		a b		С	d	е	f	g	h	
7	6	5	4	3	2	1	0	"little-endia	n offs	set							
		De	stina	tion r	egist	er co	ntent	s after instruc	ction	(shac	led is	s unc	hang	jed)			
	Bię	g-enc	lian b	oyte d	orderi	ing		vAddr ₂₀		Litt	le-en	dian	byte	orde	ring		
I	J	Κ	L	М	Ν	0	Ρ	0	Р	b	С	d	е	f	g	ł	
J	K	L	М	Ν	0	Р	h	1	0	Р	С	d	е	f	g	ł	
Κ	L	М	Ν	0	Р	g	h	2	Ν	0	Р	d	е	f	g	ł	
L	М	Ν	0	Р	f	g	h	3	М	Ν	0	Р	е	f	g	ł	
М	Ν	0	Ρ	е	f	g	h	4	L	М	Ν	0	Ρ	f	g	ł	
Ν	0	Ρ	d	е	f	g	h	5	K	L	М	Ν	0	Ρ	g	ł	
0	Ρ	С	d	е	f	g	h	6	J	K	L	М	Ν	0	Ρ	h	
Р	b	С	d	е	f	g	h	7	1	J	К	L	М	Ν	0	F	

Figure 2.4 Bytes Loaded by LDL Instruction

Restrictions:

ENESAS

LDI

None

Operation:

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel (\mathsf{pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3) \\ \mathsf{if} \ \mathsf{BigEndianMem} = 0 \ \mathsf{then} \\ & \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{0}^3 \\ \mathsf{endif} \\ \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^3 \\ \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{byte}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \end{array}$

 $GPR[rt] \leftarrow memdouble_{7+8*byte..0} || GPR[rt]_{55-8*byte..0}$

64-bit processors

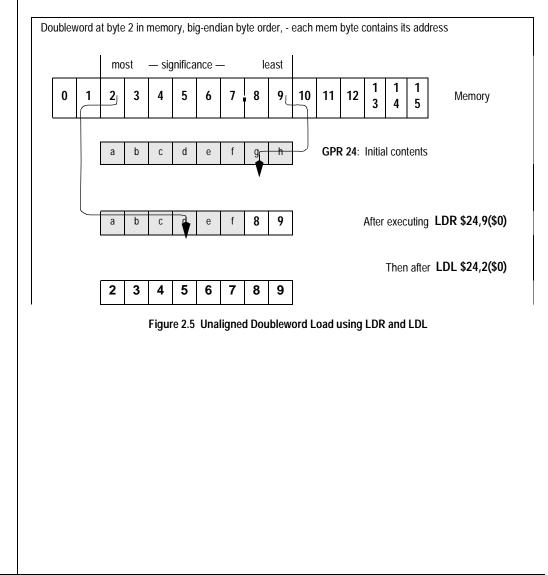
Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

3	1 26	25	21	20		16	15 0				
	LDR 011011		base		rt		offset				
	6		5		5		16				
-	ormat: urpose:		rt, offset(ad the leas	MIPS III of a doubleword from an unaligned memory address.							
D	escription:	rt ←	rt ← rt MERGE memory[base+offset]								

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the least-significant of eight consecutive bytes forming a doubleword in memory (*DW*) starting at an arbitrary byte boundary. A part of *DW*, the least-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. This part of *DW* is loaded appropriately into the least-significant (right) part of GPR *rt* leaving the remainder of GPR *rt* unchanged.

The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, two bytes, is contained in the aligned doubleword containing the least-significant byte at 9. First, LDR loads these two bytes into the right part of the destination register and leaves the remainder of the destination unchanged. Next, the complementary LDL loads the remainder of the unaligned doubleword.



Load Doubleword Right

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr_{2.0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.

	most – significance – least								Initial contents of Destination Register							
mc	ost	- S	igniti	canc	e-	least				Destination Register						
0	1	2	3	4	5	6	7	$\leftarrow big-$	mc	st	-s	ignifi	canc	e–	le	eas
I	J	Κ	L	М	Ν	0	Ρ		а	b	С	d	е	f	g	h
7	6	5	4	3	2	1	0	\leftarrow little-er	ndiar	n off	set					
[Dest	inati	on r	egis	ter o	cont	ents	after instru	ictio	n (s	hade	ed is	s uno	char	ged)
	Big-	endi	an t	oyte	orde	ering	J	vAddr ₂ 0	L	ittle	-end	lian	byte	ord	erin	g
а	b	С	d	е	f	g	I	0	Ι	J	Κ	L	М	Ν	0	F
						1										
а	b	с	d	е	f	I	J	1	а	Ι	J	κ	L	М	Ν	C
a a	b b	c c	d d	e e	f	J	J K	1 2	a a	b	J	K J	L K	M L	N M	C N
					-	_	-			<u> </u>	-					N
а	b	С	d	e	1	J	K	2	a	b	1		к	L	М	N
a a	b b	C C	d d	e I J	l J	J	K	2	a a	b b	l c	J	K	L K	M	N
a a a	b b b	C C C	d d l	e I J	I J K	J K L	K L M	2 3 4	a a a	b b b	с С	J I d	K J I	L K J	M L K	

Figure 2.6 Bytes Loaded by LDR Instruction

Restrictions:

None

CENESAS

LDR

Operation:

 $\label{eq:product} \begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel (\mathsf{pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3) \\ \mathsf{if} \ \mathsf{BigEndianMem} = 1 \ \mathsf{then} \\ & \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{0}^3 \\ \mathsf{endif} \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^3 \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{byte}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{GPR}[\mathsf{rt}]_{63..64 \cdot 8^* \mathsf{byte}} \parallel \mathsf{memdouble}_{63..8^* \mathsf{byte}} \end{array}$

64-bit processors

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

31	26	25	21	20	16	15		11	10	6	5		0	
SPECIA 0 0 0 0 0		rs		000	00		rd		0000	0		JALR 0 0 1 0 0 1		
6		5		5			5		5			6		
Format:		JALR rs (rd = 31 implied) JALR rd, rs								MIPS I				
Purpose: To procedure call to an instruction address in a register.														

Description: $rd \leftarrow return_addr, PC \leftarrow rs$

Place the return address link in GPR *rd*. The return link is the address of the second instruction following the branch, where execution would continue after a procedure call.

Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

Register specifiers *rs* and *rd* must not be equal, because such an instruction does not have the same effect when re-executed. The result of executing such an instruction is undefined. This restriction permits an exception handler to resume execution by re-executing the branch when an exception occurs in the branch delay slot.

The effective target address in GPR *rs* must be naturally aligned. If either of the two least-significant bits are not -zero, then an Address Error exception occurs, not for the jump instruction, but when the branch target is subsequently fetched as an instruction.

Operation:

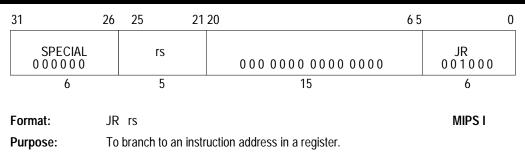
```
I: temp \leftarrow GPR[rs]
GPR[rd] \leftarrow PC + 8
I+1: PC \leftarrow temp
```

Exceptions:

None

Programming Notes:

This is the only branch-and-link instruction that can select a register for the return link; all other link instructions use GPR 31 The default register for *GPR rd*, if omitted in the assembly language instruction, is GPR 31.



Description: $PC \leftarrow rs$

Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.

Restrictions:

The effective target address in GPR *rs* must be naturally aligned. If either of the two least-significant bits are not -zero, then an Address Error exception occurs, not for the jump instruction, but when the branch target is subsequently fetched as an instruction.

Operation:

I: temp \leftarrow GPR[rs] I+1: PC \leftarrow temp

Exceptions:

None

Load Byte 26 25 0 31 21 20 16 15 offset LB base rt 100000 6 5 5 16 **MIPS I** Format: LB rt, offset(base) Purpose: To load a byte from memory as a signed value. Description: rt ← memory[base+offset] The contents of the 8-bit byte at the memory location specified by the effective address are fetched, sign-extended, and placed in GPR rt. The 16-bit signed offset is added to the contents of GPR base to form the effective address.

Restrictions:

None

Operation: 32-bit processors

vAddr ← sign_extend(offset) + GPR[base] (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{(PSIZE-1)...2} || (pAddr_{1..0} xor ReverseEndian²) memword ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA) byte ← vAddr_{1..0} xor BigEndianCPU² GPR[rt] ← sign_extend(memword_{7+8*byte.8*byte})

Operation: 64-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{(pAddr, uncached)} \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr, DATA, LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..3}} \parallel \mathsf{(pAddr}_{2..0} \, \mathsf{xor} \, \mathsf{ReverseEndian}^3) \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \, \mathsf{(uncached, BYTE, pAddr, vAddr, DATA)} \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \, \mathsf{xor} \, \mathsf{BigEndianCPU}^3 \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{sign_extend}(\mathsf{memdouble}_{7+8^*\mathsf{byte}..8^*\mathsf{byte}}) \\ \end{array}$

Exceptions:

TLB Refill, TLB Invalid Address Error

						.00				
31	26	25 27	20	16	15	0				
LBU 1 0 0 1 0 0)	base		rt	offset					
6		5		5	16					
Format:		LBU rt, offset	base)		MIPS I					
Purpose:		To load a byte	from me	emory as a	an unsigned value.					
Description: rt ← memory[base+offset]										
The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR <i>rt</i> . The 16-bit signed <i>offset</i> is added to the contents of GPR <i>base</i> to form										

Restrictions:

the effective address.

None

Operation: 32-bit processors

vAddr ← sign_extend(offset) + GPR[base] (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE - 1 ... 2} || (pAddr_{1..0} xor ReverseEndian²) memword ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA) byte ← vAddr_{1..0} xor BigEndianCPU² GPR[rt] ← zero_extend(memword_{7+8*} byte..8* byte)

Operation: 64-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{(pAddr, uncached)} \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr, DATA, LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..3}} \parallel \mathsf{(pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3 \mathsf{)} \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ \mathsf{(uncached, BYTE, pAddr, vAddr, DATA)} \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^3 \\ \mathsf{GPR}[\mathsf{rl}] \leftarrow \mathsf{zero_extend} (\mathsf{memdouble}_{7+8^* \ \mathsf{byte..8^* \ \mathsf{byte}}) \end{aligned}$

Exceptions:

TLB Refill, TLB Invalid Address Error

Load Doubleword

31	26	25 2	1 20	16	15 0
1	LD 10111	base		rt	offset
<u>.</u>	6	5		5	16
Format Purpos		LD rt, offset(b To load a doul	MIPS III		
Descrip	otion:	rt ← memory[

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If any of the three least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

64-bit processors

 $vAddr \leftarrow sign_extend(offset) + GPR[base]$ if $(vAddr_{2..0}) \neq 0^3$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD) memdouble \leftarrow LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) GPR[rt] ← memdouble

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

31	26	25 21	20 16	15	0
	LDCz 1 1 0 1 z z	base	rt	offset	
	6	5	5	16	
For	mat:	LDC1 rt, offset LDC2 rt, offs		MIPS II	
Pur	pose:	To load a double	eword from mem	ory to a coprocessor general register.	
_			aa		

Description: rt ← memory[base+offset]

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and made available to coprocessor unit *zz*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The manner in which each coprocessor uses the data is defined by the individual coprocessor specifications. The usual operation would place the data into coprocessor general register *rt*.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3. The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

This instruction is not available for coprocessor 0, the System Control coprocessor, and the opcode may be used for other instructions.

The effective address must be naturally aligned. If any of the three least-significant bits of the effective address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

vAddr ← sign_extend(offset) + GPR[base]

if $(vAddr_{2..0}) \neq 0^3$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD) memdouble \leftarrow LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) COP_LD (z, rt, memdouble)

Operation: 64-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] if (vAddr_{2..0}) \neq 0³ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD) memdouble \leftarrow LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) COP_LD (z, rt, memdouble)

Exceptions:

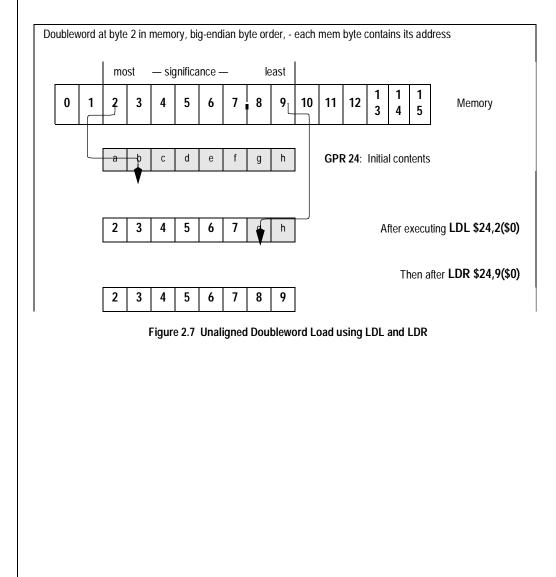
TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction Coprocessor Unusable

Load Doubleword Left 26 25 0 31 21 20 1615 offset LDL base rt 011010 6 5 5 16 Format: LDL rt, offset(base) MIPS III Purpose: To load the most-significant part of a doubleword from an unaligned memory address. Description:

escription: rt ← rt MERGE memory[base+offset] The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*.

EffAddr is the address of the most-significant of eight consecutive bytes forming a doubleword in memory *(DW)* starting at an arbitrary byte boundary. A part of *DW*, the most-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. This part of *DW* is loaded appropriately into the most-significant (left) part of GPR *rt* leaving the remainder of GPR *rt* unchanged.

The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, six bytes, is contained in the aligned doubleword containing the most-significant byte at 2. First, LDL loads these six bytes into the left part of the destination register and leaves the remainder of the destination unchanged. Next, the complementary LDR loads the remainder of the unaligned doubleword.



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr_{2.0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.

WIC	mory	com	CIII		yic i	511501	.5 (07	ddr ₂₀)					ntent			
mo	st	—s	ignifi	canc	е—	I	east				Desti	natio	n Re	giste	r	
0	1	2	3	4	5	6	7	¨ big-	mos	st	—s	ignifi	canc	e—	I	eas
Ι	J	K	L	М	Ν	0	Р		а	b	С	d	е	f	g	h
7	6	5	4	3	2	1	0	"little-endia	n offs	set						
		Des	stina	tion r	egist	er co	ntent	s after instruc	ction	(shac	led is	s unc	hang	jed)		
	Bię	g-end	lian b	oyte d	orderi	ing		vAddr ₂₀		Litt	le-en	dian	byte	orde	ring	
I	J	K	L	М	Ν	0	Ρ	0	Ρ	b	С	d	е	f	g	ł
J	Κ	L	М	Ν	0	Ρ	h	1	0	Р	С	d	е	f	g	ł
К	L	М	Ν	0	Ρ	g	h	2	Ν	0	Р	d	е	f	g	ł
L	Μ	Ν	0	Ρ	f	g	h	3	М	Ν	0	Ρ	е	f	g	ł
М	Ν	0	Ρ	е	f	g	h	4	L	М	Ν	0	Ρ	f	g	ł
Ν	0	Р	d	е	f	g	h	5	К	L	М	Ν	0	Р	g	h
0	Ρ	С	d	е	f	g	h	6	J	Κ	L	М	Ν	0	Ρ	h
Р	b	С	d	е	f	g	h	7	I	J	К	L	М	Ν	0	F

Figure 2.8 Bytes Loaded by LDL Instruction

Restrictions:

ENESAS

LDI

None

Operation:

 $\label{eq:sign_extend(offset) + GPR[base]} (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD) \\ pAddr \leftarrow pAddr_{(PSIZE-1)..3} \parallel (pAddr_{2..0} \mbox{ xor ReverseEndian}^3) \\ if BigEndianMem = 0 then \\ pAddr \leftarrow pAddr_{(PSIZE-1)..3} \parallel 0^3 \\ endif \\ byte \leftarrow vAddr_{2..0} \mbox{ xor BigEndianCPU}^3 \\ memdouble \leftarrow LoadMemory (uncached, byte, pAddr, vAddr, DATA) \\ \end{array}$

 $GPR[rt] \leftarrow memdouble_{7+8*byte..0} || GPR[rt]_{55-8*byte..0}$

64-bit processors

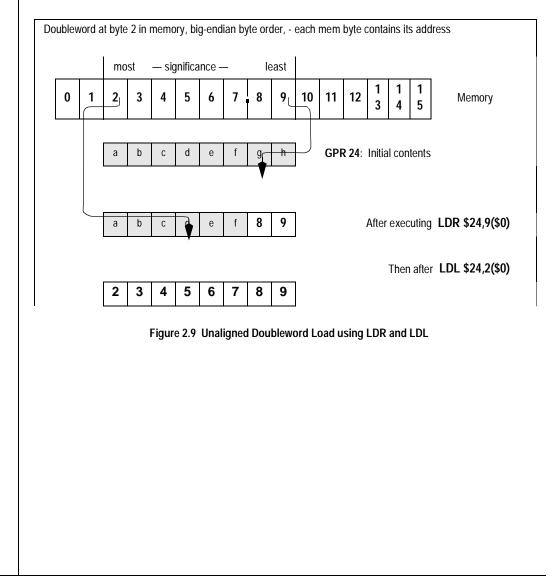
Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

3	1 26	25	21	20		16	15 0
	LDR 0 1 1 0 1 1	ba	ase		rt		offset
	6		5		5		16
	ormat:		t, offset(k	,	С I		MIPS III
Ρ	urpose:	10 1080	the leas	t-signii	ficant	part	of a doubleword from an unaligned memory address.
D	escription:	rt ← rt	MERGE	memo	ory[bas	se+0	fset]

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the least-significant of eight consecutive bytes forming a doubleword in memory (*DW*) starting at an arbitrary byte boundary. A part of *DW*, the least-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. This part of *DW* is loaded appropriately into the least-significant (right) part of GPR *rt* leaving the remainder of GPR *rt* unchanged.

The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, two bytes, is contained in the aligned doubleword containing the least-significant byte at 9. First, LDR loads these two bytes into the right part of the destination register and leaves the remainder of the destination unchanged. Next, the complementary LDL loads the remainder of the unaligned doubleword.



Load Doubleword Right

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr_{2.0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.

-	cont			•			-				Desti	al co natio			r	
mo	51	- 5	igniii	canc	e –	I	east				0000	nauo		gioto	•	
0	1	2	3	4	5	6	7	¨ big-	mo	st	-	signifi	cance) —		leas
I	J	Κ	L	М	Ν	0	Р		а	b	С	d	е	f	g	h
7	6	5	4	3	2	1	0	"little-endia	n offs	set						
		De	stina	tion r	egist	er co	ntent	s after instruc	ction	(shac	led is	s unc	hang	jed)		
	Big	g-enc	lian k	oyte d	orderi	ing		vAddr ₂₀		Litt	le-en	dian	byte	orde	ring	
а	b	С	d	е	f	g	Ι	0	Ι	J	K	L	М	Ν	0	Р
а	b	С	d	е	f	I	J	1	а	Ι	J	Κ	L	М	Ν	0
а	b	С	d	е	Ι	J	K	2	а	b	Ι	J	Κ	L	М	N
а	b	С	d	I	J	K	L	3	а	b	С	Ι	J	Κ	L	Μ
а	b	С	Ι	J	Κ	L	М	4	а	b	С	d	Ι	J	K	L
а	b	Ι	J	Κ	L	М	Ν	5	а	b	С	d	е	Ι	J	K
а	Т	J	Κ	L	М	Ν	0	6	а	b	С	d	е	f	I	J
I	J	К	L	М	Ν	0	Р	7	а	b	С	d	е	f	g	1

Figure 2.10 Bytes Loaded by LDR Instruction

Restrictions:

CENESAS

LDR

None

Operation:

 $\label{eq:sign_extend} \begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{(pAddr, uncached)} \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr, DATA, LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{(pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3) \\ \mathsf{if} \ \mathsf{BigEndianMem} = 1 \ \mathsf{then} \\ & \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{0}^3 \\ \mathsf{endif} \\ \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^3 \\ \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ \mathsf{(uncached, byte, pAddr, vAddr, DATA)} \end{array}$

$GPR[rt] \leftarrow GPR[rt]_{63..64-8^{*}byte} \parallel memdouble_{63..8^{*}byte}$

64-bit processors

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

Load Halfword

31	26	25 21	20 16	15 0)
	LH 1 0 0 0 0 1	base	rt	offset	
	6	5	5	16	_
	rmat: rpose:	LH rt, offset(ba To load a halfwo		MIPS I as a signed value.	

Description: rt ← memory[base+offset]

The contents of the 16-bit halfword at the memory location specified by the aligned effective address are fetched, sign-extended, and placed in GPR rt. The 16-bit signed offset is added to the contents of GPR base to form the effective address.

Restrictions:

The effective address must be naturally aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

MIPS IV: The low-order bit of the offset field must be zero. If it is not, the result of the instruction is undefined.

Operation: 32-bit processors vAddr ← sign_extend(offset) + GPR[base]

if $(vAddr_0) \neq 0$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr \leftarrow pAddr_{PSIZE - 1.2} || (pAddr_{1.0} xor (ReverseEndian || 0)) memword

LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA) byte \leftarrow vAddr_{1 0} xor (BigEndianCPU || 0) $GPR[rt] \leftarrow sign_extend(memword_{15+8*byte..8*byte})$

Operation:

64-bit processors vAddr \leftarrow sign_extend(offset) + GPR[base]

if $(vAddr_0) \neq 0$ then SignalException(AddressError) endif

 $(pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD)$

 $pAddr \leftarrow pAddr_{PSIZE - 1..3} \parallel (pAddr_{2..0} \text{ xor (ReverseEndian} \parallel 0))$

memdouble - LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA)

byte \leftarrow vAddr_{2.0} xor (BigEndianCPU² || 0)

 $GPR[rt] \leftarrow sign_extend(memdouble_{15+8*byte..8*byte})$

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error

31	26	25 21	20 16	15 0
	LHU 100101	base	rt	offset
	6	5	5	16
For	mat:	LHU rt, offset(b	base)	MIPS I
Pur	pose:	To load a halfwo	ord from memory	as an unsigned value.

Description: rt ← memory[base+offset]

The contents of the 16-bit halfword at the memory location specified by the aligned effective address are fetched, zero-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

MIPS IV: The low-order bit of the *offset* field must be zero. If it is not, the result of the instruction is undefined.

Operation: 32-bit processors vAddr ← sign_extend(offset) + GPR[base] if (vAddr₀) ≠ 0 then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD)

pAddr \leftarrow pAddr_{PSIZE - 1..2} || (pAddr_{1..0} xor (ReverseEndian || 0)) memword \leftarrow LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA) byte \leftarrow vAddr_{1..0} xor (BigEndianCPU || 0)

 $GPR[rt] \leftarrow zero_extend(memword_{15+8*byte..8*byte})$

Operation:

n: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr₀) ≠ 0 then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE - 1..3} || (pAddr_{2..0} xor (ReverseEndian² || 0)) memdouble ← LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA) byte ← vAddr_{2..0} xor (BigEndianCPU² || 0) GPR[rt] ← zero_extend(memdouble_{15+8*byte..8*byte})

Exceptions:

TLB Refill, TLB Invalid Address Error

Load Linked Word

31	26	25 21	20 16	15	0
	LL 1 1 0 0 0 0	base	rt	offset	
	6	5	5	16	_
	mat: pose:	LL rt, offset(ba To load a word t		MIPS II an atomic read-modify-write.	

Description: rt ← memory[base+offset]

The LL and SC instructions provide primitives to implement atomic Read-Modify-Write (RMW) operations for cached memory locations.

The 16-bit signed offset is added to the contents of GPR base to form an effective address.

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched, sign-extended to the GPR register length if necessary, and written into GPR rt. This begins a RMW sequence on the current processor.

There is one active RMW sequence per processor. When an LL is executed it starts the active RMW sequence replacing any other sequence that was active.

The RMW sequence is completed by a subsequent SC instruction that either completes the RMW sequence atomically and succeeds, or does not and fails. See the description of SC for a list of events and conditions that cause the SC to fail and an example instruction sequence using LL and SC.

Executing LL on one processor does not cause an action that, by itself, would cause an SC for the same block to fail on another processor.

An execution of LL does not have to be followed by execution of SC; a program is free to abandon the RMW sequence without attempting a write.

Restrictions:

The addressed location must be cached; if it is not, the result is undefined.

The effective address must be naturally aligned. If either of the two least-significant bits of the effective address are non-zero an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the offset field must be zero. If they are not, the result of the instruction is undefined.

Operation:

32-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] if $(vAddr_{1,0}) \neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) memword

LoadMemory (uncached, WORD, pAddr, vAddr, DATA) GPR[rt] ← memword LLbit $\leftarrow 1$

Operation:

64-bit processors vAddr ← sign_extend(offset) + GPR[base] if $(vAddr_{1,0}) \neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr \leftarrow pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²)) memdouble
 LoadMemory (uncached, WORD, pAddr, vAddr, DATA) byte \leftarrow vAddr_{2.0} xor (BigEndianCPU || 0²) $GPR[rt] \leftarrow sign_extend(memdouble_{31+8*byte..8*byte})$ LLbit $\leftarrow 1$



Exceptions:

TLB Refill, TLB Invalid Address Error Reserved Instruction

Programming Notes:

There is no Load Linked Word Unsigned operation corresponding to Load Word Unsigned.

Implementation Notes:

An LL on one processor must not take action that, by itself, would cause an SC for the same block on another processor to fail. If an implementation depends on retaining the data in cache during the RMW sequence, cache misses caused by LL must not fetch data in the exclusive state, thus removing it from the cache, if it is present in another cache.

RENESAS	
LLD	

31	26	25 2	1 20		16	15	0
	LLD 110100	base		rt		offset	
	6	5	·	5		16	
For	mat:	LLD rt, offset	(base)			MIPS III	
Pur	pose:	To load a dou	bleword	from r	memo	ory for an atomic read-modify-write.	

Description: rt ← memory[base+offset]

The LLD and SCD instructions provide primitives to implement atomic Read-Modify-Write (RMW) operations for cached memory locations.

The 16-bit signed offset is added to the contents of GPR base to form an effective address.

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and written into GPR *rt*. This begins a RMW sequence on the current processor.

There is one active RMW sequence per processor. When an LLD is executed it starts the active RMW sequence replacing any other sequence that was active.

The RMW sequence is completed by a subsequent SCD instruction that either completes the RMW sequence atomically and succeeds, or does not and fails. See the description of SCD for a list of events and conditions that cause the SCD to fail and an example instruction sequence using LLD and SCD.

Executing LLD on one processor does not cause an action that, by itself, would cause an SCD for the same block to fail on another processor.

An execution of LLD does not have to be followed by execution of SCD; a program is free to abandon the RMW sequence without attempting a write.

Restrictions:

The addressed location must be cached; if it is not, the result is undefined.

The effective address must be naturally aligned. If either of the three least-significant bits of the effective address are non-zero an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{2..0}) \neq 0³ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) memdouble ← LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) GPR[rt] ← memdouble LLbit ← 1

Exceptions:

TLB Refill, TLB Invalid Address Error Reserved Instruction

Programming Notes:

Implementation Notes:

An LLD on one processor must not take action that, by itself, would cause an SCD for the same block on another processor to fail. If an implementation depends on retaining the data in cache during the RMW sequence, cache misses caused by LLD must not fetch data in the exclusive state, thus removing it from the cache, if it is present in another cache.

Load Upper Immediate

31 2	6 25 21	20 16	15 0
LUI	0	rt	immediate
001111	00000		
6	5	5	16
Format:	LUI rt, immedi	ate	MIPS I
Purpose:	To load a const	ant into the uppe	r half of a word.
Description:	$rt \leftarrow immediate$	e 0 ¹⁶	
The 16-hit <i>im</i>	mediate is shifted l	eft 16 hits and c	oncatenated with 16 bits of low-order zeros. The 32-

The 16-bit *immediate* is shifted left 16 bits and concatenated with 16 bits of low-order zeros. The 32-bit result is sign-extended and placed into GPR *rt*.

Restrictions:

None

Operation:

GPR[rt] \leftarrow sign_extend(immediate || 0¹⁶)

Exceptions:

None

31 26	25 21	20 16	15	0
LW 100011	base	rt	offset	
6	5	5	16	
Format: Purpose:	LW rt, offset(ba To load a word f	ase) from memory as		MIPS I

Load Word

Description: rt ← memory[base+offset]

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched, sign-extended to the GPR register length if necessary, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow sign_extend(offset) + \mathsf{GPR}[base] \\ \mathsf{if} (\mathsf{vAddr}_{1..0}) \neq 0^2 \ \mathsf{then} \ \mathsf{SignalException}(\mathsf{AddressError}) \ \mathsf{endif} \\ (\mathsf{pAddr}, \ \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} \ (\mathsf{vAddr}, \ \mathsf{DATA}, \ \mathsf{LOAD}) \\ \mathsf{memword} \leftarrow \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{WORD}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{memword} \\ \end{array}$

Operation:

: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{1.0}) ≠ 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²)) memdouble ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA) byte ← vAddr_{2..0} xor (BigEndianCPU || 0²) GPR[rt] ← sign_extend(memdouble_{31+8*byte..8*byte})

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error

Load Word To Coprocessor 0 31 26 25 21 20 16 15 offset LWCz base rt 1100zz 5 5 16 6 MIPS I Format: LWC1 rt, offset(base) LWC2 rt, offset(base) LWC3 rt, offset(base) Purpose: To load a word from memory to a coprocessor general register.

Description: rt ← memory[base+offset]

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched and made available to coprocessor unit *zz*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The manner in which each coprocessor uses the data is defined by the individual coprocessor specification. The usual operation would place the data into coprocessor general register *rt*.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3 (see Section titled "Coprocessor Instructions" earlier in this Chapter). The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

This instruction is not available for coprocessor 0, the System Control coprocessor, and the opcode may be used for other instructions.

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

 I: vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{1..0}) ≠ 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) memword ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA)
 I+1: COP_LW (z, rt, memword)

Operation: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base} if (vAddr_{1..0}) ≠ 0^2 then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0^2)) memdouble ← LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA) byte ← vAddr_{2..0} xor (BigEndianCPU || 0^2) memword ← memdouble_{31+8*byte..8*byte} COP_LW (z, rt, memdouble)



Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Coprocessor Unusable



Load Word Left

31	26	25 21	20 16	15 0
	LWL 100010	base	rt	offset
	6	5	5	16
Fo	rmat:	LWL rt, offset(base)	MIPS I
Pu	rpose:	To load the mos address.	t-significant part	of a word as a signed value from an unaligned memory
De	scription:	rt ← rt MERGE	memory[base+	offset]

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the most-significant of four consecutive bytes forming a word in memory (*W*) starting at an arbitrary byte boundary. A part of *W*, the most-significant one to four bytes, is in the aligned word containing *EffAddr*. This part of *W* is loaded into the most-significant (left) part of the word in GPR *rt*. The remaining least-significant part of the word in GPR *rt* is unchanged.

If GPR *rt* is a 64-bit register, the destination word is the low-order word of the register. The loaded value is treated as a signed value; the word sign bit (bit 31) is always loaded from memory and the new sign bit value is copied into bits 63..32.

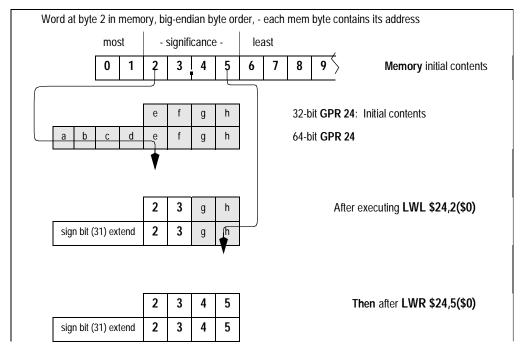


Figure 2.11 Unaligned Word Load using LWL and LWR

The figure above illustrates this operation for big-endian byte ordering for 32-bit and 64-bit registers. The four consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, two bytes, is in the aligned word containing the most-significant byte at 2. First, LWL loads these two bytes into the left part of the destination register word and leaves the right part of the destination word unchanged. Next, the complementary LWR loads the remainder of the unaligned word.

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, i.e. the low two bits of the address (vAddr_{1..0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.

	N	lemor	y con	tents a	and b	yte of	fsets			Initia	l cont	ents o	of Des	st Reg	gister	
0	1	2	3	" big∙	endi	an						64-bitı	egister			
I	J	К	L		offse	et (vA	ddr ₁₀)	а	b	С	d	е	f	g	h
3	2	1	0	" little	e-end	lian			mos	t	_	- signifi	cance			leas
most			least							32-bit	regist	er	е	f	g	h
_	- signifi	cance	_													
		De	stinati	ion 64	-bit re	egiste	r cont	ents after ins	tructio	n (sh	aded	is unc	hang	ed)		
						5				·			5	,		
	В	lig-en	dian b	yte or	derin	g		vAddr ₁₀		Li	ttle-er	ndian	byte o	orderi	ng	
sign	bit (31) exter	nded	Ι	J	К	L	0	sign	bit (31) exter	nded	L	f	g	h
sign	bit (31) exter	nded	J	K	L	h	1	sign	bit (31) exter	nded	К	L	g	h
sign	bit (31) exter	nded	К	L	g	h	2	sign	bit (31) exter	nded	J	К	L	h
sign	bit (31) exter	nded	L	f	g	h	3	sign	bit (31) exter	nded	Ι	J	К	L
The	word	sign ((31) is	alway	ys loa	nded a	and th	e value is co	oied ir	nto bit	s 63	32.				
	word egiste	•	(31) is			nded a		e value is co vAddr ₁₀	oied ir	nto bit	s 63	32.		_ittle-e	endia	n
		•	(31) is						oied ir	nto bit	s 63	32.	l L	_ittle-e	endia g	n h
		•	(31) is		Big-e	ndian		vAddr ₁₀	oied ir	nto bit	s 63	32.				
		•	(31) is	1	Big-e J	ndian K	L	vAddr ₁₀ 0	d ir	nto bit	s 63	32.	L	f	g	h

Figure 2.12 Bytes Loaded by LWL Instruction

The unaligned loads, LWL and LWR, are exceptions to the load-delay scheduling restriction in the MIPS I architecture. An unaligned load instruction to GPR *rt* that immediately follows another load to GPR *rt* can "read" the loaded data. It will correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction.

Restrictions:

MIPS I scheduling restriction: The loaded data is not available for use by the following instruction. The instruction immediately following this one, unless it is an unaligned load (LWL, LWR), may not use GPR *rt* as a source register. If this restriction is violated, the result of the operation is undefined.

Operation: 32-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{(pAddr, uncached)} \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr, DATA, LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..2} \parallel \mathsf{(pAddr}_{1..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^2 \mathsf{)} \\ \mathsf{if} \ \mathsf{BigEndianMem} = 0 \ \mathsf{then} \\ \qquad \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..2} \parallel \mathsf{0}^2 \\ \mathsf{endif} \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{1..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^2 \\ \mathsf{memword} \leftarrow \mathsf{LoadMemory} \ \mathsf{(uncached, byte, pAddr, vAddr, DATA)} \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow \mathsf{memword}_{7+8^* \mathsf{byte}..0} \parallel \mathsf{GPR}[\mathsf{rt}]_{23-8^* \mathsf{byte}..0} \\ \end{array}$

ENESAS

Operation: 64-bit processors

 $\label{eq:product} \begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{LOAD}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel (\mathsf{pAddr}_{2..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^3) \\ \mathsf{if} \ \mathsf{BigEndianMem} = 0 \ \mathsf{then} \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{0}^3 \\ \mathsf{endif} \\ \mathsf{byte} \leftarrow 0 \parallel (\mathsf{vAddr}_{1..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^2) \\ \mathsf{word} \leftarrow \mathsf{vAddr}_2 \ \mathsf{xor} \ \mathsf{BigEndianCPU} \\ \mathsf{memdouble} \leftarrow \mathsf{LoadMemory} \ (\mathsf{uncached}, \ \mathsf{byte}, \ \mathsf{pAddr}, \ \mathsf{vAddr}, \ \mathsf{DATA}) \\ \mathsf{temp} \leftarrow \ \mathsf{memdouble}_{31+32^*\mathsf{word}-8^*\mathsf{byte}..32^*\mathsf{word}} \parallel \mathsf{GPR}[\mathsf{rt}]_{23\cdot8^*\mathsf{byte}..0} \\ \mathsf{GPR}[\mathsf{rt}] \leftarrow (\mathsf{temp}_{31})^{3^2} \parallel \mathsf{temp} \end{array}$

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error

Programming Notes:

The architecture provides no direct support for treating unaligned words as unsigned values, i.e. zeroing bits 63..32 of the destination register when bit 31 is loaded. See SLL or SLLV for a single-instruction method of propagating the word sign bit in a register into the upper half of a 64-bit register.



Load Word Right 31 26 25 21 20 16 15 0 LWR offset base rt 100110 5 5 16 6 MIPS I Format: LWR rt, offset(base) Purpose: To load the least-significant part of a word from an unaligned memory address as a signed value. Description: rt ← rt MERGE memory[base+offset]

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the least-significant of four consecutive bytes forming a word in memory (*W*) starting at an arbitrary byte boundary. A part of *W*, the least-significant one to four bytes, is in the aligned word containing *EffAddr*. This part of *W* is loaded into the least-significant (right) part of the word in GPR *rt*. The remaining most-significant part of the word in GPR *rt* is unchanged.

If GPR *rt* is a 64-bit register, the destination word is the low-order word of the register. The loaded value is treated as a signed value; if the word sign bit (bit 31) is loaded (i.e. when all four bytes are loaded) then the new sign bit value is copied into bits 63..32. If bit 31 is not loaded then the value of bits 63..32 is implementation dependent; the value is either unchanged or a copy of the current value of bit 31. Executing both LWR and LWL, in either order, delivers in a sign-extended word value in the destination register.

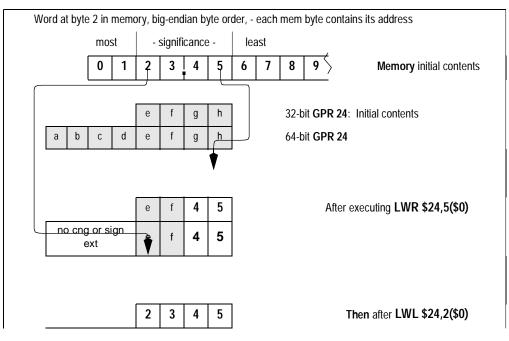


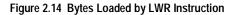
Figure 2.13 Unaligned Word Load using LWR and LWL

The figure above illustrates this operation for big-endian byte ordering for 32-bit and 64-bit registers. The four consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of W, two bytes, is in the aligned word containing the least-significant byte at 5. First, LWR loads these two bytes into the right part of the destination register. Next, the complementary LWL loads the remainder of the unaligned word.

The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, i.e. the low two bits of the address (vAddr_{1..0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes loaded for every combination of offset and byte ordering.



	Memory contents and byte offsets 0 1 2 3 ^{°°} big-endian									Initia	I cont	ents o	of Des	st Reg	jister	
0	1	2	3	" big	-endi	an						64.bit	register			
Т	J	К	L		offse	et (vA	ddr ₁₍))	а	b	С	d	е	f	g	h
3	2	1	0	" littl	e-end	ian			most — signi			signifi	icance —			least
most			least							32-bit	regist	er	е	f	g	h
_	signifi	cance	_													
Destination 64-bit register contents after instruction (shaded is unchanged)																
Big-endian byte ordering vAddr _{1.0} Little-endian byte ordering																
No cng or sign-extend e f g I 0						sign bit (31) extended			nded	Т	J	К	L			
No c	ng or s	sign-ex	xtend	е	f	I	J	1	No c	ng or s	sign-ex	tend	е	I	J	К
No c	ng or s	sign-ex	xtend	е	I	J	К	2	No c	ng or s	sign-ex	tend	е	f	I	J
sign	bit (31) exte	nded	Ι	J	К	L	3	No c	ng or s	sign-ex	tend	е	f	g	Ι
beha bit 3	avior i	s imp opied		itation hem.	spec		its 63	alue is copiec 32 are eithe vAddr _{1.0}					alue o		unloa	ded
				е	f	g	1	0						J	К	L
				е	f	I	J	1				e	1	J	К	
				е	1	J	К	2				е	f	1	J	
				1	J	K	L	3				е	f	g	I	
								l								



The unaligned loads, LWL and LWR, are exceptions to the load-delay scheduling restriction in the MIPS I architecture. An unaligned load to GPR *rt* that immediately follows another load to GPR *rt* can "read" the loaded data. It will correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction.

Restrictions:

MIPS I scheduling restriction: The loaded data is not available for use by the following instruction. The instruction immediately following this one, unless it is an unaligned load (LWL, LWR), may not use GPR *rt* as a source register. If this restriction is violated, the result of the operation is undefined.

Restrictions:

None

ENESAS WR Operation:

32-bit processors vAddr \leftarrow sign_extend(offset) + GPR[base] (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) $pAddr \leftarrow pAddr_{(PSIZE-1)..2} \parallel (pAddr_{1..0} \text{ xor ReverseEndian}^2)$ if BigEndianMem = 0 then pAddr \leftarrow pAddr_{(PSIZE-1),2} || 0² endif byte \leftarrow vAddr_{1.0} xor BigEndianCPU² memword

LoadMemory (uncached, byte, pAddr, vAddr, DATA) $GPR[rt] \leftarrow memword_{31..32-8^*byte} \parallel GPR[rt]_{31-8^*byte..0}$ **Operation:** 64-bit processors vAddr \leftarrow sign_extend(offset) + GPR[base] $(pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, LOAD)$ pAddr \leftarrow pAddr_{(PSIZE-1)..3} || (pAddr_{2..0} xor ReverseEndian³) if BigEndianMem = 1 then $pAddr \leftarrow pAddr_{(PSIZE-1)..3} \parallel 0^3$ endif byte \leftarrow vAddr_{1.0} xor BigEndianCPU² word \leftarrow vAddr₂ xor BigEndianCPU memdouble \leftarrow LoadMemory (uncached, 0 || byte, pAddr, vAddr, DATA) temp \leftarrow GPR[rt]_{31.32-8*byte} || memdouble_{31+32*word.32*word+8*byte} if byte = 4 then /* loaded bit 31, must sign extend */ utemp \leftarrow (temp₃₁)³² else one of the following two behaviors: utemp \leftarrow GPR[rt]_{63..32} /* leave what was there alone */ /* sign-extend bit 31 */ utemp \leftarrow (GPR[rt]₃₁)³ endif $GPR[rt] \leftarrow utemp \parallel temp$

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error

Programming Notes:

The architecture provides no direct support for treating unaligned words as unsigned values, i.e. zeroing bits 63..32 of the destination register when bit 31 is loaded. See SLL or SLLV for a single-instruction method of propagating the word sign bit in a register into the upper half of a 64-bit register.

31	26	25 21	20 16	15 0	
	LWU 100111	base	rt	offset	
	6	5	5	16	
For	mat:	LWU rt, offset(oase)	MIPS III	
Pur	pose:	To load a word f	rom memory as	an unsigned value.	

Description: rt ← memory[base+offset]

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched, zero-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{1..0}) ≠ 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr ← pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²)) memdouble ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA) byte ← vAddr_{2..0} xor (BigEndianCPU || 0²) GPR[rt] ← 0³² || memdouble_{31+8*byte..8*byte}

Exceptions:

TLB Refill, TLB Invalid Bus Error Address Error Reserved Instruction

31	26	25 21	20 16	15 11	10 6	5 0
	Special 2	rs	rt	0	0	MAD
	011100	15	п	Ū	Ũ	00000
	6	5	5	5	5	6

Format: MAD rs, rt

Description:

The RC4650 and RC32364 add a MAD instruction (multiply-accumulate, with HI and LO as the accumulator) to the base MIPS-III ISA. The MAD instruction is defined as:

 $HI,LO \leftarrow HI,LO + rs^{*}rt$

The lower 32-bits of the accumulator are stored in the lower 32 bits of LO, while the upper 32 bits of the result are stored in the lower 32 bits of HI. This is done to allow this instruction to operate compatibly in 32-bit processors.

The actual repeat rate and latency of this operation are dependent on the size of the operands.

Operation:

T: temp " (HI $_{31..0}$ || LO $_{31..0}$) + ((rs $_{31}$)³² || rs $_{31..0}$) x ((rt $_{31}$)³² || rt $_{31..0}$) Hi " (temp $_{63}$)³² || temp $_{63..32}$ LO " (temp $_{31}$)³² || temp $_{31..0}$

Exceptions:

None

Programming Notes:

This is an IDT proprietary extension.

31	26	25 2	1 20 16	6 15 11	I 10 6	5 0
	Special2 011100	rs	rt	0	0	MAD 00001
	6	5	5	5	5	6

Format: MADU rs, rt

Description:

The RC4650 and RC32364 add a MAD instruction (multiply-accumulate, with HI and LO as the accumulator) to the base MIPS-III ISA. The MAD instruction is defined as:

HI,LO "HI,LO + rs*rt

The lower 32-bits of the accumulator are stored in the lower 32 bits of LO, while the upper 32 bits of the result are stored in the lower 32 bits of HI. This is done to allow this instruction to operate compatibly in 32-bit processors. The actual repeat rate and latency of this operation are dependent on the size of the operands.

Operation:

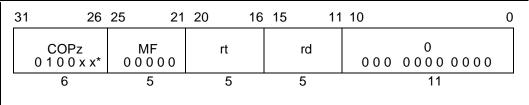
T: temp " (HI $_{31..0}$ || LO $_{31..0}$) + (0³² || rs $_{31..0}$) x (0³² || rt $_{31..0}$) Hi " (temp $_{63}$)³² || temp $_{63..32}$ LO " (temp $_{31}$) ³² || temp $_{31..0}$

Exceptions:

None

Programming Notes:

This is an IDT proprietary extension.



Format: MFCz rt, rd

Description:

The contents of coprocessor register rd of coprocessor z are loaded into general register rt.

Execution of the instruction referencing coprocessor 3 causes a reserved instruction exception, not a coprocessor unusable exception.

Note: *See "Opcode Bit Encoding" on page 120, or "CPU InstructionEncoding" at the end of Appendix A.

Operation:

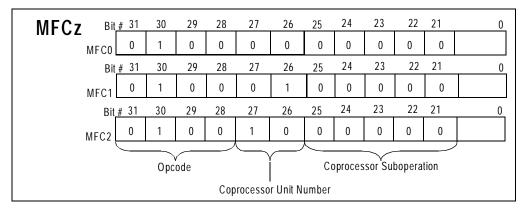
T: if $rd_0 = 0$ then data $"CPR[z, rd_{4..1} || 0]_{31..0}$ else data $"CPR[z, rd_{4..1} || 0]_{63..32}$ endif T+1: $GPR[rt] "(data_{31})^{32} || data$

Exceptions:

Coprocessor unusable exception

Reserved instruction exception (coprocessor 3)

Opcode Bit Encoding:





31	26	25 16	15 1	1 10 6	5 0
	SPECIAL 0 0 0 0 0 0 0	$\begin{smallmatrix}&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&$	rd	0 0 0 0 0 0	MFHI 0 1 0 0 0 0
	6	10	5	5	6
	rmat: rpose:	MFHI rd To copy the special purpo	ose HI register to a	GPR.	MIPS I
De	scription:	$rd \gets HI$			

The contents of special register HI are loaded into GPR rd.

Restrictions:

The two instructions that follow an MFHI instruction must not be instructions that modify the *HI* register: DDIV, DDIVU, DIV, DIVU, DMULT, DMULTU, MTHI, MULT, MULTU. If this restriction is violated, the result of the MFHI is undefined.

Operation:

 $\mathsf{GPR}[\mathsf{rd}] \gets \mathsf{HI}$

Exceptions:

None

Move From LO Register

31	26	25 16	15	11 10	6	5	0
	SPECIAL 0 0 0 0 0 0 0	000000000000000000000000000000000000000	rd	0 0 0 0 0 0		MFLO 0 1 0 0 1	0
	6	10	5	5		6	
	ormat: irpose:	MFLO rd To copy the special purp	ose LO register t	o a GPR.		MIPS I	
De	escription:	$rd \gets LO$					

The contents of special register LO are loaded into GPR rd.

Restrictions:

The two instructions that follow an MFLO instruction must not be instructions that modify the *LO* register: DDIV, DDIVU, DIV, DIVU, DMULT, DMULTU, MTLO, MULT, MULTU. If this restriction is violated, the result of the MFLO is undefined.

Operation:

 $\mathsf{GPR}[\mathsf{rd}] \leftarrow \mathsf{LO}$

Exceptions:

None

31	26	25	21	20 16	15 11	10 6	5	0
SPE 0 0 0 0	CIAL) 0 0	rs		rt	rd	0 00000	MOVN 0 0 1 0 1 1	
6)	5		5	5	5	6	
Format: Purpose	-	MOVN To cond	rd, r itional	s, rt Ily move a GPR a	fter testing a G	MIPS IV,RC32 PR value.	2364	
Descrip	tion:	if (rt ≠ 0)) then	$rd \leftarrow rs$				
If the	e value ir	n GPR <i>rt</i> is n	iot equ	ual to zero, then t	he contents of	GPR <i>rs</i> are place	ed into GPR <i>rd</i> .	
Restrict None								
Onorati	٥n·							

Operation:

 $\begin{array}{l} \text{if GPR[rt]} \neq 0 \text{ then} \\ & \text{GPR[rd]} \leftarrow \text{GPR[rs]} \\ \text{endif} \end{array}$

Exceptions:

Reserved Instruction

Programming Notes:

The nonzero value tested here is the "condition true" result from the SLT, SLTI, SLTU, and SLTIU comparison instructions.

Move Conditional on Zero

31	26	25	21	20	16	15	11	10 6	5	0	
SPECI <i>I</i> 0 0 0 0 0		rs		rt		rd		0 0 0 0 0 0	MOVZ 0 0 1 0 1 0		
6		5		5		5		5	6		
Format: Purpose:		MOVZ To cond	rd, rs itional	s, rt ly move a G	SPR at	fter testing	a GI	MIPS IV,RC32 PR value.	364		
Descriptio	Description: if $(rt = 0)$ then $rd \leftarrow rs$										
If the va	alue in	GPR <i>rt</i> is e	equal t	o zero, ther	n the c	ontents of	GPR	rs are placed in	to GPR <i>rd</i> .		
Restriction None	ns:										
Operation if GPF	R[rt] =	0 then d] ← GPR[i	rs]								

Exceptions:

Reserved Instruction

Programming Notes:

The zero value tested here is the "condition false" result from the SLT, SLTI, SLTU, and SLTIU comparison instructions.



31	26 2	25	21	20	16	15	11	10 6	5		0
SPECI		rs		rt		rd		0 0 0 0 0 0		MSUB 0 0 0 1 0 0	
6		5		5		5		5		6	
Format:		MSUB	rs, rt							RC32364	

Description:

The RC32364 adds this new instruction. The content of general registers rs and rt are multiplied, treating both operands as 32-bit two's complement values, and the result is subtracted from HI/LO. No overflow exception occur under any circumstances.

When the operation is complete, the low-order word of the double result is loaded in LO, and the highorder word of the double result is loaded into HI. The instruction is not interlocked so any attempt to read HI/ LO before the operation completes returns undefined value.

Operation:

T: temp <-- (HI || LO) - GPR[rs] * GPR[rt] LO <-- temp HI <-- temp

Exceptions:

None

Programming Notes:

This is an IDT proprietary extension.



31	26 25	4	21 20	16 15	11	10 6	5	0
SPECI 0 1 1		rs	rt		rd	0 0 0 0 0 0	MSUB 0 0 0 1 0 0	
6		5	5		5	5	6	
Format:	N	ISUB rs	, rt				RC32364	

Description:

The RC32364 adds this new instruction. The content of general registers rs and rt are multiplied, treating both operand as 32-bit unsigned values, and the result is subtracted from HI/LO. No overflow exception occur under any circumstances.

When the operation completes, the low-order word of the double result is loaded in LO, and the highorder word of the double result is loaded in HI. The instruction is not interlocked so any attempt to read HI/ LO before the operation completes returns undefined value.

Operation:

T: temp <-- (HI || LO) - (0||GPR[rs]) * (0||GPR[rt]) LO <-- temp HI <-- temp

Exceptions:

None

Programming Notes:

This is an IDT proprietary extension.

3	1 26	25 21	20 16	15 1	1 10	0
	COPz 0 1 0 0 x x*	MT 0 0 1 0 0	rt	rd	0 000 0000 0000	
	6	5	5	5	11	

Format: MTCz rt, rd

Note: *See "Opcode Bit Encoding" on this page, or "CPU Instruction Encoding" at the end of Appendix A.

Description:

The contents of general register *rt* are loaded into coprocessor register *rd* of coprocessor *z*. Execution of the instruction referencing coprocessor 3 causes a reserved instruction exception, not a coprocessor unusable exception.

Operation:

Exceptions:

Coprocessor unusable exception

Reserved instruction exception (coprocessor 3)

Opcode Bit Encoding:

MTCz Bit	t <u>#</u> 31	30	29	28	27	26	25	24	23	22	21	0
COPO	0	1	0	0	0	0	0	0	1	0	0	
Bit	# 31	30	29	28	27	26	25	24	23	22	21	0
C0P1	0	1	0	0	0	1	0	0	1	0	0	
Bit	# 31	30	29	28	27	26	25	24	23	22	21	0
C0P2	0	1	0	0	1	0	0	0	1	0	0	
Opcode Coprocessor Unit Number Coprocessor Suboperation												



31 26	25 21	20 6	5 0)
SPECIAL 0 0 0 0 0 0 0	rs	0 0 0000 0000 0000 00	MTHI 0 1 0 0 0 1	
6	5	15	6	-
Format:	MTHI rs		MIPS I	
Purpose:	To copy a GPR	to the special purpose HI register.		
Description:	HI ← rs			
The contents of		a dinta an a sial na sisten 111		

The contents of GPR *rs* are loaded into special register *HI*.

Restrictions:

If either of the two preceding instructions is MFHI, the result of that MFHI is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

A computed result written to the *HILO* pair by DDIV, DDIVU, DIVU, DIVU, DMULT, DMULTU, MULT, or MULTU must be read by MFHI or MFLO before another result is written into either *HI* or *LO*. If an MTHI instruction is executed following one of these arithmetic instructions, but before a MFLO or MFHI instruction, the contents of *LO* are undefined. The following example shows this illegal situation:

MUL	r2,r4	# start operation that will eventually write to HI,LO
		# code not containing mfhi or mflo
MTHI	r6	
		# code not containing mflo
MFLO	r3	# this mflo would get an undefined value

Operation:

I-2:, I-1:	$HI \gets undefined$
l:	$HI \gets GPR[rs]$

Exceptions:

None



31 26	5 25 21	20 6	5 5 0
SPECIAL 0 0 0 0 0 0 0	rs	0 0 0000 0000 0000 00	MTLO 0 1 0 0 1 1
6	5	15	6
Format:	MTLO rs		MIPS I
Purpose:	To copy a GPR	to the special purpose LO register.	
Description:	$L0 \leftarrow rs$		
The contents of	f GPR <i>rs</i> are load	ed into special register LO.	

Restrictions:

If either of the two preceding instructions is MFLO, the result of that MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

A computed result written to the *HILO* pair by DDIV, DDIVU, DIVU, DIVU, DMULT, DMULTU, MULT, or MULTU must be read by MFHI or MFLO before another result is written into either *HI* or *LO*. If an MTLO instruction is executed following one of these arithmetic instructions, but before a MFLO or MFHI instruction, the contents of *HI* are undefined. The following example shows this illegal situation:

r2,r4	# start operation that will eventually write to HI,LO
	# code not containing mfhi or mflo
r6	
	# code not containing mfhi
r3	# this mfhi would get an undefined value
	r6

Operation:

I-2:, I-1:	$\text{LO} \gets \text{undefined}$
I:	$LO \leftarrow GPR[rs]$

Exceptions:

None

31 26	25 21	20 16	5 15 1 ⁻	1 10 6	5 0
SPECIAL2 011100	rs	rt	rd	0	MUL 00010
6	5	5	5	5	6

Format: MUL rd, rs, rt

Description:

The RC4650 and RC32364 add a true 3-operand $32x32 \rightarrow 32$ multiply instruction to the MIPS-III ISA, where by rd = rs*rt. This instruction eliminates the need to explicitly move the multiply result from the LO register back to a general register. The execution time of this operation is operand size dependent.

The HI and LO registers are undefined after executing this instruction. For 16-bit operands, the latency of MUL is 3 cycles, with a repeat rate of 2 cycles. In addition, the MUL instruction will unconditionally slip or stall for all but 2 cycles of its latency.

Operation:

T: Temp " rs 31 . . . 0 x rt 31 . . 0 rd " (temp31)32 || temp 31. . . 0 HI " undefined LO " undefined

Exceptions:

None

Programming Notes:

This instruction is an IDT proprietary extension.



31 26	25 21	20 16	15	6	5 0
SPECIAL 0 0 0 0 0 0 0	rs	rt	0 00 0000 0000		MULT 0 1 1 0 0 0
6	5	5	10		6
Format:	MULT rs, rt	it classed into con-			MIPS I
Purpose:	To multiply 32-b	it signed integers	S.		

Description: (LO, HI) \leftarrow rs \times rt

The 32-bit word value in GPR *rt* is multiplied by the 32-bit value in GPR *rs*, treating both operands as signed values, to produce a 64-bit result. The low-order 32-bit word of the result is placed into special register *LO*, and the high-order 32-bit word is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif

I-2:, I-1:	LO, HI	\leftarrow undefined
l:	prod	$\leftarrow GPR[rs]_{310} * GPR[rt]_{310}$
	LO	\leftarrow sign_extend(prod ₃₁₀)
	HI	\leftarrow sign_extend(prod ₆₃₃₂)

Exceptions:

None

Programming Notes:

In some processors the integer multiply operation may proceed asynchronously and allow other CPU instructions to execute before it is complete. An attempt to read *LO* or *HI* before the results are written will wait (interlock) until the results are ready. Asynchronous execution does not affect the program result, but offers an opportunity for performance improvement by scheduling the multiply so that other instructions can execute in parallel.

Programs that require overflow detection must check for it explicitly.



31	26	25 21	20 16	15	6	5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	0 00 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		MULTU 0 1 1 0 0 1	
	6	5	5	10		6	
For	mat:	MULTU rs, rt				MIPS I	
Pu	rpose:	To multiply 32-b	it unsigned integ	jers.			

Description: (LO, HI) \leftarrow rs \times rt

The 32-bit word value in GPR *rt* is multiplied by the 32-bit value in GPR *rs*, treating both operands as unsigned values, to produce a 64-bit result. The low-order 32-bit word of the result is placed into special register *LO*, and the high-order 32-bit word is placed into special register *HI*.

No arithmetic exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

If either of the two preceding instructions is MFHI or MFLO, the result of the MFHI or MFLO is undefined. Reads of the *HI* or *LO* special registers must be separated from subsequent instructions that write to them by two or more other instructions.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif

I-2:, I-1:	LO, HI	\leftarrow undefined
l:	prod	\leftarrow (0 GPR[rs]_{310}) * (0 GPR[rt]_{310})
	LO	\leftarrow sign_extend(prod ₃₁₀)
	ΗI	\leftarrow sign_extend(prod ₆₃₃₂)

Exceptions:

None

Programming Notes:

In some processors the integer multiply operation may proceed asynchronously and allow other CPU instructions to execute before it is complete. An attempt to read *LO* or *HI* before the results are written will wait (interlock) until the results are ready. Asynchronous execution does not affect the program result, but offers an opportunity for performance improvement by scheduling the multiply so that other instructions can execute in parallel.

Programs that require overflow detection must check for it explicitly.



31	26	25 21	20 16	15 1	1 10 6	5 0
SPE 0 0 0 0		rs	rt	rd	00000	NOR 1 0 0 1 1 1
6	6	5	5	5	5	6
Format:		NOR rd, rs, rt				MIPS I
Purpose:		To do a bitwise	logical NOT OR.			

Description: $rd \leftarrow rs NOR rt$

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical NOR operation. The result is placed into GPR *rd*.

Restrictions:

None

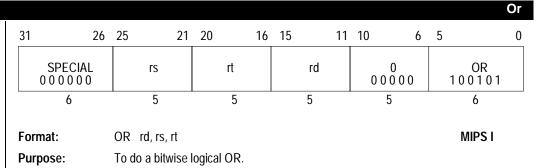
Operation:

 $GPR[rd] \leftarrow GPR[rs] \text{ nor } GPR[rt]$

Exceptions:

None





Description: $rd \leftarrow rs OR rt$

The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical OR operation. The result is placed into GPR *rd*.

Restrictions:

None

Operation:

 $GPR[rd] \leftarrow GPR[rs] \text{ or } GPR[rt]$

Exceptions:



Or Immediate 26 25 0 31 21 20 16 15 ORI 0 0 1 1 0 1 immediate rs rt 6 5 5 16 Format: ORI rt, rs, immediate **MIPS I** Purpose: To do a bitwise logical OR with a constant. Description: $\mathsf{rd} \gets \mathsf{rs} \ \mathsf{OR} \ \mathsf{immediate}$ The 16-bit immediate is zero-extended to the left and combined with the contents of GPR rs in a bitwise logical OR operation. The result is placed into GPR rt.

Restrictions:

None

Operation:

 $GPR[rt] \leftarrow zero_extend(immediate) \text{ or } GPR[rs]$

Exceptions:



					Prefetch
3	1 26	25 21	20 16	15	0
	PREF 110011	base	hint	offset	
	6	5	5	16	
Format:		PREF hint, offs	set(base)	MIPS IV,RC32364	
Purpose:		To prefetch data	a from memory.		

Description: prefetch_memory(base+offset)

PREF adds the 16-bit signed *offset* to the contents of GPR *base* to form an effective byte address. It advises that data at the effective address may be used in the near future. The *hint* field supplies information about the way that the data is expected to be used.

PREF is an advisory instruction. It may change the performance of the program. For all *hint* values and all effective addresses, it neither changes architecturally-visible state nor alters the meaning of the program. An implementation may do nothing when executing a PREF instruction.

If MIPS IV instructions are supported and enabled, PREF does not cause addressing-related exceptions. If it raises an exception condition, the exception condition is ignored. If an addressing-related exception condition is raised and ignored, no data will be prefetched, Even if no data is prefetched in such a case, some action that is not architecturally-visible, such as writeback of a dirty cache line, might take place.

PREF will never generate a memory operation for a location with an uncached memory access type (see the section titled "Memory Access Types" earlier in this Chapter).

If PREF results in a memory operation, the memory access type used for the operation is determined by the memory access type of the effective address, just as it would be if the memory operation had been caused by a load or store to the effective address.

PREF enables the processor to take some action, typically prefetching the data into cache, to improve program performance. The action taken for a specific PREF instruction is both system and context dependent. Any action, including doing nothing, is permitted that does not change architecturally-visible state or alter the meaning of a program. It is expected that implementations will either do nothing or take an action that will increase the performance of the program.

For a cached location, the expected, and useful, action is for the processor to prefetch a block of data that includes the effective address. The size of the block, and the level of the memory hierarchy it is fetched into are implementation specific.

The *hint* field supplies information about the way the data is expected to be used. No *hint* value causes an action that modifies architecturally-visible state. A processor may use a *hint* value to improve the effectiveness of the prefetch action. The defined *hint* values and the recommended prefetch action are shown in the table below. The *hint* table may be extended in future implementations.

Value	Name	Data use and desired prefetch action				
0	load	Data is expected to be loaded (not modified). Fetch data as if for a load.				
1	store	Data is expected to be stored or modified. Fetch data as if for a store.				
31	Ignore hit (Kernel Mode only)	Invalidate the cache line and bring in the new data from memory regardless of the state of the valid bit.				

Table 2.29 Values of Hint Field for Prefetch Instruction in RC32364

Value	Name	Data use and desired prefetch action
0	load	Data is expected to be loaded (not modified). Fetch data as if for a load.
1	store	Data is expected to be stored or modified. Fetch data as if for a store.
2-3		Not yet defined.
4	load_streamed	Data is expected to be loaded (not modified) but not reused extensively; it will "stream" through cache. Fetch data as if for a load and place it in the cache so that it will not displace data prefetched as "retained".
5	store_streamed	Data is expected to be stored or modified but not reused extensively; it will "stream" through cache. Fetch data as if for a store and place it in the cache so that it will not displace data prefetched as "retained".
6	load_retained	Data is expected to be loaded (not modified) and reused extensively; it should be "retained" in the cache. Fetch data as if for a load and place it in the cache so that it will not be displaced by data prefetched as "streamed".
7	store_retained	Data is expected to be stored or modified and reused extensively; it should be "retained" in the cache. Fetch data as if for a store and place it in the cache so that will not be displaced by data prefetched as "streamed".
8-31		Not yet defined.

Table 2.30 Values of Hint Field for Prefetch Instruction in RC5000

Restrictions:

None

Operation:

vAddr ← GPR[base] + sign_extend(offset) (pAddr, uncached) ← AddressTranslation(vAddr, DATA, LOAD) Prefetch(uncached, pAddr, vAddr, DATA, hint)

Exceptions:

Reserved Instruction

Programming Notes:

Prefetch can not prefetch data from a mapped location unless the translation for that location is present in the TLB. Locations in memory pages that have not been accessed recently may not have translations in the TLB, so prefetch may not be effective for such locations.

Prefetch does not cause addressing exceptions. It will not cause an exception to prefetch using an address pointer value before the validity of a pointer is determined.

Implementation Notes:

It is recommended that a reserved *hint* field value either cause a default prefetch action that is expected to be useful for most cases of data use, such as the "load" *hint*, or cause the instruction to be treated as a NOP.

	31	26	25	24					6	5	0
	COPO		CO			0				RFE	
	010000		1		000	0000	0000	0000	0000	010000	
-	6		1				19			6	

Format: RFE

Description:

This instruction is not implemented on RC4000 and RISCore32300 processors; use ERET instead.

RFE restores the previous interrupt mask and Kernel/User-mode bits (IEp and KUp) of the Status register (SR) into the corresponding current status bits (IEc and KUc) and restores the old status bits (IEo and KUo) into the corresponding previous status bits (IEp and KUp). The old status bits remain unchanged.

The architecture does not specify the operation of memory references associated with load/store instructions immediately prior to an RFE instruction. Normally, the RFE instruction follows in the delay slot of a JR (jump register)instruction to restore the PC.

R2000/RC3000/RC6000

Operation:

T: SR [°] SR31..4|| SR5..2 LLbit [°] 0

Exceptions:

Coprocessor unusable exception

Reserved instruction exception (RC4000)

Store Byte

31 26	25	21	20	16	5 15 C)		
SB 1 0 1 0 0 0	b	base		rt	offset			
6		5		5	16	_		
Format:	SB rt,	, offset(ba	se)		MIPS I			
Note: It is recommended that a reserved <i>hint</i> field value either cause a default prefetch action that is expected to be useful for most cases of data use, such as the "load" <i>hint</i> , or cause the instruction to be treated as								

a NOP.

Purpose: To store a byte to memory.

Description: memory[base+offset] \leftarrow rt

The least-significant 8-bit byte of GPR *rt* is stored in memory at the location specified by the effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

None

Operation: 32-bit processors

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ \mathsf{(pAddr, uncached)} \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr, DATA, STORE}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..2}} \parallel (\mathsf{pAddr}_{1..0} \ \mathsf{xor} \ \mathsf{ReverseEndian}^2) \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{1..0} \ \mathsf{xor} \ \mathsf{BigEndianCPU}^2 \\ \mathsf{dataword} \leftarrow \mathsf{GPR}[\mathsf{rt}]_{31-8^* \mathsf{byte..0}} \parallel 0^{8^* \mathsf{byte}} \\ \mathsf{StoreMemory} \ \mathsf{(uncached, BYTE, dataword, pAddr, vAddr, DATA)} \\ \end{array}$

Operation: 64-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) pAddr \leftarrow pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor ReverseEndian³) byte \leftarrow vAddr_{2..0} xor BigEndianCPU³ datadouble \leftarrow GPR[rt]_{63-8*byte..0} || 0^{8*byte} StoreMemory (uncached, BYTE, datadouble, pAddr, vAddr, DATA)

Exceptions:

TLB Refill, TLB Invalid TLB Modified Bus Error Address Error

3	1 26	25 21	20	16	15 0				
	SC 1 1 1 0 0 0	base		rt	offset				
	6	5		5	16				
F	ormat:	SC rt, offset(ba	se)		MIPS II				
Ρ	urpose:	To store a word	to me	mory to co	mplete an atomic read-modify-write.				
Description: if (atomic_update) then memory[base+offset] \leftarrow rt, rt \leftarrow 1 else rt \leftarrow 0									
tio	The LL and SC instructions provide primitives to implement atomic Read-Modify-Write (RMW) operations for cached memory locations.								

The 16-bit signed offset is added to the contents of GPR base to form an effective address.

The SC completes the RMW sequence begun by the preceding LL instruction executed on the processor. If it would complete the RMW sequence atomically, then the least-significant 32-bit word of GPR *rt* is stored into memory at the location specified by the aligned effective address and a one, indicating success, is written into GPR *rt*. Otherwise, memory is not modified and a zero, indicating failure, is written into GPR *rt*.

If any of the following events occurs between the execution of LL and SC, the SC will fail:

- A coherent store is completed by another processor or coherent I/O module into the block of physical memory containing the word. The size and alignment of the block is implementation dependent. It is at least one word and is at most the minimum page size.
- An exception occurs on the processor executing the LL/SC. An implementation may detect "an exception" in one of three ways:
 1) Detect exceptions and fail when an exception occurs.
 2) Fail after the return-from-interrupt instruction (RFE or ERET) is executed.
 3) Do both 1 and 2.

If any of the following events occurs between the execution of LL and SC, the SC may succeed or it may fail; the success or failure is unpredictable. Portable programs should not cause one of these events:

- A load, store, or prefetch is executed on the processor executing the LL/SC.
- The instructions executed starting with the LL and ending with the SC do not lie in a 2048-byte contiguous region of virtual memory. The region does not have to be aligned, other than the alignment required for instruction words.

The following conditions must be true or the result of the SC will be undefined:

- Execution of SC must have been preceded by execution of an LL instruction.
- A RMW sequence executed without intervening exceptions must use the same address in the LL and SC. The address is the same if the virtual address, physical address, and cache-coherence algorithm are identical.

Atomic RMW is provided only for cached memory locations. The extent to which the detection of atomicity operates correctly depends on the system implementation and the memory access type used for the location. See the section titled "**Memory Access Types**" earlier in this Chapter.

MP atomicity: To provide atomic RMW among multiple processors, all accesses to the location must be made with a memory access type of cached coherent.

Uniprocessor atomicity: To provide atomic RMW on a single processor, all accesses to the location must be made with memory access type of either cached noncoherent or cached coherent. All accesses must be to one or the other access type, they may not be mixed.

I/O System: To provide atomic RMW with a coherent I/O system, all accesses to the location must be made with a memory access type of cached coherent. If the I/O system does not use coherent memory operations, then atomic RMW cannot be provided with respect to the I/O reads and writes.



The definition above applies to user-mode operation on all MIPS processors that support the MIPS II architecture. There may be other implementation-specific events, such as privileged CP0 instructions, that will cause an SC instruction to fail in some cases. System programmers using LL/SC should consult implementation-specific documentation.

Restrictions:

The addressed location must have a memory access type of cached noncoherent or cached coherent; if it does not, the result is undefined (see the section titled "Memory Access Types" earlier in this Chapter).

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

 $vAddr \leftarrow sign_extend(offset) + GPR[base]$ if $(vAddr_{1..0}) \neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) dataword \leftarrow GPR[rt] if LLbit then StoreMemory (uncached, WORD, dataword, pAddr, vAddr, DATA) endif GPR[rt] $\leftarrow 0^{31}$ || LLbit **Operation:** 64-bit processors

eration: 64-bit proces

vAddr \leftarrow sign_extend(offset) + GPR[base] if (vAddr_{1 0}) \neq 0² then SignalException(AddressError) endif

 $(pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE)$

pAddr \leftarrow pAddr_{PSIZE-1,3} || (pAddr_{2,0} xor (ReverseEndian || 0²))

byte \leftarrow vAddr_{2 0} xor (BigEndianCPU || 0²)

datadouble \leftarrow GPR[rt]_{63-8*byte..0} || 0^{8*byte}

if LLbit then

StoreMemory (uncached, WORD, datadouble, pAddr, vAddr, DATA)

endif

 $GPR[rt] \leftarrow 0^{63} \parallel LLbit$

Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction

Programming Notes:

LL and SC are used to atomically update memory locations as shown in the example atomic increment operation below.

L1:			
	LL	T1, (T0)	# load counter
	ADDI	T2, T1, 1	# increment
	SC	T2, (T0)	# try to store, checking for atomicity
	BEQ	T2, 0, L1	# if not atomic (0), try again
	NOP		# branch-delay slot

Exceptions between the LL and SC cause SC to fail, so persistent exceptions must be avoided. Some examples of these are arithmetic operations that trap, system calls, floating-point operations that trap or require software emulation assistance.



LL and SC function on a single processor for cached noncoherent memory so that parallel programs can be run on uniprocessor systems that do not support cached coherent memory access types.

Implementation Notes:

The block of memory that is "locked" for LL/SC is typically the largest cache line in use.

				Store Conditional Doubleword				
31 26	25 21	20	16	15 0				
SCD 111100	base	rt		offset				
6	5	5		16				
Format:	SCD rt, offset(I	oase)		MIPS III				
Purpose:	To store a doub	eword to r	nemor	y to complete an atomic read-modify-write.				
Description:	if (atomic_updat	e) then me	emory[base+offset] \leftarrow rt, rt \leftarrow 1 else rt \leftarrow 0				
The 16-bit signe	ed <i>offset</i> is added	to the cor	ntents	of GPR base to form an effective address.				
processor. If it work stored into memory	uld complete the at the location s	RMW see	quence / the al	n by the preceding LLD instruction executed on the e atomically, then the 64-bit doubleword of GPR <i>rt</i> is ligned effective address and a one, indicating success, nodified and a zero, indicating failure, is written into				
If any of the follo	owing events occ	urs betwe	en the	execution of LLD and SCD, the SCD will fail:				
 A coherent store is completed by another processor or coherent I/O module into the block of physical memory containing the word. The size and alignment of the block is implementation dependent. It is at least one doubleword and is at most the minimum page size. An exception occurs on the processor executing the LLD/SCD. An implementation may detect "an exception" in one of three ways: 1) Detect exceptions and fail when an exception occurs. 2) Fail after the return-from-interrupt instruction (RFE or ERET) is executed. 3) Do both 1 and 2. 								
				execution of LLD and SCD, the SCD may succeed or rtable programs should not cause one of these events.				
A memory a LLD/SCD.	access instructior	n (load, sto	ore, or	prefetch) is executed on the processor executing the				
contiguous		nemory. Ti		D and ending with the SCD do not lie in a 2048-byte ion does not have to be aligned, other than the align-				

The following conditions must be true or the result of the SCD will be undefined:

- Execution of SCD must have been preceded by execution of an LLD instruction.
- A RMW sequence executed without intervening exceptions must use the same address in the LLD and SCD. The address is the same if the virtual address, physical address, and cache-coherence algorithm are identical.

Atomic RMW is provided only for memory locations with cached noncoherent or cached coherent memory access types. The extent to which the detection of atomicity operates correctly depends on the system implementation and the memory access type used for the location. See the section titled "Memory Access Types" earlier in this Chapter.

MP atomicity: To provide atomic RMW among multiple processors, all accesses to the location must be made with a memory access type of cached coherent.

Uniprocessor atomicity: To provide atomic RMW on a single processor, all accesses to the location must be made with memory access type of either cached noncoherent or cached coherent. All accesses must be to one or the other access type, they may not be mixed.

I/O System: To provide atomic RMW with a coherent I/O system, all accesses to the location must be made with a memory access type of cached coherent. If the I/O system does not use coherent memory operations, then atomic RMW cannot be provided with respect to the I/O reads and writes.

The defemination above applies to user-mode operation on all MIPS processors that support the MIPS III architecture. There may be other implementation-specific events, such as privileged CP0 instructions, that will cause an SCD instruction to fail in some cases. System programmers using LLD/SCD should consult implementation-specific documentation.

Restrictions:

The addressed location must have a memory access type of cached noncoherent or cached coherent; if it does not, the result is undefined (see the section titled "Memory Access Types" earlier in this Chapter. The 64-bit doubleword of register *rt* is conditionally stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The effective address must be naturally aligned. If any of the three least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{2..0}) \neq 0³ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, STORE) datadouble ← GPR[rt] if LLbit then StoreMemory (uncached, DOUBLEWORD, datadouble, pAddr, vAddr, DATA) endif GPR[rt] ← 0⁶³ || LLbit

Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction

Programming Notes:

LLD and SCD are used to atomically update memory locations as shown in the example atomic increment operation below.

L1:			
	LLD	T1, (T0)	# load counter
	ADDI	T2, T1, 1	# increment
	SCD	T2, (T0)	# try to store, checking for atomicity
	BEQ	T2, 0, L1	# if not atomic (0), try again
	NOP		# branch-delay slot

Exceptions between the LLD and SCD cause SCD to fail, so persistent exceptions must be avoided. Some examples of these are arithmetic operations that trap, system calls, floating-point operations that trap or require software emulation assistance.

LLD and SCD function on a single processor for cached noncoherent memory so that parallel programs can be run on uniprocessor systems that do not support cached coherent memory access types.

Implementation Notes:

The block of memory that is "locked" for LLD/SCD is typically the largest cache line in use.

	31 26	25 21	20 16	15	0
	SD 111111	base	rt	offset	
	6	5	5	16	
	Format: Purpose:	SD rt, offset(ba To store a doub	•	MIPS III y.	
Description:		memory[base+o			

The 64-bit doubleword in GPR *rt* is stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If any of the three least-significant bits of the effective address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 64-bit processors

vAddr ← sign_extend(offset) + GPR[base]

if $(vAddr_{2,0}) \neq 0^3$ then SignalException(AddressError) endif

 $(pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE)$

 $datadouble \gets \mathsf{GPR}[\mathsf{rt}]$

StoreMemory (uncached, DOUBLEWORD, datadouble, pAddr, vAddr, DATA)

Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction

3	1 26	25 21	20 16	15	0
	SDCz 1 1 1 1 z z	base	rt	offset	
	6	5	5	16	
Format: SDC1 rt, offset(base) SDC2 rt, offset(base)			. ,	MIPS II	
Purpose:		To store a doub	leword from a co	processor general register to memory.	

Description: memory[base+offset] \leftarrow rt

Coprocessor unit *zz* supplies a 64-bit doubleword which is stored at the memory location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The data supplied by each coprocessor is defined by the individual coprocessor specifications. The usual operation would read the data from coprocessor general register *rt*.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3. The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

This instruction is not defined for coprocessor 0, the System Control coprocessor, and the opcode may be used for other instructions.

The effective address must be naturally aligned. If any of the three least-significant bits of the effective address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] if (vAddr_{2..0}) $\neq 0^3$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) datadouble \leftarrow COP_SD(z, rt) StoreMemory (uncached, DOUBLEWORD, datadouble, pAddr, vAddr, DATA)

Operation: 64-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] if (vAddr_{2..0}) \neq 0³ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) datadouble \leftarrow COP_SD(z, rt) StoreMemory (uncached, DOUBLEWORD, datadouble, pAddr, vAddr, DATA)

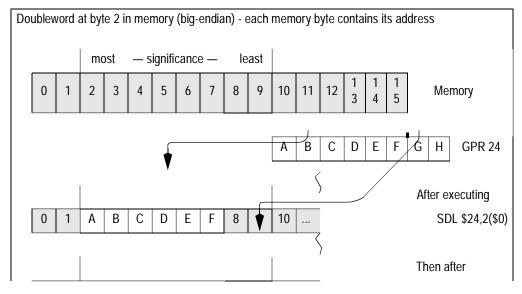
Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction Coprocessor Unusable

	31 26	25	21	20	16	15 0	
	SDL 101100	bas	е		rt	offset	
	6	5			5	16	
Format:SDLrt, offset(base)Purpose:To store the most-significant part					ificant par	MIPS III of a doubleword to an unaligned memory address.	
Description:		memory[l	base+c	ffset] ∢	— Some_	Bytes_From rt	

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*. *EffAddr* is the address of the most-significant of eight consecutive bytes forming a doubleword in memory *(DW)* starting at an arbitrary byte boundary. A part of *DW*, the most-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. The same number of most-significant (left) bytes of GPR *rt* are stored into these bytes of *DW*.

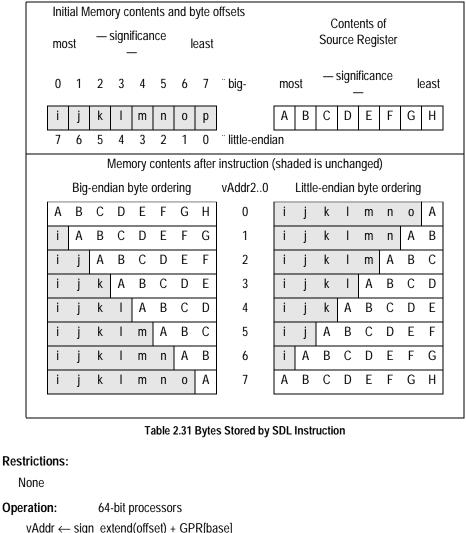
The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, six bytes, is contained in the aligned doubleword containing the most-significant byte at 2. First, SDL stores the six most-significant bytes of the source register into these bytes in memory. Next, the complementary SDR instruction stores the remainder of *DW*.





Store Doubleword Left

The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr_{2.0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes stored for every combination of offset and byte ordering.



 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{sign_extend}(\mathsf{offset}) + \mathsf{GPR}[\mathsf{base}] \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation} (\mathsf{vAddr}, \mathsf{DATA}, \mathsf{STORE}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel (\mathsf{pAddr}_{2..0} \mathsf{xor} \mathsf{ReverseEndian}^3) \\ \mathsf{If} \mathsf{BigEndianMem} = \mathsf{0} \mathsf{then} \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{(\mathsf{PSIZE-1})..3} \parallel \mathsf{0}^3 \\ \mathsf{endif} \\ \mathsf{byte} \leftarrow \mathsf{vAddr}_{2..0} \mathsf{ xor} \mathsf{BigEndianCPU}^3 \\ \mathsf{datadouble} \leftarrow \mathsf{0}^{56-8^*\mathsf{byte}} \parallel \mathsf{GPR}[\mathsf{rt}]_{63..56-8^*\mathsf{byte}} \\ \mathsf{StoreMemory} (\mathsf{uncached}, \mathsf{byte}, \mathsf{datadouble}, \mathsf{pAddr}, \mathsf{vAddr}, \mathsf{DATA}) \\ \end{array}$

Exceptions:

TLB Refill, TLB Invalid TLB Modified Bus Error Address Error Reserved Instruction

RENESAS

SDL

;	31 2	26	25 2	1 20	16	15	0
	SDR 1 0 1 1 0 1	1	base		rt	offset	
	6		5		5	16	
	Format: Purpose:		SDR rt, offse To store the le	. ,		MIPS III t of a doubleword to an unaligned memory addres	S.
[Description:		memory[base	+offset]	\leftarrow Some_	Bytes_From rt	

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address *(EffAddr)*. *EffAddr* is the address of the least-significant of eight consecutive bytes forming a doubleword in memory *(DW)* starting at an arbitrary byte boundary. A part of *DW*, the least-significant one to eight bytes, is in the aligned doubleword containing *EffAddr*. The same number of least-significant (right) bytes of GPR *rt* are stored into these bytes of *DW*.

The figure below illustrates this operation for big-endian byte ordering. The eight consecutive bytes in 2..9 form an unaligned doubleword starting at location 2. A part of *DW*, two bytes, is contained in the aligned doubleword containing the least-significant byte at 9. First, SDR stores the two least-significant bytes of the source register into these bytes in memory. Next, the complementary SDL stores the remainder of *DW*.

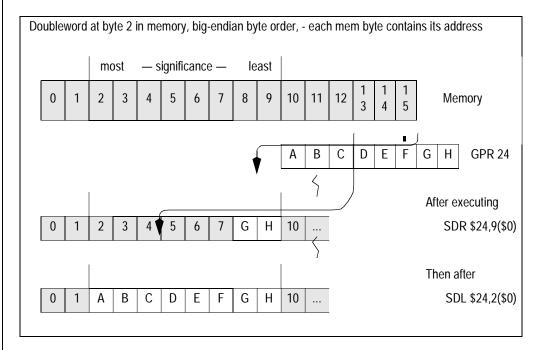
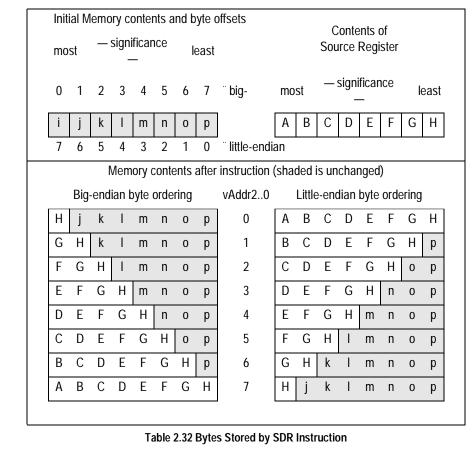


Figure 2.16 Unaligned Doubleword Store with SDR and SDL

Store Doubleword Right

RENESAS SDR

> The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned doubleword, i.e. the low three bits of the address (vAddr2.0), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes stored for every combination of offset and byte ordering.



Restrictions:

None

Operation:

64-bit processors

vAddr ← sign_extend(offset) + GPR[base]

(pAddr, uncached) ← AddressTranslation (vAddr, DATA, STORE)

pAddr \leftarrow pAddr_{(PSIZE-1)..3} || (pAddr_{2..0} xor ReverseEndian³)

If BigEndianMem = 0 then

 $pAddr \leftarrow pAddr_{(PSIZE-1)..3} \parallel 0^3$

endif

byte \leftarrow vAddr_{1.0} xor BigEndianCPU³

datadouble \leftarrow GPR[rt]_{63-8*byte} || 0^{8*byte}

StoreMemory (uncached, DOUBLEWORD-byte, datadouble, pAddr, vAddr, DATA)

Exceptions:

TLB Refill, TLB Invalid **TLB Modified** Bus Error Address Error

Reserved Instruction

31 26	25 21	20 16	15 0
SH 101001	base	rt	offset
6	5	5	16
Format: Purpose:	SH rt, offset(ba To store a halfw		MIPS I
Description:	memory[base+o	ıffset] ← rt	

The least-significant 16-bit halfword of register rt is stored in memory at the location specified by the aligned effective address. The 16-bit signed offset is added to the contents of GPR base to form the effective address.

Restrictions:

The effective address must be naturally aligned. If the least-significant bit of the address is non-zero, an Address Error exception occurs.

MIPS IV: The low-order bit of the offset field must be zero. If it is not, the result of the instruction is undefined.

Operation: 32-bit processors vAddr \leftarrow sign extend(offset) + GPR[base] if $(vAddr_0) \neq 0$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, STORE) $pAddr \leftarrow pAddr_{PSIZE-1,,2} \parallel (pAddr_{1,,0} \text{ xor (ReverseEndian} \parallel 0))$ byte \leftarrow vAddr_{1.0} xor (BigEndianCPU || 0) dataword $\leftarrow \text{GPR[rt]}_{31-8^*\text{byte..0}} \parallel 0^{8^*\text{byte}}$ StoreMemory (uncached, HALFWORD, dataword, pAddr, vAddr, DATA)

64-bit processors

Operation:

vAddr \leftarrow sign_extend(offset) + GPR[base] if $(vAddr_0) \neq 0$ then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, STORE) pAddr \leftarrow pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian² || 0)) byte \leftarrow vAddr_{2.0} xor (BigEndianCPU² || 0) datadouble \leftarrow GPR[rt]_{63-8*byte.0} || 0^{8*byte} StoreMemory (uncached, HALFWORD, datadouble, pAddr, vAddr, DATA)

Exceptions:

TLB Refill, TLB Invalid **TLB Modified** Address Error

31 2	5 25	21	20	16	15	11	10	6	5		0
SPECIAL 0 0 0 0 0 0	0 0	0000	rt			rd	\$	sa		SLL 0 0 0 0 0 0 0	
6		5	5		ļ	5	5)		6	
Format:		d, rt, sa								MIPS I	
Purpose:	l o left	shift a wo	ord by a fixe	ed nui	mber of	bits.					

Description: $rd \leftarrow rt \ll sa$

The contents of the low-order 32-bit word of GPR *rt* are shifted left, inserting zeroes into the emptied bits; the word result is placed in GPR *rd*. The bit shift count is specified by *sa*. If *rd* is a 64-bit register, the result word is sign-extended.

Restrictions:

None

Operation:

s ← sa temp ← GPR[rt]_{(31-s)..0} \parallel 0^s GPR[rd]← sign_extend(temp)

Exceptions:

None

Programming Notes:

Unlike nearly all other word operations the input operand does not have to be a properly sign-extended word value to produce a valid sign-extended 32-bit result. The result word is always sign extended into a 64-bit destination register; this instruction with a zero shift amount truncates a 64-bit value to 32 bits and sign extends it.

Some assemblers, particularly 32-bit assemblers, treat this instruction with a shift amount of zero as a NOP and either delete it or replace it with an actual NOP.

31 20	5 25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	SLLV 0 0 0 1 0 0
6	5	5	5	5	6
Format:	SLLV rd, rt, rs				MIPS I
Purpose:	To left shift a w	ord by a variable	number of bits.		

Description: $rd \leftarrow rt \ll rs$

The contents of the low-order 32-bit word of GPR *rt* are shifted left, inserting zeroes into the emptied bits; the result word is placed in GPR *rd*. The bit shift count is specified by the low-order five bits of GPR *rs*. If *rd* is a 64-bit register, the result word is sign-extended.

Restrictions:

None

Operation:

s \leftarrow GP[rs]_{4.0} temp \leftarrow GPR[rt]_{(31-s).0} || 0^s GPR[rd] \leftarrow sign_extend(temp)

Exceptions:

None

Programming Notes:

Unlike nearly all other word operations the input operand does not have to be a properly sign-extended word value to produce a valid sign-extended 32-bit result. The result word is always sign extended into a 64-bit destination register; this instruction with a zero shift amount truncates a 64-bit value to 32 bits and sign extends it.

Some assemblers, particularly 32-bit assemblers, treat this instruction with a shift amount of zero as a NOP and either delete it or replace it with an actual NOP.



31 26	25 21	20 16	15 11	10 6	5 0					
SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	SLT 1 0 1 0 1 0					
6	5	5	5	5	6					
Format:	SLT rd, rs, rt				MIPS I					
Purpose:	To record the result of a less-than comparison.									
Description:	$rd \gets (rs < rt)$									
Compare the	contents of GPR	s signed integers	and record the	Boolean result of the						

comparison in GPR *rd*. If GPR *rs* is less than GPR *rt* the result is 1 (true), otherwise 0 (false). The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Operation:

```
\begin{array}{l} \text{if GPR[rs]} < \text{GPR[rt] then} \\ \text{GPR[rd]} \leftarrow 0^{\text{GPRLEN-1}} \parallel 1 \\ \text{else} \\ \text{GPR[rd]} \leftarrow 0^{\text{GPRLEN}} \end{array}
```

endif

Exceptions:

Set on Less Than Immediate

31 26	25 21	20	16	15 0
SLTI 0 0 1 0 1 0	rs		rt	immediate
6	5		5	16
Format:	SLTI rt, rs, im	mediate	9	MIPS I
Purpose:	To record the r	esult of	a less-tha	n comparison with a constant.
Description:	rt ← (rs < imm	ediate)		
Compare the c	ontents of GPR	rs and	the 16-bit	signed <i>immediate</i> as signed integers and record the

Boolean result of the comparison in GPR *rs* and the 16-bit signed *immediate* as signed integers and record the Boolean result of the comparison in GPR *rt*. If GPR *rs* is less than *immediate* the result is 1 (true), otherwise 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Operation:

```
\label{eq:GPR[rs] < sign_extend(immediate) then} \\ GPR[rd] \leftarrow 0^{GPRLEN-1} \| \ 1 \\ else \\ GPR[rd] \leftarrow 0^{GPRLEN} \\ \end{aligned}
```

endif

Exceptions:

3	1 26	25 21	20 16	15 (2
	SLTIU 0 0 1 0 1 1	rs	rt	immediate	
	6	5	5	16	_
	ormat: urpose:	SLTIU rt, rs, im To record the re		MIPS I ed less-than comparison with a constant.	

Description: $rt \leftarrow (rs < immediate)$

Compare the contents of GPR *rs* and the sign-extended 16-bit *immediate* as unsigned integers and record the Boolean result of the comparison in GPR *rt*. If GPR *rs* is less than *immediate* the result is 1 (true), otherwise 0 (false).

Because the 16-bit *immediate* is sign-extended before comparison, the instruction is able to represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Operation:

```
if (0 || GPR[rs]) < (0 || sign_extend(immediate)) then GPR[rd] \leftarrow 0^{GPRLEN-1} \parallel 1
```

else

 $GPR[rd] \leftarrow 0^{GPRLEN}$

endif

Exceptions:



31	26	25 21	20 16	15 11	10 6	5	0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	00000	SLTU 101011	
	6	5	5	5	5	6	
Fo	rmat:	SLTU rd, rs, rt				MIPS I	
Pu	rpose:	To record the re	sult of an unsign	ed less-than cor	nparison.		

Description: $rd \leftarrow (rs < rt)$

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers and record the Boolean result of the comparison in GPR *rd*. If GPR *rs* is less than GPR *rt* the result is 1 (true), otherwise 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

Restrictions:

None

Operation:

```
if (0 || GPR[rs]) < (0 || GPR[rt]) then
GPR[rd] ← 0<sup>GPRLEN-1</sup> || 1
```

else $\text{GPR[rd]} \leftarrow 0^{\text{GPRLEN}}$

endif

Exceptions:

31	26	25	21	20	16	15		11	10		6	5		0
SPECIA 0 0 0 0 0		0 0) 0 0 0	r	t		rd			sa		0	SRA 0 0 0 1 1	
6			5		5		5			5			6	
Format:		SRA ro	d, rt, sa										MIPS I	
Purpose:		To arith	metic rig	ht shift a	a word b	y a fix	ed num	nber	of bits.					

Description: $rd \leftarrow rt >> sa$ (arithmetic)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, duplicating the sign-bit (bit 31) in the emptied bits; the word result is placed in GPR *rd*. The bit shift count is specified by *sa*. If *rd* is a 64-bit register, the result word is sign-extended.

Restrictions:

On 64-bit processors, if GPR *rt* does not contain a sign-extended 32-bit value (bits 63..31 equal) then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rt])) then UndefinedResult() endif

Exceptions:

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	00000	SRAV 0 0 0 1 1 1
6	5	5	5	5	6
Format:	SRAV rd, rt, rs				MIPS I

Purpose:

To arithmetic right shift a word by a variable number of bits.

Description: $\mathsf{rd} \gets \mathsf{rt} \mathrel{>>} \mathsf{rs}$ (arithmetic)

The contents of the low-order 32-bit word of GPR rt are shifted right, duplicating the sign-bit (bit 31) in the emptied bits; the word result is placed in GPR rd. The bit shift count is specified by the low-order five bits of GPR rs. If rd is a 64-bit register, the result word is sign-extended.

Restrictions:

On 64-bit processors, if GPR rt does not contain a sign-extended 32-bit value (bits 63..31 equal) then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rt])) then UndefinedResult() endif

```
S
                      \leftarrow \text{GPR}[\text{rs}]_{4.0}
```

 $\leftarrow (GPR[rt]_{31})^{s} \parallel GPR[rt]_{31..s}$ temp

 $GPR[rd] \leftarrow sign_extend(temp)$

Exceptions:

	31 26	25	21	20	16	15		11	10		6	5	0
	SPECIAL 0 0 0 0 0 0	0000	00	rt			rd			sa		SRL 0 0 0 0 1 0	
	6	5	•	5			5			5		6	
I	Format:	SRL rd, r	t, sa									MIPS I	
Purpose:		To logical	right sh	ift a word	l by a f	ixed n	umber	of b	oits.				

Description: $rd \leftarrow rt >> sa$ (logical)

The contents of the low-order 32-bit word of GPR *rt* are shifted right, inserting zeros into the emptied bits; the word result is placed in GPR *rd*. The bit shift count is specified by *sa*. If *rd* is a 64-bit register, the result word is sign-extended.

Restrictions:

On 64-bit processors, if GPR *rt* does not contain a sign-extended 32-bit value (bits 63..31 equal) then the result of the operation is undefined.

Operation:

 $if \ (NotWordValue(GPR[rt])) \ then \ UndefinedResult() \ endified$

Exceptions:

31	26	25 21	20 16	15 11	10 6	5 0
	SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	SRLV 0 0 0 1 1 0
	6	5	5	5	5	6
For	mat:	SRLV rd, rt, rs				MIPS I

Purpose:

To logical right shift a word by a variable number of bits.

Description: $\mathsf{rd} \gets \mathsf{rt} \mathrel{>>} \mathsf{rs}$ (logical)

The contents of the low-order 32-bit word of GPR rt are shifted right, inserting zeros into the emptied bits; the word result is placed in GPR rd. The bit shift count is specified by the low-order five bits of GPR rs. If *rd* is a 64-bit register, the result word is sign-extended.

Restrictions:

On 64-bit processors, if GPR rt does not contain a sign-extended 32-bit value (bits 63..31 equal) then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rt])) then UndefinedResult() endif

 $\leftarrow \text{GPR[rs]}_{4..0}$ S $\leftarrow 0^{s} \parallel \text{GPR}[\text{rt}]_{31..s}$ temp GPR[rd] ← sign_extend(temp)

Exceptions:

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	SUB 1 0 0 0 1 0
6	5	5	5	5	6
Format:	SUB rd, rs, rt				MIPS I

To subtract 32-bit integers. If overflow occurs, then trap.

Purpose:

Description: $rd \leftarrow rs - rt$

The 32-bit word value in GPR *rt* is subtracted from the 32-bit value in GPR *rs* to produce a 32-bit result. If the subtraction results in 32-bit 2's complement arithmetic overflow then the destination register is not modified and an Integer Overflow exception occurs. If it does not overflow, the 32-bit result is placed into GPR *rd*.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif temp \leftarrow GPR[rs] - GPR[rt]

if (32_bit_arithmetic_overflow) then

SignalException(IntegerOverflow)

else

GPR[rd] ←temp

endif

Exceptions:

Integer Overflow

Programming Notes:

SUBU performs the same arithmetic operation but, does not trap on overflow.

31	26	25 21	20 16	15 11	10 6	5 0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	00000	SUBU 100011
	6	5	5	5	5	6
Format: SUBU rd, rs, rt				MIPS I		

Purpose: To subtract 32-bit integers.

Description: $rd \leftarrow rs - rt$

The 32-bit word value in GPR *rt* is subtracted from the 32-bit value in GPR *rs* and the 32-bit arithmetic result is placed into GPR *rd*.

No integer overflow exception occurs under any circumstances.

Restrictions:

On 64-bit processors, if either GPR *rt* or GPR *rs* do not contain sign-extended 32-bit values (bits 63..31 equal), then the result of the operation is undefined.

Operation:

if (NotWordValue(GPR[rs]) or NotWordValue(GPR[rt])) then UndefinedResult() endif temp \leftarrow GPR[rs] - GPR[rt] GPR[rd] \leftarrow temp

Exceptions:

None

Programming Notes:

The term "unsigned" in the instruction name is a misnomer; this operation is 32-bit modulo arithmetic that does not trap on overflow. It is appropriate for arithmetic which is not signed, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as "C" language arithmetic.

26 25 0 31 21 20 16 15 offset SW base rt 101011 6 5 5 16 **MIPS I** Format: SW rt, offset(base) Purpose: To store a word to memory.

Store Word

Description: memory[base+offset] \leftarrow rt

The least-significant 32-bit word of register *rt* is stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

Restrictions:

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit Processors

 $vAddr \leftarrow sign_extend(offset) + GPR[base]$ if $(vAddr_{1..0}) \neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) dataword \leftarrow GPR[rt] StoreMemory (uncached, WORD, dataword, pAddr, vAddr, DATA)

Operation: 64-bit Processors

vAddr ← sign_extend(offset) + GPR[base] if (vAddr_{1..0}) ≠ 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, STORE) pAddr ← pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²) byte ← vAddr_{2..0} xor (BigEndianCPU || 0²) datadouble ← GPR[rt]_{63-8*byte} || 0^{8*byte} StoreMemory (uncached, WORD, datadouble, pAddr, vAddr, DATA)

Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error

Store Word From Coprocessor

31	26	25 21	20 1	6 15 0
	SWCz 1 1 1 0 z z	base	rt	offset
	6	5	5	16
For	mat:	SWC1 rt, offset(base) SWC2 rt, offset(base) SWC3 rt, offset(base)		MIPS I
Pur	pose:	To store a word from a coprocessor general register to memory.		
Des	cription:	memory[base+offset] ← rt		

Coprocessor unit *zz* supplies a 32-bit word which is stored at the memory location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The data supplied by each coprocessor is defined by the individual coprocessor specifications. The usual operation would read the data from coprocessor general register *rt*.

Each MIPS architecture level defines up to 4 coprocessor units, numbered 0 to 3. The opcodes corresponding to coprocessors that are not defined by an architecture level may be used for other instructions.

Restrictions:

Access to the coprocessors is controlled by system software. Each coprocessor has a "coprocessor usable" bit in the System Control coprocessor. The usable bit must be set for a user program to execute a coprocessor instruction. If the usable bit is not set, an attempt to execute the instruction will result in a Coprocessor Unusable exception. An unimplemented coprocessor must never be enabled. The result of executing this instruction for an unimplemented coprocessor when the usable bit is set, is undefined.

This instruction is not available for coprocessor 0, the System Control coprocessor, and the opcode may be used for other instructions.

The effective address must be naturally aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit processors

 $vAddr \leftarrow sign_extend(offset) + GPR[base]$ if $(vAddr_{1..0}) \neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) dataword \leftarrow COP_SW (z, rt) StoreMemory (uncached, WORD, dataword, pAddr, vAddr, DATA)

Operation: 64-bit processors

vAddr \leftarrow sign_extend(offset) + GPR[base] if (vAddr_{1..0}) $\neq 0^2$ then SignalException(AddressError) endif (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) pAddr \leftarrow pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²) byte \leftarrow vAddr_{2..0} xor (BigEndianCPU || 0²) dataword \leftarrow COP_SW (z, rt) datadouble $\leftarrow 0^{32 \cdot 8^* byte}$ || dataword || 0^{8* byte} StoreMemory (uncached, WORD, datadouble, pAddr, vAddr DATA)



Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction Coprocessor Unusable

31 26	25 21	20 16	15	0
SWL 101010	base	rt	offset	
6	5	5	16	
Format:SWL rt, offset(base)Purpose:To store the most-significant par			MIPS I to an unaligned memory address.	
Description: memory[base+offset] ← rt				

Store Word Left

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the most-significant of four consecutive bytes forming a word in memory (*W*) starting at an arbitrary byte boundary. A part of *W*, the most-significant one to four bytes, is in the aligned word containing *EffAddr*. The same number of the most-significant (left) bytes from the word in GPR *rt* are stored into these bytes of *W*.

If GPR rt is a 64-bit register, the source word is the low word of the register.

Figures Figure 1.2.11 illustrates this operation for big-endian byte ordering for 32-bit and 64-bit registers. The four consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, two bytes, is contained in the aligned word containing the most-significant byte at 2. First, SWL stores the most-significant two bytes of the low-word from the source register into these two bytes in memory. Next, the complementary SWR stores the remainder of the unaligned word.

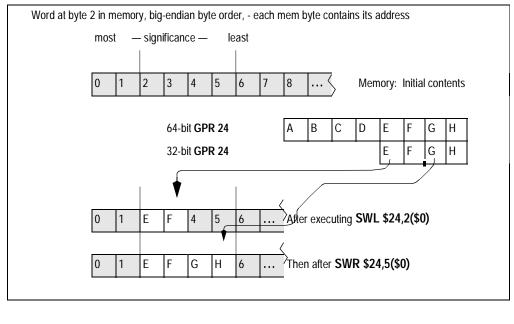
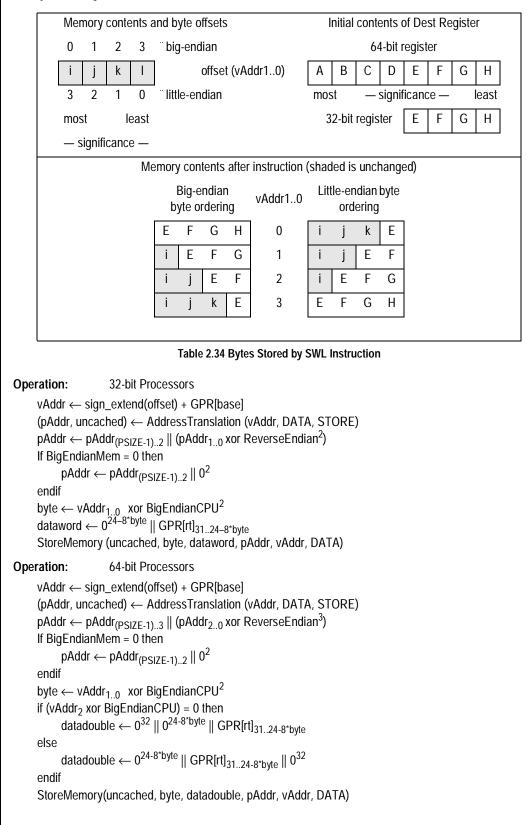


Table 2.33 Unaligned Word Store using SWL and SWR

Store Word Left

The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word, i.e. the low two bits of the address (vAddr_{1..0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes stored for every combination of offset and byte ordering.



CENESAS

SWL



Exceptions:

TLB Refill, TLB Invalid TLB Modified Bus Error Address Error

 Store Word Right

 16
 15

SWR 101110	base	rt	offset
6	5	5	16
Format:	SWR rt, offset(base)	MIPS I
Purpose: To store the least-significant part of a word to an unaligned memory add			

Description: memory[base+offset] \leftarrow rt

26 25

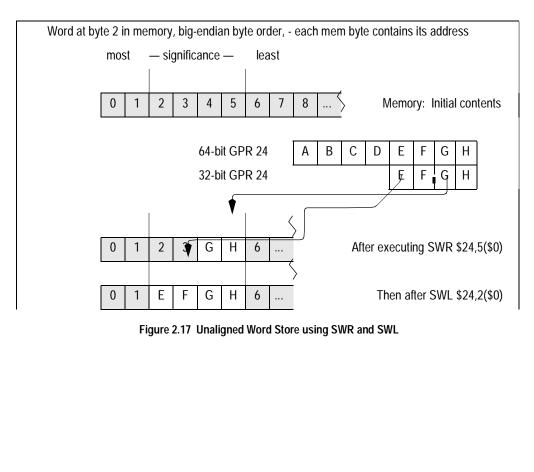
31

The 16-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the least-significant of four consecutive bytes forming a word in memory (*W*) starting at an arbitrary byte boundary. A part of *W*, the least-significant one to four bytes, is in the aligned word containing *EffAddr*. The same number of the least-significant (right) bytes from the word in GPR *rt* are stored into these bytes of *W*.

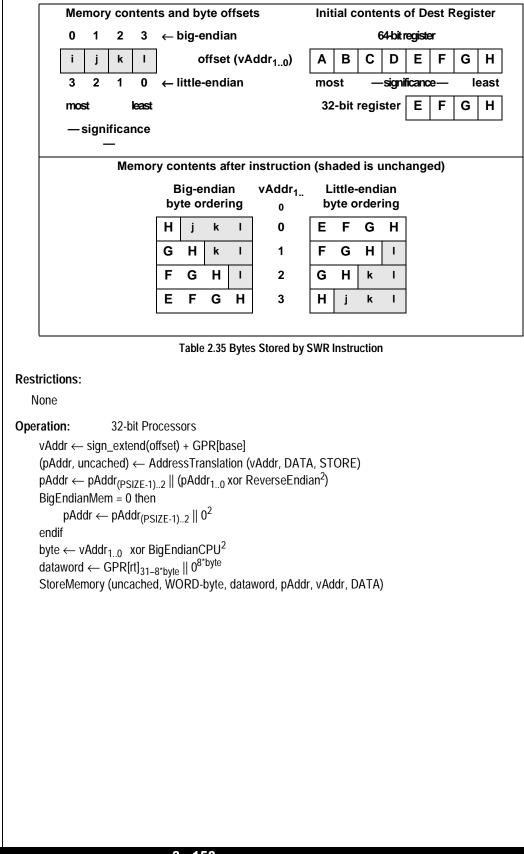
If GPR *rt* is a 64-bit register, the source word is the low word of the register.

21 20

Figures Figure 1.2.11 illustrates this operation for big-endian byte ordering for 32-bit and 64-bit registers. The four consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, two bytes, is contained in the aligned word containing the least-significant byte at 5. First, SWR stores the least-significant two bytes of the low-word from the source register into these two bytes in memory. Next, the complementary SWL stores the remainder of the unaligned word.



The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word, i.e. the low two bits of the address (vAddr_{1..0}), and the current byte ordering mode of the processor (big- or little-endian). The table below shows the bytes stored for every combination of offset and byte ordering.



SENESV

SWR



Operation: 64-bit Processors

vAddr \leftarrow sign_extend(offset) + GPR[base] (pAddr, uncached) \leftarrow AddressTranslation (vAddr, DATA, STORE) pAddr \leftarrow pAddr_{(PSIZE-1)..3} || (pAddr_{2..0} xor ReverseEndian³) If BigEndianMem = 0 then pAddr \leftarrow pAddr_{(PSIZE-1)..2} || 0² endif byte \leftarrow vAddr_{1..0} xor BigEndianCPU² if (vAddr₂ xor BigEndianCPU) = 0 then datadouble \leftarrow 0³² || GPR[rt]_{31-8*byte..0} || 0^{8*byte} else datadouble \leftarrow GPR[rt]_{31-8*byte..0} || 0^{8*byte} || 0³² endif StoreMemory(uncached, WORD-byte, datadouble, pAddr, vAddr, DATA) Exceptions:

TLB Refill, TLB Invalid TLB Modified Bus Error Address Error

31 2	26 25	11 10	6 5 0
SPECIAL 0 0 0 0 0 0	0 00 0000 0000 00	000 0 stype	SYNC 0 0 1 1 1 1
6	15	5	6
Format:	SYNC (stype = 0 i	-	MIPS II

Purpose: To order loads and stores to shared memory in a multiprocessor system.

Description:

To serve a broad audience, two descriptions are given. A simple description of SYNC that appeals to intuition is followed by a precise and detailed description.

A Simple Description:

SYNC affects only uncached and cached coherent loads and stores. The loads and stores that occur prior to the SYNC must be completed before the loads and stores after the SYNC are allowed to start.

Loads are completed when the destination register is written. Stores are completed when the stored value is visible to every other processor in the system.

A Precise Description:

If the *stype* field has a value of zero, every synchronizable load and store that occurs in the instruction stream prior to the SYNC instruction must be globally performed before any synchronizable load or store that occurs after the SYNC may be performed with respect to any other processor or coherent I/O module.

Sync does not guarantee the order in which instruction fetches are performed.

The stype values 1-31 are reserved; they produce the same result as the value zero.

Synchronizable: A load or store instruction is *synchronizable* if the load or store occurs to a physical location in shared memory using a virtual location with a memory access type of either uncached or cached coherent. *Shared memory* is memory that can be accessed by more than one processor or by a coherent I/ O system module.

Performed load: A load instruction is *performed* when the value returned by the load has been determined. The result of a load on processor A has been *determined* with respect to processor or coherent I/O module B when a subsequent store to the location by B cannot affect the value returned by the load. The store by B must use the same memory access type as the load.

Performed store: A store instruction is *performed* when the store is observable. A store on processor A is *observable* with respect to processor or coherent I/O module B when a subsequent load of the location by B returns the value written by the store. The load by B must use the same memory access type as the store.

Globally performed load: A load instruction is *globally performed* when it is performed with respect to all processors and coherent I/O modules capable of storing to the location.

Globally performed store: A store instruction is *globally performed* when it is globally observable. It is *globally observable* when it observable by all processors and I/O modules capable of loading from the location.

Coherent I/O module: A coherent I/O module is an Input/Output system component that performs coherent Direct Memory Access (DMA). It reads and writes memory independently as though it were a processor doing loads and stores to locations with a memory access type of cached coherent.

Restrictions:

The effect of SYNC on the global order of the effects of loads and stores for memory access types other than uncached and cached coherent is not defined.



Operation:

SyncOperation(stype)

Exceptions:

Reserved Instruction

Programming Notes:

A processor executing load and store instructions observes the effects of the loads and stores that use the same memory access type in the order that they occur in the instruction stream; this is known as *program order.* A *parallel program* has multiple instruction streams that can execute at the same time on different processors. In multiprocessor (MP) systems, the order in which the effects of loads and stores are observed by other processors, the *global order* of the loads and stores, determines the actions necessary to reliably share data in parallel programs.

When all processors observe the effects of loads and stores in program order, the system is *strongly ordered*. On such systems, parallel programs can reliably share data without explicit actions in the programs. For such a system, SYNC has the same effect as a NOP. Executing SYNC on such a system is not necessary, but is also not an error.

If a multiprocessor system is not strongly ordered, the effects of load and store instructions executed by one processor may be observed out of program order by other processors. On such systems, parallel programs must take explicit actions in order to reliably share data. At critical points in the program, the effects of loads and stores from an instruction stream must occur in the same order for all processors. SYNC separates the loads and stores executed on the processor into two groups and the effects of these **groups** are seen in program order by all processors. The effect of all loads and stores in one group is seen by all processors before the effect of any load or store in the other group. In effect, SYNC causes the system to be strongly ordered for the executing processor at the instant that the SYNC is executed.

Many MIPS-based multiprocessor systems are strongly ordered or have a mode in which they operate as strongly ordered for at least one memory access type. The MIPS architecture also permits MP systems that are not strongly ordered. SYNC enables the reliable use of shared memory on such systems. A parallel program that does not use SYNC will generally not operate on a system that is not strongly ordered, however a program that does use SYNC will work on both types of systems. System-specific documentation will describe the actions necessary to reliably share data in parallel programs for that system.

The behavior of a load or store using one memory access type is undefined if a load or store was previously made to the same physical location using a different memory access type. The presence of a SYNC between the references does not alter this behavior.

SYNC affects the order in which the effects of load and store instructions appears to all processors; it not generally affect the **physical** memory-system ordering or synchronization issues that arise in system programming. The effect of SYNC on implementation specific aspects of the cached memory system, such as writeback buffers, is not defined. The effect of SYNC on reads or writes to memory caused by privileged implementation-specific instructions, such as CACHE, is not defined.

Prefetch operations have no effects detectable by user-mode programs so ordering the effects of prefetch operations is not meaningful.



EXAMPLE: These code fragments show how SYNC can be used to coordinate the use of shared data between separate writer and reader instruction streams in a multiprocessor environment. The FLAG location is used by the instruction streams to determine whether the shared data item DATA is valid. The SYNC executed by processor A forces the store of DATA to be performed globally before the store to FLAG is performed. The SYNC executed by processor B ensures that DATA is not read until after the FLAG value indicates that the shared data is valid.

	Processor A (writer)					
	# Conditions at entry:					
# -	# The value 0 has been stored in FLAG and that value is observable by B.					
SW	SW R1, DATA # change shared DATA value					
LI	R2, 1					
SYNC		# perform DATA store before performing FLAG store				
SW	R2, FLAG	# say that the shared DATA value is valid				

	Processor B (reader)							
	LI	R2, 1						
1:	LW	R1, FLAG	# get FLAG					
	BNE	R2, R1, 1B	# if it says that DATA is not valid, poll again					
	NOP							
	SYNC		# FLAG value checked before doing DATA reads					
	LW	R1, DATA	# read (valid) shared DATA values					

Implementation Notes:

There may be side effects of uncached loads and stores that affect cached coherent load and store operations. To permit the reliable use of such side effects, buffered uncached stores that occur before the SYNC must be written to memory before cached coherent loads and stores after the SYNC may be performed.

RENESAS

SYNC



System Call 6 5 0 31 26 25 SYSCALL 0 0 1 1 00 SPECIAL Code 000000 6 20 6 Format: SYSCALL **MIPS I** Purpose: To cause a System Call exception.

Description:

A system call exception occurs, immediately and unconditionally transferring control to the exception handler.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

Restrictions:

None

Operation:

SignalException(SystemCall)

Exceptions:

System Call



Trap if Equal

31	26	25 21	20 16	15 6	5 0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	code	TEQ 1 1 0 1 0 0
6		5	5	10	6
Format:TEQ rs, rtPurpose:To compare GPRs and do a conditional Trap.					MIPS II
Description: if (rs = rt) then Trap					

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is equal to GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

if GPR[rs] = GPR[rt] then SignalException(Trap)

endif

Exceptions:



Trap if Equal Immediate

3	1 26	25 21	20	6 15	0		
	REGIMM 0 0 0 0 0 1	rs	TEQI 0 1 1 0 0	immediate			
	6	5	5	16			
_	ormat: urpose:	TEQI rs, imme To compare a Q		int and do a conditional Trap.	MIPS II		
D	escription:	if (rs = immediate) then Trap					

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is equal to *immediate* then take a Trap exception.

Restrictions:

None

Operation:

if GPR[rs] = sign_extend(immediate) then SignalException(Trap) endif

Exceptions:



31	26	25 21	20 16	15 6	5 0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	code	TGE 1 1 0 0 0 0
6		5	5	10	6
Format:TGE rs, rtPurpose:To compare GPRs and do a conditional Trap.					MIPS II
Description: if (rs \geq rt) then Trap					

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is greater than or equal to GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

```
if GPR[rs] ≥ GPR[rt] then
SignalException(Trap)
```

endif

Exceptions:



31	26	25 21	20 16	15 0		
	REGIMM 0 0 0 0 0 1	rs	TGEI 0 1 0 0 0	immediate		
	6	6 5 5		16		
For	mat:	TGEI rs, imme	diate	MIPS II		
Pur	pose:	To compare a G	PR to a constant	t and do a conditional Trap.		
Des	cription:	if (rs \geq immedia	te) then Trap			
Compare the contents of GPR <i>rs</i> and the 16-bit signed <i>immediate</i> as signed integers; if GPR <i>rs</i> is greater than or equal to <i>immediate</i> then take a Trap exception.						

Restrictions:

None

Operation:

if GPR[rs] ≥ sign_extend(immediate) then SignalException(Trap) endif

Exceptions:

Trap If Greater Or Equal Immediate Unsigned

3	1 26	25 21	20 16	15	0		
	REGIMM 0 0 0 0 0 1	rs	TGEIU 0 1 0 0 1	immediate			
6		5	5	16			
	ormat: urpose:	M t and do a conditional Trap.	IPS II				
D	escription:	if (rs \geq immediate) then Trap					

Compare the contents of GPR *rs* and the 16-bit sign-extended *immediate* as unsigned integers; if GPR *rs* is greater than or equal to *immediate* then take a Trap exception.

Because the 16-bit *immediate* is sign-extended before comparison, the instruction is able to represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

Restrictions:

None

Operation:

if (0 || GPR[rs]) \geq (0 || sign_extend(immediate)) then SignalException(Trap)

```
endif
```

Exceptions:



	31 26	25 21	20 16	15 6	5 0	
	SPECIAL 0 0 0 0 0 0	rs	rt	code	TGEU 1 1 0 0 0 1	
	6	5	5	10	6	-
Format:TGEU rs, rtPurpose:To compare GPRs and do a conditional Trap.					MIPS II	
	Decembration					

Description: if $(rs \ge rt)$ then Trap

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers; if GPR *rs* is greater than or equal to GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

if $(0 || GPR[rs]) \ge (0 || GPR[rt])$ then SignalException(Trap)

endif

Exceptions:

Trap if Less Than

31	26	25 21	20 16	15 6	5 0		
	SPECIAL 0 0 0 0 0 0 0	rs	rt	code	TLT 1 1 0 0 1 0		
	6	5	5	10	6		
Forr Purj	nat: pose:	ditional Trap.	MIPS II				
Des	cription:	otion: if (rs < rt) then Trap					

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is less than GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

if GPR[rs] < GPR[rt] then SignalException(Trap)

endif

Exceptions:

RENESAS TL TI

Trap if Less Than Immediate

31	26	25	21	20	16	15				0
REGI 0 0 0 0		rs			_TI 0 1 0			immediate		
6		5			5	16				
Format:		TLTI rs,	imme	diate					MIPS II	

Purpose: To compare a GPR to a constant and do a conditional Trap.

Description: if (rs < immediate) then Trap

Compare the contents of GPR rs and the 16-bit signed immediate as signed integers; if GPR rs is less than *immediate* then take a Trap exception.

Restrictions:

None

Operation:

if GPR[rs] < sign_extend(immediate) then SignalException(Trap) endif

Exceptions:



Trap if Less Than Immediate Unsigned 0 31 26 25 21 20 16 15 REGIMM rs TLTIU immediate 000001 01011 6 5 5 16 Format: TLTIU rs, immediate **MIPS II** Purpose: To compare a GPR to a constant and do a conditional Trap.

Description: if (rs < immediate) then Trap

Compare the contents of GPR *rs* and the 16-bit sign-extended *immediate* as unsigned integers; if GPR *rs* is less than *immediate* then take a Trap exception.

Because the 16-bit *immediate* is sign-extended before comparison, the instruction is able to represent the smallest or largest unsigned numbers. The representable values are at the minimum [0, 32767] or maximum [max_unsigned-32767, max_unsigned] end of the unsigned range.

Restrictions:

None

Operation:

if (0 || GPR[rs]) < (0 || sign_extend(immediate)) then SignalException(Trap)

```
endif
```

Exceptions:

31	26	25 21	20 16	15 6	5 0
	SPECIAL 0 0 0 0 0 0 0	rs	rt	code	TLTU 1 1 0 0 1 1
L	6	5	5	10	6
Format: Purpose:		TLTU rs, rt To compare GP	Rs and do a con	ditional Trap.	MIPS II

Description: if (rs < rt) then Trap

Compare the contents of GPR *rs* and GPR *rt* as unsigned integers; if GPR *rs* is less than GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

if (0 || GPR[rs]) < (0 || GPR[rt]) then SignalException(Trap)

endif

Exceptions:



Trap if Not Equal

31	26	25 21	20 16	15 6	5 0	
	SPECIAL 0 0 0 0 0 0	rs	rt	code	TNE 1 1 0 1 1 0	
6		5	5	10	6	
Format: Purpose:		TNE rs, rt To compare GP	Rs and do a con	ditional Trap.	MIPS II	
Description:		if (rs ≠ rt) then T	rap			

Compare the contents of GPR *rs* and GPR *rt* as signed integers; if GPR *rs* is not equal to GPR *rt* then take a Trap exception.

The contents of the *code* field are ignored by hardware and may be used to encode information for system software. To retrieve the information, system software must load the instruction word from memory.

Restrictions:

None

Operation:

if GPR[rs] ≠ GPR[rt] then SignalException(Trap)

endif

Exceptions:



31	26	25 21	20 16	15 0
	REGIMM 0 0 0 0 0 1	rs	TNEI 0 1 1 1 0	immediate
<u></u>	6	5	5	16

Format: TNEI rs, immediate

MIPS II

Purpose: To compare a GPR to a constant and do a conditional Trap.

Description: if (rs \neq immediate) then Trap

Compare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is not equal to *immediate* then take a Trap exception.

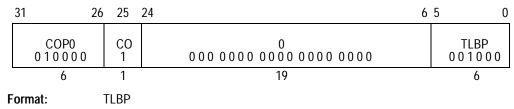
Restrictions:

None

Operation:

if GPR[rs] ≠ sign_extend(immediate) then SignalException(Trap) endif

Exceptions:



Description:

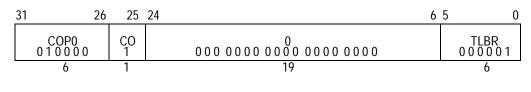
The *Index* register is loaded with the address of the TLB entry whose contents match the contents of the *EntryHi* register. If no TLB entry matches, the high-order bit of the *Index* register is set.

The architecture does not specify the operation of memory references associated with the instruction immediately after a TLBP instruction, nor is the operation specified if more than one TLB entry matches.

Operation:

T:	Index" 1 0 31
	for i in 0TLBEntries-1
	if (TLB[i]167141 and not (015 TLB[i]216205))
	= EntryHi3913) and not (015 TLB[i]216205)) and
	(TLB[i]140 or (TLB[i]135128 = EntryHi70)) then
	Index 026 i 50
	endif
	endfor

Exceptions:



Format: TLBR

Description:

The *G* bit (which controls ASID matching) read from the TLB is written into both of the *EntryLo0* and *EntryLo1* registers.

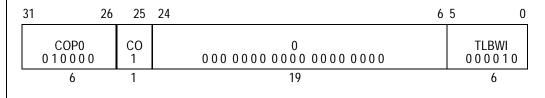
The *EntryHi* and *EntryLo* registers are loaded with the contents of the TLB entry pointed at by the contents of the TLB *Index* register. The operation is invalid (and the results are unspecified) if the contents of the TLB *Index* register are greater than the number of TLB entries in the processor.

Operation:

T: PageMask TLB[Index5..0]255..192 EntryHi TLB[Index5..0]191..128 and not TLB[Index5..0]255..192 EntryLo1 TLB[Index5..0]127..65 || TLB[Index5..0]140 EntryLo0 TLB[Index5..0]63..1 || TLB[Index5..0]140

Exceptions:





Format: TLBWI

Description:

The *G* bit of the TLB is written with the logical AND of the *G* bits in the *EntryLo0* and *EntryLo1* registers.

The TLB entry pointed at by the contents of the TLB *Index* register is loaded with the contents of the *EntryHi* and *EntryLo* registers.

The operation is invalid (and the results are unspecified) if the contents of the TLB *Index* register are greater than the number of TLB entries in the processor.

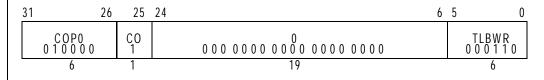
Operation:

T: TLB[Index5..0]

PageMask || (EntryHi and not PageMask) || EntryLo1 || EntryLo0

Exceptions:





Format: TLBWR

Description:

The *G* bit of the TLB is written with the logical AND of the *G* bits in the *EntryLo0* and *EntryLo1* registers.

The TLB entry pointed at by the contents of the TLB *Random* register is loaded with the contents of the *EntryHi* and *EntryLo* registers.

Operation:

T: TLB[Random5..0]

PageMask || (EntryHi and not PageMask) || EntryLo1 || EntryLo0

Exceptions:







31	26	25	24	65	0
	COP0 0 1 0 0 0 0	CO 1	$\begin{smallmatrix} 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ 0\\ $		WAIT 1 0 0 0 0 0
	6	1	19		6

Format: WAIT

Purpose: To stop the internal pipeline and reduce power used by the CPU.

Description:

The WAIT instruction is used to halt the internal pipeline and thus reduce the power consumption of the CPU.

Operation:

T: if SysAD bus is idle then StopPipeline endif

Exceptions:



31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL 0 0 0 0 0 0 0	rs	rt	rd	0 0 0 0 0 0	XOR 1 0 0 1 1 0
6	5	5	5	5	6
Format: Purpose:	XOR rd, rs, rt To do a bitwise l	logical EXCLUSI	VE OR.		MIPS I

Description: $rd \leftarrow rs XOR rt$

Combine the contents of GPR *rs* and GPR *rt* in a bitwise logical exclusive OR operation and place the result into GPR *rd*.

Restrictions:

None

Operation:

 $GPR[rd] \leftarrow GPR[rs] \text{ xor } GPR[rt]$

Exceptions:

None



Exclusive OR Immediate

31 26	25 21	20 16	15 0
XORI 0 0 1 1 1 0	rs	rt	immediate
6	5	5	16
Format:	XORI rt, rs, imn	MIPS I	
Purpose:	To do a bitwise	VE OR with a constant.	

Description: $rt \leftarrow rs XOR$ immediate

Combine the contents of GPR *rs* and the 16-bit zero-extended *immediate* in a bitwise logical exclusive OR operation and place the result into GPR *rt*.

Restrictions:

None

Operation:

GPR[rt] ← GPR[rs] xor zero_extend(immediate)

Exceptions:

None







0

offset

16



CPU Instructions Encoding

Notes

A CPU instruction is a single 32-bit aligned word. The major instruction formats are shown in Table 3.1.

16 15

rt

5

I-Type (Immediate). 31 26 25 21 20 opcode rs

5

31

6

	26	25	
opcod	е	instr_index	
6		26	

R-Type (Register).

31 26	25	21	20	16	15	11	10	6	5	0
opcode		rs rt		I	ď	sa		function		
6		5	5	1	Ę)		5	6	
opcode		6-bit primary operation code								
rd		5-bit destination register specifier								
rs	-	5-bit source register specifier								
rt		5-bit target (source/destination) register specifier or used to specify functions within the primary opcode value <i>REGIMM</i>								
immediat		16-bit signed immediate used for: logical operands, arithmetic signed operands, load/store address byte offsets, PC-relative branch signed instruction displacement								
instr_inde		26-bit index shifted left two bits to supply the low-order 28 bits of the jump target address.								
sa	-	5-bit shift amount								
function		6-bit function field used to specify functions within the primary operation code value <i>SPECIAL</i> .								
Table 3.1 CPU Instruction Formats										



CPU Instruction Encoding

This section describes the encoding of user-level, i.e. non-privileged, CPU instructions for the four levels of the MIPS architecture, MIPS I through MIPS IV. Each architecture level includes the instructions in the previous level;¹ MIPS IV includes all instructions in MIPS I, MIPS II, and MIPS III. This section presents eight different views of the instruction encoding.

- Separate encoding tables for each architecture level.
- A MIPS IV encoding table showing the architecture level at which each opcode was originally defined and subsequently modified (if modified).
- Separate encoding tables for each architecture revision showing the changes made during that revision.

Instruction Decode

Instruction field names are printed in **bold** in this section.

The primary **opcode** field is decoded first. Most **opcode** values completely specify an instruction that has an immediate value or offset. **Opcode** values that do not specify an instruction specify an instruction class. Instructions within a class are further specified by values in other fields. The **opcode** values *SPECIAL* and *REGIMM* specify instruction classes. The *COP0*, *COP1*, *COP2*, *COP3*, and *COP1X* instruction classes are not CPU instructions; See "Non-CPU Instructions in the Tables" below.

SPECIAL Instruction Class

The **opcode**=*SPECIAL* instruction class encodes 3-register computational instructions, jump register, and some special purpose instructions. The class is further decoded by examining the **format** field. The **format** values fully specify the CPU instructions; the *MOVCI* instruction class is not a CPU instruction class.

REGIMM Instruction Class

The **opcode**=*REGIMM* instruction class encodes conditional branch and trap immediate instructions. The class is further decode, and the instructions fully specified, by examining the **rt** field.

Instruction Subsets of MIPS III and MIPS IV Processors

MIPS III processors, such as the RC4000, RC4200, RC4300, RC4400, and RC4600, have a processor mode in which only the MIPS II instructions are valid. The MIPS II encoding table describes the MIPS II-only mode except that the Coprocessor 3 instructions (COP3, LWC3, SWC3, LDC3, SDC3) are not available and cause a Reserved Instruction exception.

MIPS IV processors, such as the R8000 and R10000, have processor modes in which only the MIPS II or MIPS III instructions are valid. The MIPS II encoding table describes the MIPS II-only mode except that the Coprocessor 3 instructions (COP3, LWC3, SWC3, LDC3, SDC3) are not available and cause a Reserved Instruction exception. The MIPS III encoding table describes the MIPS III-only mode.

Non-CPU Instructions in the Tables

The encoding tables show all values for the field they describe and by doing this they include some entries that are not user-level CPU instructions. The primary opcode table includes coprocessor instruction classes (COP0, COP1, COP2, COP3/COP1X) and coprocessor load/store instructions (LWCx, SWCx, LDCx, SDCx for x=1, 2, or 3). The **opcode**=*SPECIAL* + **function**=*MOVCI* instruction class is an FPU instruction.

Coprocessor 0 - COPO

COP0 encodes privileged instructions for Coprocessor 0, the System Control Coprocessor. The definition of the System Control Coprocessor is processor-specific and further information on these instructions are not included in this document.

^{1.} An exception to this rule is that the reserved, but never implemented, Coprocessor 3 instructions were removed or changed to another use starting in MIPS III.

Coprocessor 1 - COP1, COP1X, MOVCI, and CP1 load/store

Coprocessor 1 is the floating-point unit in the MIPS architecture. *COP1*, *COP1X*, and the (opcode=*SPECIAL* + function=*MOVCI*) instruction classes encode floating-point instructions. LWC1, SWC1, LDC1, and SDC1 are floating-point loads and stores. The FPU instruction encoding is documented in section FPU" (CP1) Instruction Opcode Bit Encoding in the Chapter "FPU Instruction Set"..

Coprocessor 2 - COP2 and CP2 load/store

Coprocessor 2 is optional and implementation-specific. No standard processor from MIPS has implemented coprocessor 2, but MIPS' semiconductor licensees may have implemented it in a product based on one of the standard MIPS processors. At this time the standard processors are: RC2000, RC3000, RC4000, RC4200, RC4300, RC4400, RC4600, RC6000, R8000, and R10000.

Coprocessor 3 - COP3 and CP3 load/store

Coprocessor 3 is optional and implementation-specific in the MIPS I and MIPS II architecture levels. It was removed from MIPS III and later architecture levels. Note that in MIPS IV the *COP3* primary opcode was reused for the *COP1X* instruction class. No standard processor from MIPS has implemented coprocessor 2, but MIPS' semiconductor licensees may have implemented it in a product based on one of the standard MIPS processors. At this time the standard processors are: RC2000, RC3000, RC4000, RC4200, RC4300, RC4400, RC4600, RC6000, R8000, and R10000.



31 26

opcode

opcode		bits 2826 Instructions encoded by opcode field.									
bits	3129	0	1	2	3	4	5	6	7		
		000	001	010	011	100	101	110	111		
0	000	SPECIAL d	REGIMM d	J	JAL	BEQ	BNE	BLEZ	BGTZ		
1	001	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI		
2	010	COP0 d,p	COP1 d,p	COP2 d,p	COP3 d,p,k	*	*	*	*		
3	011	*	*	*	*	*	*	*	*		
4	100	LB	LH	LWL	LW	LBU	LHU	LWR	*		
5	101	SB	SH	SWL	SW	*	*	SWR	*		
6	110	*	LWC1 p	LWC2 p	LWC3 p,k	*	*	*	*		
7	111	*	SWC1 p	SWC2 p	SWC3 p,k	*	*	*	*		

31 26	5	0
opcode = SPECIAL	function	1

fun	nction bits 20 Instructions encoded by function field when opcode field = SPECIAL.								
	bits	0	1	2	3	4	5	6	7
53		000	001	010	011	100	101	110	111
0	000	SLL	*	SRL	SRA	SLLV	*	SRLV	SRAV
1	001	JR	JALR	*	*	SYSCALL	BREAK	*	*
2	010	MFHI	MTHI	MFLO	MTLO	*	*	*	*
3	011	MULT	MULTU	DIV	DIVU	*	*	*	*
4	100	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR
5	101	*	*	SLT	SLTU	*	*	*	*
6	110	*	*	*	*	*	*	*	*
7	111	*	*	*	*	*	*	*	*

31 26	 20	16	0	
opcode = <i>REGIMM</i>	rt			

	rt	bits 1816	bits 1816 Instructions encoded by the rt field when opcode field = REGIMM.									
t	oits	0	1	2	3	4	5	6	7			
20)19	000	001	010	011	100	101	110	111			
0	00	BLTZ	BGEZ	=	=	=	=	=	=			
1	01	=	=	=	=	=	=	=	=			
2	10	BLTZAL	BGEZAL	=	=	=	=	=	=			
3	11	=	=	=	=	=	=	=	=			

Table 3.2 CPU Instruction Encoding - MIPS I Architecture



31 26

opcode

ор	code	bits 2826 Instructions encoded by opcode field.										
bits	3129	0	1	2 3		4	5	6	7			
		000	001	010	011	100	101	110	111			
0	000	SPECIAL d	REGIMM d	J	JAL	BEQ	BNE	BLEZ	BGTZ			
1	001	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI			
2	010	COP0 d,p	COP1 d,p	COP2 d,p	COP3 d,p,k	BEQL	BNEL	BLEZL	BGTZL			
3	011	*	*	*	*	*	*	*	*			
4	100	LB	LH	LWL	LW	LBU	LHU	LWR	*			
5	101	SB	SH	SWL	SW	*	*	SWR	r			
6	110	LL	LWC1 p	LWC2 p	LWC3 p,k	*	LDC1 p	LDC2 p	LDC3 p,k			
7	111	SC	SWC1 p	SWC2 p	SWC3 p,k	*	SDC1 p	SDC2 p	SDC3 p,k			

31 26	5	0
opcode = SPECIAL	function	

fun	oction	bits 20 Instructions encoded by function field when opcode field = SPECIAL.										
t	bits	0	1	2	3	4	5	6	7			
53		000	001	010	011	100	101	110	111			
0	000	SLL	*	SRL	SRA	SLLV	*	SRLV	SRAV			
1	001	JR	JALR	*	*	SYSCALL	BREAK	*	SYNC			
2	010	MFHI	MTHI	MFLO	MTLO	*	*	*	*			
3	011	MULT	MULTU	DIV	DIVU	*	*	*	*			
4	100	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR			
5	101	*	*	SLT	SLTU	*	*	*	*			
6	110	TGE	TGEU	TLT	TLTU	TEQ	*	TNE	*			
7	111	*	*	*	*	*	*	*	*			

31 26	20	16	0	
opcode = <i>REGIMM</i>	rt	t		

	rt	bits 1816		Instructions encoded by the rt field when opcode field = REGIMM.								
bits		0	1	2	3	4	5	6	7			
20)19	000	001	010	011	100	101	110	111			
0	00	BLTZ	BGEZ	BLTZL	BGEZL	*	*	*	*			
1	01	TGEI	TGEIU	TLTI	TLTIU	TEQI	*	TNEI	*			
2	10	BLTZAL	BGEZAL	BLTZALL	BGEZALL	*	*	*	*			
3	11	*	*	*	*	*	*	*	*			

Table 3.3 CPU Instruction Encoding - MIPS II Architecture



31 26

opcode

opcode		bits 2826 Instructions encoded by opcode field.										
bits	3129	0	1	2	3	4	5	6	7			
		000	001	010	011	100	101	110	111			
0	000	SPECIAL d	REGIMM d	J	JAL	BEQ	BNE	BLEZ	BGTZ			
1	001	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI			
2	010	COP0 d,p	COP1 d,p	COP2 d,p	*	BEQL	BNEL	BLEZL	BGTZL			
3	011	DADDI	DADDIU	LDL	LDR	*	*	*	*			
4	100	LB	LH	LWL	LW	LBU	LHU	LWR	LWU			
5	101	SB	SH	SWL	SW	SDL	SDR	SWR	r			
6	110	LL	LWC1 p	LWC2 p	*	LLD	LDC1 p	LDC2 p	LD			
7	111	SC	SWC1 p	SWC2 p	*	SCD	SDC1 p	SDC2 p	SD			

31 26	5	0
opcode = SPECIAL	function	

fun	oction	bits 20 Instructions encoded by function field when opcode field = SPECIAL.										
	bits	0	1	2	3	4	5	6	7			
53		000	001	010	011	100	101	110	111			
0	000	SLL	*	SRL	SRA	SLLV	*	SRLV	SRAV			
1	001	JR	JALR	*	*	SYSCALL	BREAK	*	SYNC			
2	010	MFHI	MTHI	MFLO	MTLO	DSLLV	*	DSRLV	DSRAV			
3	011	MULT	MULTU	DIV	DIVU	DMULT	DMULTU	DDIV	DDIVU			
4	100	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR			
5	101	*	*	SLT	SLTU	DADD	DADDU	DSUB	DSUBU			
6	110	TGE	TGEU	TLT	TLTU	TEQ	*	TNE	*			
7	111	DSLL	*	DSRL	DSRA	DSLL32	*	DSRL32	DSRA32			

31 26	20	16	<u> </u>	C
opcode = <i>REGIMM</i>	rt			

	rt	bits 1816		Instructions er	ncoded by the r	t field when opc	ode field = REG	GIMM.	
ł	oits	0	1	2	3	4	5	6	7
20)19	000	001	010	011	100	101	110	111
0	00	BLTZ	BGEZ	BLTZL	BGEZL	*	*	*	*
1	01	TGEI	TGEIU	TLTI	TLTIU	TEQI	*	TNEI	*
2	10	BLTZAL	BGEZAL	BLTZALL	BGEZALL	*	*	*	*
3	11	*	*	*	*	*	*	*	*

Table 3.4 CPU Instruction Encoding - MIPS III Architecture



31 26

opcode

ор	code	bits 2826		Instructions en	icoded by opco	de field.			
bits	3129	0	1	2	3	4	5	6	7
		000	001	010	011	100	101	110	111
0	000	SPECIAL d	REGIMM d	J	JAL	BEQ	BNE	BLEZ	BGTZ
1	001	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI
2	010	COP0 d,p	COP1 d,p	COP2 d,p	COP1X d,p	BEQL	BNEL	BLEZL	BGTZL
3	011	DADDI	DADDIU	LDL	LDR		*	*	*
4	100	LB	LH	LWL	LW	LBU	LHU	LWR	LWU
5	101	SB	SH	SWL	SW	SDL	SDR	SWR	r
6	110	LL	LWC1 p	LWC2 p	PREF	LLD	LDC1 p	LDC2 p	LD
7	111	SC	SWC1 p	SWC2 p	*	SCD	SDC1 p	SDC2 p	SD

31 26	5	0
opcode = SPECIAL	function	

fun	oction								
Ī	bits	0	1	2	3	4	5	6	7
Ę	53	000	001	010	011	100	101	110	111
0	000	SLL	<i>MOVCI</i> d,m	SRL	SRA	SLLV	*	SRLV	SRAV
1	001	JR	JALR	MOVZ	MOVN	SYSCALL	BREAK	*	SYNC
2	010	MFHI	MTHI	MFLO	MTLO	DSLLV	*	DSRLV	DSRAV
3	011	MULT	MULTU	DIV	DIVU	DMULT	DMULTU	DDIV	DDIVU
4	100	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR
5	101	*	*	SLT	SLTU	DADD	DADDU	DSUB	DSUBU
6	110	TGE	TGEU	TLT	TLTU	TEQ	*	TNE	*
7	111	DSLL	*	DSRL	DSRA	DSLL32	*	DSRL32	DSRA32

31 26	20	16	<u> </u>)
opcode = <i>REGIMM</i>	rt			

	rt	bits 1816		Instructions er	ncoded by the r	t field when opc	ode field = RE	GIMM.	
t	oits	0	1	2	3	4	5	6	7
20)19	000	001	010	011	100	101	110	111
0	00	BLTZ	BGEZ	BLTZL	BGEZL	*	*	*	*
1	01	TGEI	TGEIU	TLTI	TLTIU	TEQI	*	TNEI	*
2	10	BLTZAL	BGEZAL	BLTZALL	BGEZALL	*	*	*	*
3	11	*	*	*	*	*	*	*	*

Table 3.5 CPU Instruction Encoding - MIPS IV Architecture



The architecture level in which each MIPS IVencoding was defined is indicated by a subscript 1, 2, 3, or 4 (for architecture level I, II, III, or IV). If an instruction or instruction class was later extended, the extending level is indicated after the defining level.

			31	26					(
			орс	ode					
op	code	bits 2826		Instructions er	ncoded by opco	ode field.			
· ·	3129	0	1	2	3	4	5	6	7
		000	001	010	011	100	101	110	111
0	000	SPECIAL 1-4	REGIMM _{1.2}	J ₁	JAL 1	BEQ 1	BNE 1	BLEZ ₁	BGTZ ₁
1	001	ADDI 1	ADDIU 1	SLTI ₁	SLTIU ₁	ANDI 1	ORI 1	XORI 1	LUI 1
2	010	COP01	COP1 _{1,2,3,4}	COP2 ₁	COP1X ₄	BEQL ₂	BNEL ₂	BLEZL ₂	BGTZL 2
3	011	DADDI 3	DADDIU 3	LDL 3	LDR 3	*1	*1	*1	*1
4	100	LB ₁	LH 1	LWL 1	LW ₁	LBU 1	LHU ₁	LWR 1	LWU 3
5	101	SB ₁	SH 1	SWL ₁	SW ₁	SDL 3	SDR 3	SWR ₁	r ₂
6	110	LL ₂	LWC11	LWC2 ₁	PREF 4	LLD 3	LDC1 ₂	LDC2 ₂	LD ₃
7	111	SC ₂	SWC1 ₁	SWC2 ₁	* 3	SCD 3	SDC1 ₂	SDC2 ₂	SD ₃
			opo = SPI	code ECIAL				1	unctior
fur	nction	bits 20		Instructions er	ncoded by func t	tion field when	opcode field =	SPECIAL.	
	bits	0	1	2	3	4	5	6	7
	53	000	004						
Į	55	000	001	010	011	100	101	110	111
5 0	000	SLL 1	MOVCI ₄	010 SRL ₁	011 SRA ₁	100 SLLV ₁	101 * 1	110 SRLV ₁	111 SRAV ₁
						1	*1 BREAK 1		SRAV 1
0	000	SLL ₁	MOVCI ₄	SRL 1	SRA ₁	SLLV ₁	* 1	SRLV 1	SRAV ₁ SYNC ₂
0 1	000 001	SLL ₁ JR ₁	MOVCI ₄ JALR ₁ MTHI ₁ MULTU ₁	SRL ₁ MOVZ ₄ MFLO ₁ DIV ₁	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁	SLLV ₁ SYSCALL ₁	*1 BREAK 1	SRLV 1 * 1 DSRLV 3 DDIV 3	SRAV 1 SYNC 2 DSRAV 2 DDIVU 3
0 1 2 3 4	000 001 010 011 100	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁	MOVCI ₄ JALR ₁ MTHI ₁ MULTU ₁ ADDU ₁	SRL ₁ MOVZ ₄ MFLO ₁ DIV ₁ SUB ₁	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁ SUBU ₁	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁	* 1 BREAK 1 * 1 DMULTU 3 OR 1	SRLV 1 1 DSRLV 3 DDIV 3 XOR 1	SRAV 1 SYNC 2 DSRAV 2 DDIVU 3 NOR 1
0 1 2 3 4 5	000 001 010 011 100 101	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁	MOVCI ₄ JALR ₁ MTHI ₁ MULTU ₁ ADDU ₁	SRL ₁ MOVZ ₄ MFLO ₁ DIV ₁ SUB ₁ SLT ₁	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁ SUBU ₁ SLTU ₁	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃	* 1 BREAK 1 * 1 DMULTU 3	SRLV 1 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3	SRAV 1 SYNC 2 DSRAV 3 DDIVU 3 NOR 1 DSUBU 3
0 1 2 3 4 5 6	000 001 010 011 100 101 110	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁ *1 TGE ₂	MOVCI ₄ JALR ₁ MTHI ₁ MULTU ₁ ADDU ₁ * 1 TGEU ₂	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁ SUBU ₁ SLTU ₁ TLTU ₂	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃ TEQ ₂	[*] 1 BREAK 1 [*] 1 DMULTU 3 OR 1 DADDU 3 [*] 1	SRLV ₁ [*] 1 DSRLV ₃ DDIV ₃ XOR ₁ DSUB ₃ TNE ₂	SRAV ₁ SYNC ₂ DSRAV DDIVU ₃ NOR ₁ DSUBU
0 1 2 3 4 5	000 001 010 011 100 101	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁	MOVCI ₄ JALR 1 MTHI 1 MULTU 1 ADDU 1 * 1	SRL ₁ MOVZ ₄ MFLO ₁ DIV ₁ SUB ₁ SLT ₁	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁ SUBU ₁ SLTU ₁	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃	* 1 BREAK 1 * 1 DMULTU 3 OR 1 DADDU 3 *	SRLV 1 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3	SRAV 1 SYNC 2 DSRAV 3 DDIVU 3 NOR 1 DSUBU 3
0 1 2 3 4 5 6	000 001 010 011 100 101 110	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁ *1 TGE ₂	MOVCI ₄ JALR 1 MTHI 1 MULTU 1 ADDU 1 * 1 TGEU 2 * 1	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26	SRA ₁ MOVN ₄ MTLO ₁ DIVU ₁ SUBU ₁ SLTU ₁ TLTU ₂	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃ TEQ ₂	[*] 1 BREAK 1 [*] 1 DMULTU 3 OR 1 DADDU 3 [*] 1	SRLV ₁ [*] 1 DSRLV ₃ DDIV ₃ XOR ₁ DSUB ₃ TNE ₂	SRAV ₁ SYNC ₂ DSRAV ₃ DDIVU ₃ NOR ₁ DSUBU ₃
0 1 2 3 4 5 6	000 001 010 011 100 101 110	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁ *1 TGE ₂	MOVCI ₄ JALR 1 MTHI 1 MULTU 1 ADDU 1 * 1 TGEU 2 * 1 31 Opt	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3	$\frac{\text{SRA}_{1}}{\text{MOVN}_{4}}$ $\frac{\text{MTLO}_{1}}{\text{DIVU}_{1}}$ $\frac{\text{SUBU}_{1}}{\text{SLTU}_{1}}$ $\frac{\text{SLTU}_{2}}{\text{DSRA}_{3}}$	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃ TEQ ₂ DSLL32 ₃	[*] 1 BREAK 1 [*] 1 DMULTU 3 OR 1 DADDU 3 [*] 1	SRLV ₁ [*] 1 DSRLV ₃ DDIV ₃ XOR ₁ DSUB ₃ TNE ₂	SRAV ₁ SYNC ₂ DSRAV DDIVU ₃ NOR ₁ DSUBU
0 1 2 3 4 5 6 7	000 001 010 011 100 101 110	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁ *1 TGE ₂	MOVCI ₄ JALR 1 MTHI 1 MULTU 1 ADDU 1 * 1 TGEU 2 * 1 31 Opt	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 code GIMM	$\frac{\text{SRA}_{1}}{\text{MOVN}_{4}}$ $\frac{\text{MTLO}_{1}}{\text{DIVU}_{1}}$ $\frac{\text{SUBU}_{1}}{\text{SLTU}_{1}}$ $\frac{\text{SLTU}_{2}}{\text{DSRA}_{3}}$	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃ TEQ ₂ DSLL32 ₃ 16 rt	* 1 BREAK 1 * 1 DMULTU 3 OR 1 DADDU 3 * 1 * 1	SRLV ₁ [*] 1 DSRLV ₃ DDIV ₃ XOR ₁ DSUB ₃ TNE ₂ DSRL32 ₃	SRAV ₁ SYNC ₂ DSRAV ₃ DDIVU ₃ NOR ₁ DSUBU ₃
0 1 2 3 4 5 6 7	000 001 010 011 100 101 110 111 rt	SLL ₁ JR ₁ MFHI ₁ MULT ₁ ADD ₁ * 1 TGE ₂ DSLL ₃	MOVCI ₄ JALR 1 MTHI 1 MULTU 1 ADDU 1 * 1 TGEU 2 * 1 31 Opt	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 code GIMM	SRA 1 MOVN 4 MTLO 1 DIVU 1 SUBU 1 SLTU 1 TLTU 2 DSRA 3 20	SLLV ₁ SYSCALL ₁ DSLLV ₃ DMULT ₃ AND ₁ DADD ₃ TEQ ₂ DSLL32 ₃ 16 rt	* 1 BREAK 1 * 1 DMULTU 3 OR 1 DADDU 3 * 1 * 1	SRLV ₁ [*] 1 DSRLV ₃ DDIV ₃ XOR ₁ DSUB ₃ TNE ₂ DSRL32 ₃	SRAV ₁ SYNC ₂ DSRAV ₃ DDIVU ₃ NOR ₁ DSUBU ₃
0 1 2 3 4 5 6 7	000 001 010 101 100 101 111 111	SLL ₁ JR ₁ MFHI ₁ ADD ₁ * 1 TGE ₂ DSLL ₃ bits 1816	$ \frac{MOVCI_4}{JALR_1} $ $ MTHI_1 $ $ MULTU_1 $ $ ADDU_1 $ $ *_1 $ $ TGEU_2 $ $ *_1 $ $ 31 $ $ Opc $ $ = REC $	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 CODE GIMM	SRA 1 MOVN 4 MTLO 1 DIVU 1 SUBU 1 SLTU 1 TLTU 2 DSRA 3 20	SLLV $_1$ SYSCALL $_1$ DSLLV $_3$ DMULT $_3$ AND $_1$ DADD $_3$ TEQ $_2$ DSLL32 $_3$ 16 rt t field when opc 4 100	$\frac{1}{1}$ BREAK 1 $\frac{1}{1}$ DMULTU 3 OR 1 DADDU 3 $\frac{1}{1}$ $\frac{1}{1}$ code field = RE0 5 101	SRLV 1 * 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3 TNE 2 DSRL32 3 GIMM. 6 110	SRAV 1 SYNC 2 DSRAV 3 DDIVU 3 NOR 1 DSUBU 3 * 1 DSRA32
0 1 2 3 4 5 6 7	000 001 010 011 100 101 110 111 rt	$\frac{SLL_{1}}{JR_{1}}$ $\frac{MFHI_{1}}{MULT_{1}}$ $\frac{ADD_{1}}{TGE_{2}}$ $\frac{SLL_{3}}{DSLL_{3}}$ bits 1816 0	$ \frac{MOVCI_4}{JALR_1} $ MTHI_1 MULTU_1 ADDU_1 * 1 TGEU_2 * 1 31 OPC = REC	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 CODE GIMM Instructions er 2	SRA 1 MOVN 4 MTLO 1 DIVU 1 SUBU 1 SLTU 1 TLTU 2 DSRA 3 20 ncoded by the rt 3	SLLV $_1$ SYSCALL $_1$ DSLLV $_3$ DMULT $_3$ AND $_1$ DADD $_3$ TEQ $_2$ DSLL32 $_3$ 16 rt t field when opc 4 100	$\frac{1}{1}$ BREAK 1 $\frac{1}{1}$ DMULTU 3 OR 1 DADDU 3 $\frac{1}{1}$ $\frac{1}{1}$ code field = REC 5 101 $\frac{1}{1}$	SRLV 1 * 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3 TNE 2 DSRL32 3 GIMM. 6 110 * 1	SRAV 1 SYNC 2 DSRAV 2 DDIVU 3 NOR 1 DSUBU 2 * 1 DSRA32
0 1 2 3 4 5 6 7	000 001 010 011 100 101 110 111 111 bits 019	SLL ₁ JR ₁ MFHI ₁ ADD ₁ * 1 TGE ₂ DSLL ₃ bits 1816 0 000	$\frac{MOVCI_4}{JALR_1}$ $MTHI_1$ $MULTU_1$ $ADDU_1$ $*_1$ $TGEU_2$ $*_1$ 31 Opc $= REC$ 1 001	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 Code GIMM Instructions er 2 010	$\frac{\text{SRA}_{1}}{\text{MOVN}_{4}}$ $\frac{\text{MTLO}_{1}}{\text{DIVU}_{1}}$ $\frac{\text{SUBU}_{1}}{\text{SLTU}_{1}}$ $\frac{\text{SLTU}_{2}}{\text{DSRA}_{3}}$ $\frac{20}{\text{ncoded by the rf}}$ $\frac{3}{011}$ $\frac{\text{BGEZL}_{2}}{\text{TLTIU}_{2}}$	SLLV 1 SYSCALL 1 DSLLV 3 DMULT 3 AND 1 DADD 3 TEQ 2 DSLL32 3 16 rt t field when opc 4 100 * 1 TEQI 2	$ \begin{array}{r} $	SRLV 1 * 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3 TNE 2 DSRL32 3 GIMM. 6 110 * 1 TNE 2	SRAV 1 SYNC 2 DSRAV 3 DDIVU 3 NOR 1 DSUBU 3 * 1 DSRA32 7 111 * 1
0 1 2 3 4 5 6 7	000 001 010 011 100 101 110 111 111 tits 019 00	SLL ₁ JR ₁ MFHI ₁ ADD ₁ * 1 TGE ₂ DSLL ₃ bits 1816 0 000 BLTZ ₁	$\frac{MOVCI_4}{JALR_1}$ $MTHI_1$ $MULTU_1$ $ADDU_1$ $*_1$ $TGEU_2$ $*_1$ 31 Opc $= REC$ 1 001 $BGEZ_1$	SRL 1 MOVZ 4 MFLO 1 DIV 1 SUB 1 SLT 1 TLT 2 DSRL 3 26 Code GIMM Instructions er 2 010 BLTZL 2	$\frac{\text{SRA}_{1}}{\text{MOVN}_{4}}$ $\frac{\text{MTLO}_{1}}{\text{DIVU}_{1}}$ $\frac{\text{SUBU}_{1}}{\text{SLTU}_{1}}$ $\frac{\text{SLTU}_{2}}{\text{DSRA}_{3}}$ 20 $\frac{20}{\text{ncoded by the rt}}$ 3 011 BGEZL_{2}	SLLV 1 SYSCALL 1 DSLLV 3 DMULT 3 AND 1 DADD 3 TEQ 2 DSLL32 3 16 rt field when opc 4 100 * 1	$\frac{1}{1}$ BREAK 1 $\frac{1}{1}$ DMULTU 3 OR 1 DADDU 3 $\frac{1}{1}$ $\frac{1}{1}$ code field = RE0 5 101	SRLV 1 * 1 DSRLV 3 DDIV 3 XOR 1 DSUB 3 TNE 2 DSRL32 3 GIMM. 6 110 * 1	SRAV 1 SYNC 2 DSRAV 3 DDIVU 3 NOR 1 DSUBU 3 * 1 DSRA32

Table 3.6 Architecture Level in Which CPU Instructions are Defined or Extended



31 26 opcode

An instruction encoding is shown if the instruction is added in this revision.

	bits 2826			encoded by opco		-	,	-
its 3129	0	1	2	3	4	5	6	7
r	000	001	010	011	100	101	110	111
000 C								
1 001								
2 010					BEQL	BNEL	BLEZL	BGTZL
3 011								
4 100								
5 101								r
6 110	LL					LDC1 p	LDC2 p	LDC3 p
7 111	SC					SDC1 p	SDC2 p	SDC3 p
		OPO = SPI	code ECIAL					unctior
unction	bits 20			encoded by funct				_
bits 53	0	1	2	3	4	5	6	7
	000	001	010	011	100	101	110	111
000								01/110
1 001								SYNC
1								
2 010								
2 010 3 011								
2 010 3 011 4 100								
2 010 3 011 4 100 5 101	TCF	ТСЕЦ	TIT	TITU	TEO		TNE	
2 010 3 011 4 100 5 101 5 110	TGE	TGEU	TLT	TLTU	TEQ		TNE	
2 010 3 011 4 100 5 101	TGE	31	26	TLTU 20	ТЕQ 16		TNE	
2 010 3 011 4 100 5 101 6 110	TGE	31 					TNE	
2 010 3 011 4 100 5 101 5 110 7 111 rt	bits 1816	31 $= RE0$	26 code <i>GIMM</i> Instructions 6	20 encoded by the rt	16 rt		GIMM.	
2 010 3 011 4 100 5 101 6 110 7 111 7 111 bits	bits 1816 0	31 $= RE0$ 1	26 code <i>GIMM</i> Instructions e 2	20 encoded by the rt 3	16 rt field when ope 4	5	GIMM. 6	7
2 010 3 011 4 100 5 101 6 110 7 111 <i>rt</i> bits 2019	bits 1816	31 $= RE0$	26 code GIMM Instructions e 2 010	20 encoded by the rt 3 011	16 rt		GIMM.	7 111
2 010 3 011 4 100 5 101 6 110 7 111 bits 20.19 0 00	bits 1816 0 000	31 $= RE0$ 1 001	26 CODE GIMM Instructions e 2 010 BLTZL	20 encoded by the rt 3 011 BGEZL	16 rt t field when opr 4 100	5	GIMM. 6 110	
2 010 3 011 4 100 5 101 6 110 7 111 <i>rt</i> bits 2019	bits 1816 0	31 $= RE0$ 1	26 code GIMM Instructions e 2 010	20 encoded by the rt 3 011	16 rt field when ope 4	5	GIMM. 6	

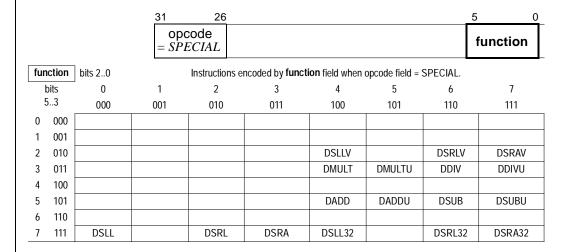
Table 3.7 CPU Instruction Encoding Changes - MIPS II Revision



31 26 opcode

An instruction encoding is shown if the instruction is added or modified in this revision.

ор	code	bits 2826		Instructions e	ncoded by opcod	le field.			
bits	3129	0	1	2	3	4	5	6	7
		000	001	010	011	100	101	110	111
0	000								
1	001								
2	010				(was COP3)				
3	011	DADDI	DADDIU	LDL	LDR				
4	100								LWU
5	101					SDL	SDR		
6	110				(was LWC3)	LLD			LD (was LDC3)
7	111				(was SWC3)	SCD			SD (was SDC3)



			31	26		20	16			0
			opo = RE	code <i>GIMM</i>		rt				
rt		bits 1816		Instruction	is encoded by	the rt fiel	d when	opcode field = RE	GIMM.	
bits	S	0	1	2	3		4	5	6	7
201	19	000	001	010	011		100	101	110	111
0	00									
1	01									
2	10									
3	11									

Table 3.8 CPU Instruction Encoding Changes - MIPS III Revision



opcode

31

An instruction encoding is shown if the instruction is added or modified in this revision.

ор	code	bits 2826		Instructions e	encoded by opcod	le field.			
bits	3129	0	1	2	3	4	5	6	7
		000	001	010	011	100	101	110	111
0	000								
1	001								
2	010				COP1X d,p				
3	011								
4	100								
5	101								
6	110				PREF				
7	111								

31 26	5	0
opcode = <i>SPECIAL</i>	function	

function bits 20 Instructions encoded by function field when opcode field = SPECIAL.									
	bits	0	1	2	3	4	5	6	7
	53	000	001	010	011	100	101	110	111
0	000		MOVCI d,m						
1	001			MOVZ	MOVN				
2	010								
3	011								
4	100								
5	101								
6	110								
7	111								

			31	26	20	16			0
			opc = REC	ode <i>GIMM</i>		rt			
	rt	bits 1816		Instructions	encoded by the	rt field when	opcode field = RE	GIMM.	
t	oits	0	1	2	3	4	5	6	7
20)19	000	001	010	011	100	101	110	111
0	00								
1	01								
2	10								
3	11								

Table 3.9 CPU Instruction Encoding Changes - MIPS IV Revision

Key to notes in CPU instruction encoding tables:

- * This opcode is reserved for future use. An attempt to execute it causes a Reserved Instruction exception.
- = This opcode is reserved for future use. An attempt to execute it produces an undefined result. The result may be a Reserved Instruction exception but this is not guaranteed.
- δ (also *italic* opcode name) This opcode indicates an instruction class. The instruction word must be further decoded by examining additional tables that show values for another instruction field.
- π This opcode is a coprocessor operation, not a CPU operation. If the processor state does not allow access to the specified coprocessor, the instruction causes a Coprocessor Unusable exception. It is included in the table because it uses a primary opcode in the instruction encoding map.
- κ This opcode is removed in a later revision of the architecture. If a MIPS III or MIPS IV processor is operated in MIPS II-only mode this opcode will cause a Reserved Instruction exception.
- µ This opcode indicates a class of coprocessor 1 instructions. If the processor state does not allow access to coprocessor 1, the opcode causes a Coprocessor Unusable exception. It is included in the table because the encoding uses a location in what is otherwise a CPU instruction encoding map. Further encoding information for this instruction class is in the FPU Instruction Encoding tables.
- ρ This opcode is reserved for Coprocessor 0 (System Control Coprocessor) instructions that require base+offset addressing. If the instruction is used for COP0 in an implementation, an attempt to execute it without Coprocessor 0 access privilege will cause a Coprocessor Unusable exception. If the instruction is not used in an implementation, it will cause a Reserved Instruction exception.



DIDT

FPU Instructions Basics

Notes

FPU Instruction Set Details

This appendix documents the instructions for the floating-point unit (FPU) in MIPS processors. It contains some descriptive material at the beginning, a detailed description for each instruction in alphabetic order, and an instruction opcode encoding table at the end of the section.

The descriptive material describes the FPU instruction categories, the instruction encoding formats, the valid operands for FPU computational instructions, compare and condition values, FPU use of the coprocessor registers, and a description of the notation used for the detailed instruction description.

This section does not describe the operation of floating-point arithmetic, the exception conditions within FP arithmetic, the exception mechanism of the FPU, or the handling of these FP exceptions.

FPU Instructions

The floating-point unit (FPU) is implemented as Coprocessor unit 1 (CP1) within the MIPS architecture. A floating-point instruction needs access to coprocessor 1 to execute; if CP1 is not enabled, an FP instruction will cause a Coprocessor Unusable exception. The FPU has a load/store architecture. All computations are done on data held in registers, and data is transferred between registers and the rest of the system with dedicated load, store, and move instructions.

- The FPU instructions fall into the following categories:
- Data Transfer
- Arithmetic
- Conversion
- Formatted Operand Value Move
- Conditional Branch
- Miscellaneous

Data Transfer Instructions

The FPU has two separate register sets: coprocessor general registers and coprocessor control registers. The FPU has a load/store architecture; all computations are done on data held in coprocessor general registers. The control registers are used to control FPU operation. Data is transferred between registers and the rest of the system with dedicated load, store, and move instructions. The transferred data is treated as unformatted binary data; no format conversions are performed and, therefore, no IEEE floating-point exceptions can occur.

The supported transfer operations are:

 FPU general reg 	\leftrightarrow	memory	(word/doubleword load/store)
FPU general reg	\leftrightarrow	CPU general reg	(word/doubleword move)
FPU control reg	\leftrightarrow	CPU general reg	(word move)

All coprocessor loads and stores operate on naturally-aligned data items. An attempt to load or store to an address that is not naturally aligned for the data item will cause an Address Error exception. Regardless of byte-numbering order (endianness), the address of a word or doubleword is the smallest byte address among the bytes in the object. For a big-endian machine this is the most-significant byte; for a little-endian machine this is the least-significant byte.

The FPU has loads and stores using the usual register+offset addressing. In MIPS IV, for the FPU only, there are also load and store instructions using register+register addressing.



MIPS I specifies that loads are delayed by one instruction and that proper execution must be insured by observing an instruction scheduling restriction. The instruction immediately following a load into an FPU register *Fn* must not use *Fn* as a source register. The time between the load instruction and the time the data is available is the "load delay slot". If no useful instruction can be put into the load delay slot, then a null operation (NOP) must be inserted.

In MIPS II, this instruction scheduling restriction is removed. Programs will execute correctly when the loaded data is used by the instruction following the load, but this may require extra real cycles. Most processors cannot actually load data quickly enough for immediate use and the processor will be forced to wait until the data is available. Scheduling load delay slots is desirable for performance reasons even when it is not necessary for correctness.

Mnemonic	Description	Defined in
LWC1	Load Word to Floating-Point	I
SWC1	Store Word to Floating-Point	I
LDC1	Load Doubleword to Floating-Point	III
SDC1	Store Doubleword to Floating-Point	III

Table 4.10 FPU Loads and Stores Using Register + Offset Address Mode
--

Mnemonic	Description	Defined in
LWXC1	Load Word Indexed to Floating-Point	IV
SWXC1	Store Word Indexed to Floating-Point	IV
LDXC1	Load Doubleword Indexed to Floating-Point	IV
SDXC1	Store Doubleword Indexed to Floating-Point	IV

Table 4.11 FPU Loads and Stores Using Register + Register Address Mode

Mnemonic	Description	Defined in
MTC1	Move Word To Floating-Point	I
MFC1	Move Word From Floating-Point	I
DMTC1	Doubleword Move To Floating-Point	III
DMFC1	Doubleword Move From Floating-Point	III
CTC1	Move Control Word To Floating-Point	I
CFC1	Move Control Word From Floating-Point	I

Table 4.12 FPU Move To/From Instructions

Arithmetic Instructions

The arithmetic instructions operate on formatted data values. The result of most floating-point arithmetic operations meets the IEEE standard specification for accuracy; a result which is identical to an infinite-precision result rounded to the specified format, using the current rounding mode. The rounded result differs from the exact result by less than one unit in the least-significant place (ulp).

Mnemonic	Description	Defined in
ADD.fmt	Floating-Point Add	I
SUB.fmt	Floating-Point Subtract	I
MUL.fmt	Floating-Point Multiply	I
DIV.fmt	Floating-Point Divide	I
ABS.fmt	Floating-Point Absolute Value	I
NEG.fmt	Floating-Point Negate	I
SQRT.fmt	Floating-Point Square Root	II
C.cond.fmt	Floating-Point Compare	I

Table 4.13 FPU IEEE Arithmetic Operations

Two operations, Reciprocal Approximation (RECIP) and Reciprocal Square Root Approximation (RSQRT), may be less accurate than the IEEE specification. The result of RECIP differs from the exact reciprocal by no more than one ulp. The result of RSQRT differs by no more than two ulp. Within these error limits, the result of these instructions is implementation specific.

Mnemonic	Description	Defined in
RECIP.fmt	Floating-Point Reciprocal Approximation	IV
RSQRT.fmt	Floating-Point Reciprocal Square Root Approximation	IV

Table 4.14 FPU Approximate Arithmetic Operations

There are four compound-operation instructions that perform variations of multiply-accumulate: multiply two operands and accumulate to a third operand to produce a result. The accuracy of the result depends which of two alternative arithmetic models is used for the computation. The unrounded model is more accurate than a pair of IEEE operations and the rounded model meets the IEEE specification.

Mnemonic	Description	Defined in
MADD.fmt	Floating-Point Multiply Add	IV
MSUB.fmt	Floating-Point Multiply Subtract	IV
NMADD.fmt	Floating-Point Negative Multiply Add	IV
NMSUB.fmt	Floating-Point Negative Multiply Subtract	IV

Table 4.15 FPU Multiply-Accumulate Arithmetic Operations

The RC5000 uses the rounded model which meets the specification.

- Rounded or non-fused
 - The product is rounded according to the current rounding mode prior to the accumulation. This model meets the IEEE accuracy specification; the result is numerically identical to the equivalent computation using multiply, add, subtract, and negate instructions.
- Unrounded or fused (R8000 implementation)
 - The product is not rounded and all bits take part in the accumulation. This model does not match the IEEE accuracy requirements; the result is more accurate than the equivalent computation using IEEE multiply, add, subtract, and negate instructions.

Conversion Instructions

There are instructions to perform conversions among the floating-point and fixed-point data types. Each instruction converts values from a number of operand formats to a particular result format. Some convert instructions use the rounding mode specified in the Floating Control and Status Register (FCSR), others specify the rounding mode directly.

Mnemoni c	Description	Defined in
CVT.S.fmt	Floating-Point Convert to Single Floating-Point	I
CVT.D.fmt	Floating-Point Convert to Double Floating-Point	I
CVT.W.fmt	Floating-Point Convert to Word Fixed-Point	I
CVT.L.fmt	Floating-Point Convert to Long Fixed-Point	I

 Table 4.1 FPU Conversion Operations Using the FCSR Rounding Mode

Mnemonic	Description	Defined in
ROUND.W.fmt	Floating-Point Round to Word Fixed-Point	
ROUND.L.fmt	Floating-Point Round to Long Fixed-Point	III
TRUNC.W.fmt	Floating-Point Truncate to Word Fixed-Point	
TRUNC.L.fmt	Floating-Point Truncate to Long Fixed-Point	III
CEIL.W.fmt	Floating-Point Ceiling to Word Fixed-Point	II
CEIL.L.fmt	Floating-Point Ceiling to Long Fixed-Point	III
FLOOR.W.fmt	Floating-Point Floor to Word Fixed-Point	
FLOOR.L.fmt	Floating-Point Floor to Long Fixed-Point	

Table 4.16 FPU Conversion Operations Using a Directed Rounding Mode

Formatted Operand Value Move Instructions

These instructions all move formatted operand values among FPU general registers. A particular operand type must be moved by the instruction that handles that type. There are three kinds of move instructions:

- Unconditional move
- Conditional move that tests an FPU condition code
- Conditional move that tests a CPU general register value against zero

The conditional move instructions operate in a way that may be unexpected. They always force the value in the destination register to become a value of the format specified in the instruction. If the destination register does not contain an operand of the specified format, before the conditional move is executed, the contents become undefined.

Mnemonic	Description	Defined in		
MOV.fmt	Floating-Point Move	I		

Table 4.17 FPU Formatted Operand Move Instructions

Mnemonic Description		Defined in
MOVT.fmt	Floating-Point Move Conditional on FP True	IV
MOVF.fmt	Floating-Point Move Conditional on FP False	IV

Table 4.18 FPU Conditional Move on True/False Instructions

Mnemonic	Description	Defined in
MOVZ.fmt	Floating-Point Move Conditional on Zero	IV
MOVN.fmt	Floating-Point Move Conditional on Nonzero	IV

Table 4.19 FPU Conditional Move on Zero/Nonzero Instructions



Conditional Branch Instructions

The FPU has PC-relative conditional branch instructions that test condition codes set by FPU compare instructions (C. cond.fmt).

All branches have an architectural delay of one instruction. When a branch is taken, the instruction immediately following the branch instruction, in the branch delay slot, is executed before the branch to the target instruction takes place. Conditional branches come in two versions that treat the instruction in the delay slot differently when the branch is not taken and execution falls through. The "branch" instructions execute the instruction in the delay slot, but the "branch likely" instructions do not (they are said to nullify it).

MIPS I defines a single condition code which is implicit in the compare and branch instructions. MIPS IV defines seven additional condition codes and includes the condition code number in the compare and branch instructions. The MIPS IV extension keeps the original condition bit as condition code zero and the extended encoding is compatible with the MIPS I encoding.

Mnemonic Description		Defined in
BC1T	Branch on FP True	I
BC1F	Branch on FP False	I
BC1TL	Branch on FP True Likely	II
BC1FL	Branch on FP False Likely	II

Table 4.20 FPU Conditional Branch Instructions

Miscellaneous Instructions

CPU Conditional Move

There are instructions to conditionally move one CPU general register to another based on an FPU condition code as shown in Table 4.21.

Mnemonic	Description	Defined in
MOVZ	Move Conditional on FP True	IV
MOVN	Move Conditional on FP False	IV

Table 4.21 CPU Conditional Move on FPU True/False Instructions

Valid Operands for FP Instructions

The floating-point unit arithmetic, conversion, and operand move instructions operate on formatted values with different precision and range limits and produce formatted values for results. Each representable value in each format has a binary encoding that is read from or stored to memory. The *fmt* or *fmt3* field of the instruction encodes the operand format required for the instruction. A conversion instruction specifies the result type in the *function* field; the result of other operations is the same format as the operands. The encoding of the *fmt* and *fmt3* fields is shown in Table 4.22.

fmt		Instruction	Size		dete turre	
	fmt3	Mnemonic	name	bits	data type	
0-15	-	Reserved				
16	0	S	single	32	floating-point	
17	1	D	double	64	floating-point	
18-19	2-3	Reserved				
20	4	W	word	32	fixed-point	
21	5	L	long	64	fixed-point	
22–31	6-7	Reserved				

Table 4.22 FPU Operand Format Field (fmt, fmt3) Decoding



Each type of arithmetic or conversion instruction is valid for operands of selected formats. A summary of the computational and operand move instructions and the formats valid for each of them is listed in Table 4.23. Implementations must support combinations that are valid either directly in hardware or through emulation in an exception handler.

The result of an instruction using operand formats marked "U" is not currently specified by this architecture and will cause an exception. They are available for future extensions to the architecture. The exact exception mechanism used is processor specific. Most implementations report this as an Unimplemented Operation for a Floating Point exception. Other implementations report these combinations as Reserved Instruction exceptions.

		0	pera	nd fr	nt	
Mnemonic	Operation	fle	float		fixed	
		S	D	W	L	
ABS	Absolute value	2	2	U	U	
ADD	Add	2	2	U	U	
C.cond	Floating-point compare	2	2	U	U	
CEIL.L	Convert to word/longword fixed-point, round toward +∞	2	2	U	U	
CEIL.W						
CVT.D	Convert to double floating-point	2	U	2	2	
CVT.L	Convert to longword fixed-point	2	2	U	U	
CVT.S	Convert to single floating-point	U	2	2	2	
CVT.W	Convert to 32-bit fixed-point	2	2	U	U	
DIV	Divide	2	2	U	U	
FLOOR.L	Convert to word/longword fixed-point, round toward $-\infty$	2	2	U	U	
FLOOR.W						
MOV	Move Register	2	2	U	U	
MOVF	FP Move Conditional on condition	2	2	U	U	
MOVT						
MOVN	FP Move Conditional on GPR ≠ zero	2	2	U	U	
MOVZ	FP Move Conditional on GPR = zero	2	2	U	U	
NEG	Negate	2	2	U	U	
RECIP	Reciprocal approximation	2	2	U	U	
ROUND.L	Convert to word/longword fixed-point, round to nearest/even	2	2	U	U	
ROUND.W						
RSQRT	Reciprocal square root approximation	2	2	U	U	
SQRT	Square root	2	2	U	U	
SUB	Subtract	2	2	U	U	
TRUNC.L	Convert to word/longword fixed-point, round toward zero	2	2	U	U	
TRUNC.W						
Key:	- Valid. U - Causes unimplemented exception traps.					

Table 4.23 Valid Formats for FPU Operations

Description of an Instruction

For the FPU instruction detail documentation, all variable subfields in an instruction format (such as *fs*, *ft*, *immediate*, and so on) are shown in lower-case. The instruction name (such as ADD, SUB, and so on) is shown in upper-case.

For clarity, we sometimes use an alias for a variable subfield in the formats of specific instructions. For example, we use *rs* = *base* in the format for load and store instructions. Such an alias is always lower case, since it refers to a variable subfield.



In some instructions, the instruction subfields *op* and *function* can have constant 6-bit values. When reference is made to these instructions, upper-case mnemonics are used. For instance, in the floating-point ADD instruction we use op = COP1 and *function* = ADD. In other cases, a single field has both fixed and variable subfields, so the name contains both upper and lower case characters. Bit encodings for mnemonics are shown at the end of this section, and are also included with each individual instruction.

Operation Notation Conventions and Functions

The instruction description includes an *Operation* section that describes the operation of the instruction in a pseudocode. The pseudocode and terms used in the description are described in "Operation Section Notation and Functions" on page 15 of Chapter 1.

Individual FPU Instruction Descriptions

The FP instructions are described in alphabetic order. For a description of the information in each instruction, see "Instruction Descriptions" on page 13 of Chapter 1.



Individual FPU Instruction Descriptions





FPU Instructions Reference

Notes

This chapter is similar to Chapter 2 except that it deals with the FPU (hardware floating point unit) instructions.

MIPS I

31	26	25		21	20	16	15		11	10		6	5		0
COP1 010001			fmt		0 0	0 0 0 0		fs			fd			ABS 000101	
6			5			5		5			5			6	

Format:

Purpose:

ABS.D fd, fs

ABS.S fd, fs

To compute the absolute value of an FP value.

Description: $fd \leftarrow absolute(fs)$

The absolute value of the value in FPR *fs* is placed in FPR *fd*. The operand and result are values in format *fmt*.

This operation is arithmetic; a NaN operand signals invalid operation.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, AbsoluteValue(ValueFPR(fs, fmt)))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation Invalid Operation



31	26	25	21	20		16	15		11	10		6	5		0
COP1 010001		fm	t		ft			fs			fd			ADD 0 0 0 0 0 0	
6		5			5			5			5			6	
Format: Purpose:	1	ADD.S f ADD.D To add Fl	fd, fs	s, ft										MIPS I	

Description: $fd \leftarrow fs + ft$

The value in FPR *ft* is added to the value in FPR *fs*. The result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) + ValueFPR(ft, fmt))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation Invalid Operation Inexact Overflow Underflow

	31	26	25	21	20	18	17	16	15	0
	COP1 0 1 0 0 0 1	1		BC 0 0 0	СС	5	nd 0	tf 0	offset	
	6			5	3		1	1	16	
F	ormat:		BC1F BC1F		fset		(cc	= C	implied) MIPS I MIPS IV	
F	urpose:		To test	an FP co	onditic	on c	ode	an	d do a PC-relative conditional branch.	

Description: if (cc = 0) then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the FP condition code bit *cc* is false (0), branch to the effective target address after the instruction in the delay slot is executed

An FP condition code is set by the FP compare instruction, C.cond.fmt.

The MIPS I architecture defines a single floating-point condition code, implemented as the coprocessor 1 condition signal (Cp1Cond) and the C bit in the FP *Control and Status* register. MIPS I, II, and III architectures must have the *cc* field set to 0, which is implied by the first format in the *Format* section.

The MIPS IV architecture adds seven more condition code bits to the original condition code 0. FP compare and conditional branch instructions specify the condition code bit to set or test. Both assembler formats are valid for MIPS IV.

Restrictions:

MIPS I, II, III: There must be at least one instruction between the compare instruction that sets a condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.

MIPS IV: None.

Operation:

ENESAS

BC1

MIPS I, II, and III define a single condition code; MIPS IV adds 7 more condition codes. This operation specification is for the general "Branch On Condition" operation with the *tf* (true/false) and *nd* (nullify delay slot) fields as variables. The individual instructions BC1F, BC1FL, BC1T, and BC1TL have specific values for *tf* and *nd*.

MIPS I

- **I-1:** condition \leftarrow COC[1] = tf
- I: target_offset (offset₁₅)^{GPRLEN-(16+2)} || offset || 0^2
- I+1: if condition then

 $\mathsf{PC} \leftarrow \mathsf{PC} + \mathsf{target}$ endif

MIPS II and MIPS III:

- **I-1:** condition $\leftarrow COC[1] = tf$
 - I: target_offset (offset₁₅)^{GPRLEN-(16+2)} || offset || 0^2
 - I+1: if condition then

 $PC \leftarrow PC + target$

else if nd then NullifyCurrentInstruction()

endif

MIPS IV:

- I: condition \leftarrow FCC[cc] = tf target_offset \leftarrow (offset₁₅)^{GPRLEN-(16+2)} || offset || 0²
- I+1: if condition then

 $PC \leftarrow PC + target$ else if nd then

NullifyCurrentInstruction() endif

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to more distant addresses.

	31	26	25	21	20	18	17	16	15	0
	COP1 0 1 0 0 0 ²	1		IC 0 0 0	СС	2	nd 1	tf 0	offset	
	6			5	3		1	1	16	
ļ	Format:		BC1FL BC1Fl	offset _ cc, c	offset	t	(C) =	0 implied)	MIPS II MIPS IV
I	Purpose:			an FP co / if the bi					do a PC-relative conditional branch; e	xecute the delay

Description: if (cc = 0) then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the FP condition code bit *cc* is false (0), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

An FP condition code is set by the FP compare instruction, C.cond.fmt.

The MIPS I architecture defines a single floating-point condition code, implemented as the coprocessor 1 condition signal (Cp1Cond) and the C bit in the FP *Control and Status* register. MIPS I, II, and III architectures must have the *cc* field set to 0, which is implied by the first format in the *Format* section.

The MIPS IV architecture adds seven more condition code bits to the original condition code 0. FP compare and conditional branch instructions specify the condition code bit to set or test. Both assembler formats are valid for MIPS IV.

Restrictions:

MIPS II, III: There must be at least one instruction between the compare instruction that sets a condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.

MIPS IV: None.

Operation:

CENESAS

BC1FL

MIPS II, and III define a single condition code; MIPS IV adds 7 more condition codes. This operation specification is for the general "Branch On Condition" operation with the *tf* (true/false) and *nd* (nullify delay slot) fields as variables. The individual instructions BC1F, BC1FL, BC1T, and BC1TL have specific values for *tf* and *nd*.

```
MIPS II and MIPS III:
```

- **I-1:** condition \leftarrow COC[1] = tf
- I: target_offset (offset_{15}) GPRLEN-(16+2) || offset || 0^2
- I+1: if condition then

 $PC \leftarrow PC + target$ else if nd then

NullifyCurrentInstruction()

endif

MIPS IV:

I: condition ← FCC[cc] = tf target_offset← (offset₁₅)^{GPRLEN-(16+2)} || offset || 0²

I+1: if condition then

 $PC \leftarrow PC + target$ else if nd then

NullifyCurrentInstruction()

endif

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to more distant addresses.

3	1 26	25 21	20 18	17	16	15		0
	COP1 010001	BC 0 1 0 0 0	сс	nd 0	tf 1	offset		
	6	5	3	1	1	16		
Fo	ormat:	BC1T offset BC1T cc, of	fset	(сс	= (1,	AIPS I AIPS IV	
P	irpose:	To test an FP co	ondition o	ode	an	d do a PC-relative conditional branch.		

Description: if (cc = 1) then branch

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the FP condition code bit *cc* is true (1), branch to the effective target address after the instruction in the delay slot is executed

An FP condition code is set by the FP compare instruction, C.cond.fmt.

The MIPS I architecture defines a single floating-point condition code, implemented as the coprocessor 1 condition signal (Cp1Cond) and the C bit in the FP *Control and Status* register. MIPS I, II, and III architectures must have the *cc* field set to 0, which is implied by the first format in the *Format* section.

The MIPS IV architecture adds seven more condition code bits to the original condition code 0. FP compare and conditional branch instructions specify the condition code bit to set or test. Both assembler formats are valid for MIPS IV.

Restrictions:

MIPS I, II, III: There must be at least one instruction between the compare instruction that sets a condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.

MIPS IV: None

Operation:

ENESAS

BC1

MIPS I, II, and III define a single condition code; MIPS IV adds 7 more condition codes. This operation specification is for the general "Branch On Condition" operation with the *tf* (true/false) and *nd* (nullify delay slot) fields as variables. The individual instructions BC1F, BC1FL, BC1T, and BC1TL have specific values for *tf* and *nd*.

MIPS I

I-1: condition \leftarrow COC[1] = tf I: target \leftarrow (offset₁₅)^{GPRLEN-(16+2)} || offset || 0² I+1: if condition then PC \leftarrow PC + target

endif

MIPS II and MIPS III:

- **I-1:** condition $\leftarrow COC[1] = tf$
- I: target \leftarrow (offset₁₅)^{GPRLEN-(16+2)} || offset || 0²
- $I{+}1{:} \text{ if condition then} \\$

 $PC \leftarrow PC + target$

else if nd then NullifyCurrentInstruction() endif

enui

MIPS IV:

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to more distant addresses.

	31 26	25 21	20 18	17 ⁻	16	15	0
	COP1 0 1 0 0 0 1	BC 0 1 0 0 0	сс	nd 1	tf 1	offset	
	6	5	3	1	1	16	
I	Format:	BC1TL offset BC1TL cc, c	offset	(cc	; =	0 implied) MIPS	
I	Purpose:	To test an FP co slot only if the br				do a PC-relative conditional branch; execute	the delay

Description: if (cc = 1) then branch_likely

An 18-bit signed offset (the 16-bit *offset* field shifted left 2 bits) is added to the address of the instruction following the branch (**not** the branch itself), in the branch delay slot, to form a PC-relative effective target address.

If the FP condition code bit *cc* is true (1), branch to the effective target address after the instruction in the delay slot is executed. If the branch is not taken, the instruction in the delay slot is not executed.

An FP condition code is set by the FP compare instruction, C.cond.fmt.

The MIPS I architecture defines a single floating-point condition code, implemented as the coprocessor 1 condition signal (Cp1Cond) and the C bit in the FP *Control and Status* register. MIPS I, II, and III architectures must have the *cc* field set to 0, which is implied by the first format in the *Format* section.

The MIPS IV architecture adds seven more condition code bits to the original condition code 0. FP compare and conditional branch instructions specify the condition code bit to set or test. Both assembler formats are valid for MIPS IV.

Restrictions:

MIPS II, III: There must be at least one instruction between the compare instruction that sets a condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.

MIPS IV: None.

Operation:

ENESAS

BC1TL

MIPS II, and III define a single condition code; MIPS IV adds 7 more condition codes. This operation specification is for the general "Branch On Condition" operation with the *tf* (true/false) and *nd* (nullify delay slot) fields as variables. The individual instructions BC1F, BC1FL, BC1T, and BC1TL have specific values for *tf* and *nd*.

```
MIPS II and MIPS III:
```

I+1: if condition then

PC ← PC + target else if nd then NullifyCurrentInstruction()

endif

MIPS IV:

- I: condition \leftarrow FCC[cc] = tf target \leftarrow (offset₁₅)^{GPRLEN-(16+2)} || offset || 0²
- I+1: if condition then

 $\mathsf{PC} \gets \mathsf{PC} + \mathsf{target}$

 $else \ \text{if} \ nd \ then$

NullifyCurrentInstruction()

endif

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is \pm 128 KBytes. Use jump (J) or jump register (JR) instructions to branch to more distant addresses.



Floating-Point Compare

31	26	25	21	20	16	15	11	10	8	7	6	5	4	3	0
COP1		fm	t		ft	fs		CC		0		FC	5	cond	
01000	1					-				0	0	1	1		
6		5			5	5		3		2)		2	4	
Format:		C.cond.S C.cond C.cond C.cond	.D .S	ft (cc = fs, ft cc, fs cc, fs			= 0 im	nplied)					IPS I IPS IV	
Purpose:		To comp	are FP	values	and recor	d the Boo	lean re	esult ir	ac	ondi	tior	1 CO(de.		
Description:		$cc \leftarrow fs$	compai	re_con	<i>d</i> ft										

The value in FPR *fs* is compared to the value in FPR *ft*; the values are in format *fmt*. The comparison is exact and neither overflows nor underflows. If the comparison specified by $cond_{2..1}$ is true for the operand values, then the result is true, otherwise it is false. If no exception is taken, the result is written into condition code *cc*; true is 1 and false is 0.

If *cond*₃ is set and at least one of the values is a NaN, an Invalid Operation condition is raised; the result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written and an Invalid Operation exception is taken immediately. Otherwise, the Boolean result is written into condition code cc.
- Imprecise exception model (R8000 normal mode): The Boolean result is written into condition code cc. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

There are four mutually exclusive ordering relations for comparing floating-point values; one relation is always true and the others are false. The familiar relations are *greater than*, *less than*, and *equal*. In addition, the IEEE floating-point standard defines the relation *unordered* which is true when at least one operand value is NaN; NaN compares unordered with everything, including itself. Comparisons ignore the sign of zero, so +0 equals -0.

The comparison condition is a logical predicate, or equation, of the ordering relations such as "less than or equal", "equal", "not less than", or "unordered or equal". Compare distinguishes sixteen comparison predicates. The Boolean result of the instruction is obtained by substituting the Boolean value of each ordering relation for the two FP values into equation. If the *equal* relation is true, for example, then all four example predicates above would yield a true result. If the *unordered* relation is true then only the final predicate, "unordered or equal" would yield a true result.

Logical negation of a compare result allows eight distinct comparisons to test for sixteen predicates as shown in Table 5.24. Each mnemonic tests for both a predicate and its logical negation. For each mnemonic, compare tests the truth of the first predicate. When the first predicate is true, the result is true as shown in the "if predicate is true" column (note that the False predicate is never true and False/True do not follow the normal pattern). When the first predicate is true, the second predicate must be false, and vice versa. The truth of the second predicate is the logical negation of the instruction result. After a compare instruction, test for the truth of the first predicate with the Branch on FP True (BC1T) instruction and the truth of the second with Branch on FP False (BC1F).



Instr	Comparison Predicat			Compari Res		Ir	str		
cond Mnemonic	name of predicate and logically negated predicate (abbreviation)		rela val		-	If predicate is true	Inv Op excp if Q	con	d field
		^	۷	=	?	13 11 40	NaN	3	2(
F	False [this predicate is always False,	F	F	F	F	F	No	0	0
	True (T) it never has a True result]	Т	Т	Т	Т				
UN	Unordered	F	F	F	Т	Т			1
	Ordered (OR)	Т	Т	Т	F	F			
EQ	Equal	F	F	Т	F	Т			2
	Not Equal (NEQ)	Т	Т	F	Т	F			
UEQ	Unordered or Equal	F	F	Т	Т	Т			3
	Ordered or Greater than or Less than (OGL)	Т	Т	F	F	F			
OLT	Ordered or Less Than	F	Т	F	F	Т			4
	Unordered or Greater than or Equal (UGE)	Т	F	Т	Т	F			
ULT	Unordered or Less Than	F	Т	F	Т	Т			5
	Ordered or Greater than or Equal (OGE)	Т	F	Т	F	F			
OLE	Ordered or Less than or Equal	F	Т	Т	F	Т			6
	Unordered or Greater Than (UGT)	Т	F	F	Т	F			
ULE	Unordered or Less than or Equal	F	Т	Τ	Т	Т			7
	Ordered or Greater Than (OGT)	Т	F	F	F	F			

Table 5.24 FPU Comparisons Without Special Operand Exceptions

There is another set of eight compare operations, distinguished by a $cond_3$ value of 1, testing the same sixteen conditions. For these additional comparisons, if at least one of the operands is a NaN, including Quiet NaN, then an Invalid Operation condition is raised. If the Invalid Operation condition is enabled in the FCSR, then an Invalid Operation exception occurs.

Instr	Comparison Predicate	9				Compai CC Res		In	str
cond Mnemonic	name of predicate and logically negated predicate (abbreviation)			tion ues		lf predicate	Inv Op excp if O	cond	l fielc
MITEIHOHIC		>	<	=	?	is true	NaN	3	20
SF	Signaling False [this predicate always False]	F	F	F	F	F	Yes	1	0
	Signaling True (ST)	Т	Т	Т	Т				
NGLE	Not Greater than or Less than or Equal	F	F	F	Т	Т			1
	Greater than or Less than or Equal (GLE)	Т	Т	Т	F	F			
SEQ	Signaling Equal	F	F	Т	F	Т			2
	Signaling Not Equal (SNE)	Т	Т	F	Т	F			
NGL	Not Greater than or Less than	F	F	Т	Т	Т			3
	Greater than or Less than (GL)	Т	Т	F	F	F			
LT	Less than	F	Т	F	F	Т			4
	Not Less Than (NLT)	Т	F	Т	Т	F			
NGE	Not Greater than or Equal	F	Т	F	Т	Т			5
	Greater than or Equal (GE)	Т	F	Т	F	F			
LE	Less than or Equal	F	Т	Τ	F	Т			6
	Not Less than or Equal (NLE)	Т	F	F	Т	F			
NGT	Not Greater than	F	Т	Т	Т	Т	1		7
	Greater than (GT)	Т	F	F	F	F			

key: "?" = unordered, ">" = greater than, "<" = less than, "=" is equal, "T" = True, "F" = False

Table 5.25 FPU Comparisons With Special Operand Exceptions for QNaNs

The instruction encoding is an extension made in the MIPS IV architecture. In previous architecture levels the *cc* field for this instruction must be 0.

The MIPS I architecture defines a single floating-point condition code, implemented as the coprocessor 1 condition signal (Cp1Cond) and the C bit in the FP *Control and Status* register. MIPS I, II, and III architectures must have the *cc* field set to 0, which is implied by the first format in the *Format* section.

The MIPS IV architecture adds seven more condition code bits to the original condition code 0. FP compare and conditional branch instructions specify the condition code bit to set or test. Both assembler formats are valid for MIPS IV.

Restrictions:

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

MIPS I, II, III: There must be at least one instruction between the compare instruction that sets a condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.



Operation:

```
if NaN(Value FPR(fs, fmt)) or NaN(ValueFPR(ft, fmt)) then

less \leftarrow false

equal \leftarrow false

unordered \leftarrow true

if t then

SignalException(InvalidOperation)

endif

else

less \leftarrow ValueFPR(fs, fmt) < ValueFPR(ft, fmt)

equal \leftarrow ValueFPR(fs, fmt) = ValueFPR(ft, fmt)

unordered \leftarrow false
```

endif

condition \leftarrow (cond₂ and less) or (cond₁ and equal) or (cond₀ and unordered) FCC[cc] \leftarrow condition if cc = 0 then COC[1] \leftarrow condition endif

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation Invalid Operation



Programming Notes:

FP computational instructions, including compare, that receive an operand value of Signaling NaN, will raise the Invalid Operation condition. The comparisons that raise the Invalid Operation condition for Quiet NaNs in addition to SNaNs, permit a simpler programming model if NaNs are errors. Using these compares, programs do not need explicit code to check for QNaNs causing the *unordered* relation. Instead, they take an exception and allow the exception handling system to deal with the error when it occurs. For example, consider a comparison in which we want to know if two numbers are equal, but for which unordered would be an error.

```
# comparisons using explicit tests for QNaN
             $f2,$f4 # check for equal
    c.eq.d
    nop
    bc1t
             L2
                      # it is equal
             $f2,$f4 # it is not equal, but might be unordered
    c.un.d
    bc1t
             ERROR# unordered goes off to an error handler
# not-equal-case code here
# equal-case code here
L2:
# ------
# comparison using comparisons that signal QNaN
    c.seq.d $f2,$f4 # check for equal
    nop
    bc1t
             L2
                      # it is equal
    nop
# it is not unordered here...
# not-equal-case code here
    ...
#equal-case code here
L2:
```



31	26	25 21	20	16	15	11	10	6	5		0
COP1 010001		fmt	0 (0 0 0 0 0		fs	fd			CEIL.L 0 0 1 0 1 0	
6		5		5		5	5			6	
Format:		CEIL.L.S fd, fs CEIL.L.D fd								MIPS III	
Purpose:	٦	To convert an F	P value	e to 64-bit	fixed-	point, rou	nding up.				
Description:	f	$d \leftarrow convert_a$	nd_rou	ınd(fs)							
The value in		? <i>fs</i> in format	fmt is	converter	t to a	value in <i>i</i>	61.hit Ion	a fivo	1-noir	nt format rou	ndina

The value in FPR *fs* in format *fmt*, is converted to a value in 64-bit long fixed-point format rounding toward $+\infty$ (rounding mode 2). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{63} to 2^{63} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2⁶³–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2⁶³–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Inexact

Unimplemented Operation Overflow



31	26 25 21	20 16	15 11	10 6	5 0
COP1 0 1 0 0 0 1	fmt	00000	fs	fd	CEIL.W 0 0 1 1 1 0
6	5	5	5	5	6
Format:	CEIL.W.S fd, f	S			MIPS II
	CEIL.W.D f	d, fs			
Purpose:	To convert an F	P value to 32-bi	t fixed-point, rou	inding up.	
Description:	$fd \leftarrow convert_a$	ind_round(fs)			

The value in FPR *fs* in format *fmt*, is converted to a value in 32-bit word fixed-point format rounding toward $+\infty$ (rounding mode 2). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{31} to 2^{31} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2³¹–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2³¹–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Unimplemented Operation Inexact Overflow

RENESAS CFC1

Move Control Word from Floating-Point

31	26	25 21	20 16	15 11	10 0
	COP1 0 1 0 0 0 1	CF 0 0 0 1 0	rt	fs	0 000 0000 0000
	6	5	5	5	11
For	mat:	CFC1 rt, fs			MIPS I

Purpose: To copy a word from an FPU control register to a GPR.

Description: $rt \leftarrow FP_Control[fs]$

Copy the 32-bit word from FP (coprocessor 1) control register fs into GPR rt, sign-extending it if the GPR is 64 bits.

Restrictions:

There are only a couple control registers defined for the floating-point unit. The result is not defined if fs specifies a register that does not exist.

For MIPS I, MIPS II, and MIPS III, the contents of GPR rt are undefined for the instruction immediately following CFC1.

Operation:

I: temp \leftarrow FCR[fs] I+1: GPR[rt] \leftarrow sign_extend(temp)

MIPS I - III

MIPS IV

Operation:

temp \leftarrow FCR[fs] GPR[rt]← sign_extend(temp)

Exceptions:

Coprocessor Unusable

3	26	25 21	20 16	15 11	10 0
	COP1 010001	CT 0 0 1 1 0	rt	fs	0 000 0000 0000
	6	5	5	5	11
Fo	ormat:	CTC1 rt, fs			MIPS I
P	irpose:	To copy a word	egister.		

Description: $FP_Control[fs] \leftarrow rt$

Copy the low word from GPR rt into FP (coprocessor 1) control register fs.

Writing to control register 31, the *Floating-Point Control and Status Register* or FCSR, causes the appropriate exception if any cause bit and its corresponding enable bit are both set. The register will be written before the exception occurs.

Restrictions:

There are only a couple control registers defined for the floating-point unit. The result is not defined if *fs* specifies a register that does not exist.

For MIPS I, MIPS II, and MIPS III, the contents of floating-point control register *fs* are undefined for the instruction immediately following CTC1.

Operation:		MIPS I - III				
I: I+1:	FCR[fs]	$ \leftarrow \text{GPR[rt]}_{310} \\ \leftarrow \text{temp} \\ \leftarrow \text{FCR[31]}_{23} $				
Operatio	n:	MIPS IV				
	FCR[fs]	$ \leftarrow \text{GPR[rt]}_{310} \\ \leftarrow \text{temp} \\ \leftarrow \text{FCR[31]}_{23} $				
Rese	rocessor L erved Instr ting-Point	uction nented Operation peration by-zero				



31	26	25	21	20	16	15		11	10		6	5	0
COP1 010001		fmt		0 0 0 0			fs			fd		CVT.D 100001	
6		5		5			5			5		6	,
Format:		CVT.D.S CVT.D.W		l, fs d, fs								MIPS I	
		CVT.D.L		d, fs								MIPS III	
Purpose:	-	To convert a	n F	P or fixed	d-point	value	to dou	uble	FP.				
Description					1/5-)								

Description: $fd \leftarrow convert_and_round(fs)$

The value in FPR *fs* in format *fmt* is converted to a value in double floating-point format rounded according to the current rounding mode in FCSR. The result is placed in FPR *fd*.

If *fmt* is S or W, then the operation is always exact.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for double floating-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR (fd, D, ConvertFmt(ValueFPR(fs, fmt), fmt, D))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Unimplemented Operation Inexact Overflow Underflow



	31	26	25 21	20	16	15	11	10	6	5	0
	COP1 010001		fmt	0 (0 0 0 0 0	1	fs	fd		CVT.L 100101	
	6		5		5		5	5		6	
	Format:		CVT.L.S fd, fs CVT.L.D fd		MIPS III						
Purpose: To convert an FP value to a 64-bit fixed-point.											
Description: $fd \leftarrow convert_and_round(fs)$											

Convert the value in format *fmt* in FPR *fs* to long fixed-point format, round according to the current rounding mode in FCSR, and place the result in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{63} to 2^{63} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active:

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 263–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2⁶³–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR (fd, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Unimplemented Operation Inexact Overflow



31	26	25	21	20	16	15		11	10	6	5		0
COP1 010001		fmt		0 0 0 0			fs			fd		CVT.S 100000	
6		5		5			5			5		6	
Format:	(CVT.S.D	fc	l, fs								MIPS I	
		CVT.S.W		d, fs									
	(CVT.S.L	f	d, fs								MIPS III	
Purpose:	-	To convert a	an Fl	P or fixe	d-point	value	to sin	gle F	P.				
Decorintion.		d oonuo	rt o	nd round	4(fo)								

Description: $fd \leftarrow convert_and_round(fs)$

The value in FPR *fs* in format *fmt* is converted to a value in single floating-point format rounded according to the current rounding mode in FCSR. The result is placed in FPR *fd*.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for single floating-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, S, ConvertFmt(ValueFPR(fs, fmt), fmt, S))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Unimplemented Operation Inexact Overflow Underflow



31	26 25 21	20 16	15 11	10 6	5 0			
COP1 0 1 0 0 0 1	fmt	00000	fs	fd	CVT.W 100100			
6	5	5	5	5	6			
Format:	CVT.W.S fd, f CVT.W.D f			MIPS I				
Purpose: To convert an FP value to 32-bit fixed-point.								
Description: $fd \leftarrow convert_and_round(fs)$								

The value in FPR *fs* in format *fmt* is converted to a value in 32-bit word fixed-point format rounded according to the current rounding mode in FCSR. The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2³¹ to 2³¹-1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2³¹–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2³¹–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Unimplemented Operation Inexact Overflow



31 26	6 25 21	20	16_15	<u>11_106</u>	5 0
COP1 0 1 0 0 0 1	fmt	ft	fs	fd	DIV 0 0 0 0 1 1
6	5	5	5	5	6
Format: Purpose:	DIV.S fd, fs, ft DIV.D fd, fs To divide FP va				MIPS I

Description: $fd \leftarrow fs / ft$

The value in FPR *fs* is divided by the value in FPR *ft*. The result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) / ValueFPR(ft, fmt))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Division-by-zero Overflow

Unimplemented Operation Invalid Operation Underflow



31 26					
51 20	25 21	20 1	6 15	11	10 (
COP1 010001	DMF 0 0 0 0 1	rt		fs	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
6	5	5		5	11
Format:	DMFC1 rt, fs			000	MIPS III
Purpose:	To copy a doubl	eword from an	1 FPR to a	I GPR.	
	$rt \leftarrow fs$			f	
If the coproces	a 64-bit process	gisters are 32 or), FPR <i>fs</i> is	ebits wid held in a	e (a nat	ve 32-bit processor or 32-bit regis dd register pair. The low word is tal
Restrictions:					
If <i>fs</i> does not sp	ecify an FPR tha	t can contain a	a doublev	ord, the	result is undefined.
For MIPS III, the	contents of GPI	R <i>rt</i> are undefir	ned for th	e instruc	tion immediately following DMFC1.
Operation:	MIPS I - III				
	R() = 64 then	I	/* 64-bit v	ide FGR	s */
elseif fs ₀	$\leftarrow FGR[fs] = 0 \text{ then} \\ \leftarrow FGR[fs+1] \parallel$		* valid sp	ecifier, 3	2-bit wide FGRs */
else	efinedResult()		* undefin	ed for od	d 32-bit FGRs */
I+1: GPR[rt] ←	– data				
Operation:	MIPS IV				
	R() = 64 then ← FGR[fs]	I	/* 64-bit v	ide FGR	s */
elseif fs ₀ data	= 0 then ← FGR[fs+1]		* valid sp	ecifier, 3	2-bit wide FGRs */
else	efinedResult()		* undefin	ed for od	d 32-bit FGRs */
GPR[rt] ←	– data				
Exceptions:					
Reserved Instr	ruction				



31 26 25 21 20 16 15 1110 0 COP1 DMT 0101 rt fs 0000000000000 6 5 5 5 5 11 Format: DMTC1 rt, fs MIPS III Purpose: To copy a doubleword from a GPR to an FPR. Description: fs ← rt The doubleword contents of GPR rt are placed into FPR fs. If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor). FPR fs is held in an even/odd register pair. The low word is placed in the ev- register fs and the high word is placed in fs+1. Restrictions: If fs does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR fs are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data ← GPR[rt] I+1: if SizeFGR0 = 64 then /* 64-bit wide FGRs */ FGR[fs] ← data elseif fs0 = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data elseif fs0 = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] ← data _{31.0} else /* undefined Result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data _{31.0} else /* undefined result for odd 32-bit FGRs */		24	25	21	20	14	15 1	1 10	
O 10 00 1O 0 0 10 1O 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0				21				1 10	
Format: DMTC1 rt, fs MIPS III Purpose: To copy a doubleword from a GPR to an FPR. Description: fs \leftarrow rt The doubleword contents of GPR <i>tt</i> are placed into FPR <i>fs</i> . If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor), FPR <i>fs</i> is held in an even/odd register pair. The low word is placed in the evergister <i>fs</i> and the high word is placed in <i>fs</i> +1. Restrictions: If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III If data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If the data \leftarrow GPR[rt] If SizeFGR0 = 64 then /* undefined result for odd 32-bit FGRs */ Undefined Result() endif Operation: MIPS IV data \leftarrow GPR[rt] GR[fs] \leftarrow data \leftarrow					rt		fs		-
Purpose:To copy a doubleword from a GPR to an FPR.Description: $fs \leftarrow rt$ The doubleword contents of GPR <i>rt</i> are placed into FPR <i>fs</i> .If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor), FPR <i>fs</i> is held in an even/odd register pair. The low word is placed in the ex register <i>fs</i> and the high word is placed in <i>fs</i> +1.Restrictions:If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined.For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1.Operation:MIPS I - IIII:data \leftarrow GPR[rt]I+1:if SizeFGR() = 64 then <i>f</i> 64-bit wide FGRs '/ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> valid specifier, 32-bit wide FGRs '/ UndefinedResult() endifOperation:MIPS IVdata \leftarrow GPR[rt]if SizeFGR() = 64 then <i>f</i> 64-bit wide FGRs '/ undefinedResult() endifOperation:MIPS IVdata \leftarrow GPR[rt]if SizeFGR() = 64 then <i>f</i> GR[fs] \leftarrow data a <i>f</i> 64-bit wide FGRs '/ undefinedResult() endifOperation:MIPS IVdata \leftarrow GPR[rt]if SizeFGR() = 64 then <i>f</i> FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> valid specifier, 32-bit wide FGRs '/ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> valid specifier, 32-bit wide FGRs '/ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> FGR[fs] \leftarrow data elseif $fs_0 = 0$ then <i>f</i> valid specifier, 32-bit wide FGRs '/ FGR[fs] \leftarrow data elseif $fs_0 =$	6		5		Ę	5	5		11
Description: fs ← rt The doubleword contents of GPR rt are placed into FPR fs. If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor), FPR fs is held in an even/odd register pair. The low word is placed in the exergister fs and the high word is placed in fs+1. Restrictions: If fs does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR fs are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data ← GPR[rt] I + 1: if SizeFGRQ) = 64 then /* 64-bit wide FGRs */ FGR[fs] ← data elseif fs_0 = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] ← data_{310} else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data ← GPR[rt] if SizeFGRQ) = 64 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] ← data_{310} elseif fs_0 = 0 then /* valid specifier, 32-bit wide FGRs */ GR[fs] ← data elseif fs_0 = 0 then /* undefined result for odd 32-bit FGRs */ FGR[fs] ← data elseif fs_0 = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] ← data_{310} else /* undefi	Format:		DMTC1 r	t, fs					MIPS III
The doubleword contents of GPR <i>rt</i> are placed into FPR <i>fs</i> . If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor), FPR <i>fs</i> is held in an even/odd register pair. The low word is placed in the ex- register <i>fs</i> and the high word is placed in <i>fs</i> +1. Restrictions: If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	Purpose:		То сору а	double	eword fro	om a GF	PR to an FPR.		
If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulat mode in a 64-bit processor), FPR <i>fs</i> is held in an even/odd register pair. The low word is placed in the evergister <i>fs</i> and the high word is placed in <i>fs</i> +1. Restrictions: If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* 64-bit wide FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	Description	า:	$fs \gets rt$						
mode in a 64-bit processor), FPR <i>fs</i> is held in an even/odd register pair. The low word is placed in the evergister <i>fs</i> and the high word is placed in <i>fs</i> +1. Restrictions: If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data _{63.32} FGR[fs] \leftarrow data _{31.0} else /* undefined result for odd 32-bit FGRs */ IndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* 04-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* 04-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data _{31.0} else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data _{31.0} else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	The dou	bleword	l contents c	of GPR	trtare p	laced in	ito FPR <i>fs</i> .		
If <i>fs</i> does not specify an FPR that can contain a doubleword, the result is undefined. For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elselif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elselif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data elselif fs ₀ = 0 then /* 04-bit wide FGRs */ FGR[fs] \leftarrow data elselif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	mode in a 6	4-bit pr	ocessor), F	PR fs	is held ir	n an eve			
For MIPS III, the contents of FPR <i>fs</i> are undefined for the instruction immediately following DMTC1. Operation: MIPS I - III I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	Restriction	s:							
Operation:MIPS I - IIII:data \leftarrow GPR[rt]I+1:if SizeFGR() = 64 thenI' 64-bit wide FGRs */FGR[fs] \leftarrow dataelseif fs_0 = 0 thenI' valid specifier, 32-bit wide FGRs */FGR[fs] \leftarrow data _{63.32} FGR[fs] \leftarrow data _{31.0} elseI' undefined result for odd 32-bit FGRs */UndefinedResult()endifOperation:MIPS IVdata \leftarrow GPR[rt]if SizeFGR() = 64 thenI' 64-bit wide FGRs */FGR[fs] \leftarrow dataelseif fs_0 = 0 thenI' valid specifier, 32-bit wide FGRs */FGR[fs] \leftarrow data _{63.32} FGR[fs] \leftarrow data _{71.0} else/* undefined result for odd 32-bit FGRs */UndefinedResult()endifEsceptions:Reserved Instruction	If <i>fs</i> doe:	s not sp	ecify an FP	PR that	t can cor	itain a c	doubleword, th	e result	is undefined.
I: data \leftarrow GPR[rt] I+1: if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₆₅₃₂ FGR[fs] \leftarrow data ₆₅₃₃ FGR[fs] \leftarrow data ₆₅₃₄ FGR[fs] \leftarrow data ₆₅₃₅ FGR[fs] \leftarrow	For MIP	S III, the	e contents o	of FPR	fs are u	ndefine	d for the instru	uction im	mediately following DMTC1.
I+1: if SizeFGR() = 64 then/* 64-bit wide FGRs */FGR[fs] \leftarrow data/* valid specifier, 32-bit wide FGRs */FGR[fs+1] \leftarrow data ₆₃₃₂ /* undefined result for odd 32-bit FGRs */FGR[fs] \leftarrow data/* undefined result for odd 32-bit FGRs */UndefinedResult()endifOperation:MIPS IVdata \leftarrow GPR[rt]/* 64-bit wide FGRs */FGR[fs] \leftarrow dataelseif fs ₀ = 0 then/* 64-bit wide FGRs */FGR[fs] \leftarrow dataelseif fs ₀ = 0 then/* valid specifier, 32-bit wide FGRs */FGR[fs] \leftarrow data ₆₃₃₂ /* undefined result for odd 32-bit FGRs */FGR[fs] \leftarrow data ₆₃₃₂ /* undefined result for odd 32-bit FGRs */UndefinedResult()/* undefined result for odd 32-bit FGRs */Esceptions:/* undefined result for odd 32-bit FGRs */Reserved Instruction/* undefined result for odd 32-bit FGRs */	Operation:		MIPS I - II	I					
elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif $fs_0 = 0$ then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction		SizeFG	R() = 64 th			/* (64-bit wide FC	GRs */	
else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Operation: MIPS IV data \leftarrow GPR[rt] if SizeFGR() = 64 then /* 64-bit wide FGRs */ FGR[fs] \leftarrow data elseif fs ₀ = 0 then /* valid specifier, 32-bit wide FGRs */ FGR[fs+1] \leftarrow data ₆₃₃₂ FGR[fs] \leftarrow data ₃₁₀ else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	el	seif fs ₀ FGF	= 0 then R[fs+1] ← d	lata _{63.}	.32	/* \	valid specifier,	32-bit w	vide FGRs */
Operation:MIPS IV $data \leftarrow GPR[rt]$ if SizeFGR() = 64 then/* 64-bit wide FGRs */FGR[fs] ← data/* valid specifier, 32-bit wide FGRs */FGR[fs+1] ← data ₆₃₃₂ FGR[fs+1] ← data ₆₃₃₂ FGR[fs] ← data/* undefined result for odd 32-bit FGRs */UndefinedResult()endifExceptions:Reserved Instruction		se Und				/* (undefined res	ult for od	ld 32-bit FGRs */
$\begin{array}{c} data \leftarrow GPR[rt] \\ \text{if SizeFGR()} = 64 \ \text{then} & /* \ 64 \ \text{bit wide FGRs }*/ \\ FGR[fs] \leftarrow data \\ else \ if \ fs_0 = 0 \ \text{then} & /* \ valid \ \text{specifier, } 32 \ \text{bit wide FGRs }*/ \\ FGR[fs+1] \leftarrow data_{6332} \\ FGR[fs] \leftarrow data_{310} \\ else & /* \ \text{undefined result for odd } 32 \ \text{bit FGRs }*/ \\ & \text{UndefinedResult()} \\ end \ \text{if} \end{array}$	-		MIPS IV						
$\begin{array}{c} FGR[fs] \leftarrow data \\ elseif \ fs_0 = 0 \ then \\ FGR[fs+1] \leftarrow data_{6332} \\ FGR[fs] \leftarrow data_{310} \\ else \\ UndefinedResult() \\ endif \end{array} \\ \\ \begin{array}{c} Exceptions: \\ Reserved Instruction \end{array} \\ \end{array}$	•								
$\begin{array}{c} \mbox{FGR[fs+1]} \leftarrow \mbox{data}_{6332} \\ \mbox{FGR[fs]} \leftarrow \mbox{data}_{310} \\ \mbox{else} & /^* \mbox{ undefined result for odd 32-bit FGRs }^*/ \\ \mbox{UndefinedResult()} \\ \mbox{endif} \\ \hline \mbox{Exceptions:} \\ \mbox{Reserved Instruction} \\ \end{array}$		SizeFG	R() = 64 th			/* (64-bit wide FC	GRs */	
else /* undefined result for odd 32-bit FGRs */ UndefinedResult() endif Exceptions: Reserved Instruction	el	FGR	$R[fs+1] \leftarrow d$.32	/* v	valid specifier,	32-bit w	vide FGRs */
Reserved Instruction		se Und				/* ı	undefined res	ult for od	ld 32-bit FGRs */
Reserved Instruction									
	Reserv	ed Inst							



Floating-Point Floor Convert to Long Fixed-Point

3	31	26	25	21	20	16	15	11	1	10	6	5		0
	COP1 010001		fmt		0 0	0 0 0 0		fs		fd			FLOOR.L 0 0 1 0 1 1	
	6		5		•	5		5		5			6	
F	ormat:		FLOOR.L.S FLOOR.L										MIPS III	
Р	Purpose: To convert an FP value to 64-bit fixed-point, rounding down.													
D	Description: $fd \leftarrow convert_and_round(fs)$													
to	The value in FPR <i>fs</i> in format <i>fmt</i> , is converted to a value in 64-bit long fixed-point format rounding toward $-\infty$ (rounding mode 3). The result is placed in FPR <i>fd</i> .													

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{63} to 2^{63} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2⁶³–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2⁶³–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Inexact



	31	26	25	21	20	16	15	11	10	6	5	0
	COP1 010001		fmt		0 0	0		fs		fd	FLOOR.W 0 0 1 1 1 1	
	6	6 5 5 5 5										
	Format:		FLOOR.W.S FLOOR.W			S					MIPS II	
Purpose:To convert an FP value to 32-bit fixed-point, rounding down.												
Description: fd \leftarrow convert and round(fs)												

The value in FPR *fs* in format *fmt*, is converted to a value in 32-bit word fixed-point format rounding toward $-\infty$ (rounding mode 3). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{31} to 2^{31} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2³¹–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2³¹–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Invalid Operation Inexact



31	26	25	21	20	16	15		0
LDC1 1 1 0 1 0 1		ba	se		ft	offset		
6		5			5	16		
Format:		LDC1 1	t, offset	(base))		MIPS II	
Purpose: To load a doubleword from memory to an F						ory to an FPR.		

Description: ft ← memory[base+offset]

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and placed in FPR *ft*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR ft is held in an even/odd register pair. The low word is placed in the even register ft and the high word is placed in ft+1.

Restrictions:

If ft does not specify an FPR that can contain a doubleword, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{2.0} \neq 0 (not doubleword-aligned).

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

Operation:	
vAddr \leftarrow sign_extend(offset) + GPR[base	
if vAddr ₂₀ \neq 0 ³ then SignalException(Ad	dressError) endif
(pAddr, uncached) \leftarrow AddressTranslatior	n (vAddr, DATA, LOAD)
data \leftarrow LoadMemory(uncached, DOUBL	EWORD, pAddr, vAddr, DATA)
if SizeFGR() = 64 then	/* 64-bit wide FGRs */
FGR[ft] ← data	
elseif ft ₀ = 0 then	/* valid specifier, 32-bit wide FGRs */
$FGR[ft+1] \leftarrow data_{6332}$	
$FGR[ft] \leftarrow data_{310}$	
else	/* undefined result for odd 32-bit FGRs */
UndefinedResult()	
endif	
Exceptions:	
Coprocessor unusable	
Reserved Instruction	
TLB Refill, TLB Invalid	
Address Error	



31	26	25 21	20 16	15 11	10 6	5 0
	COP1X 010011	base	index	0	fd	LDXC1 0 0 0 0 0 1
	6	5	5	5	5	6

Format: LDXC1 fd, index(base)

MIPS IV

Purpose: To load a doubleword from memory to an FPR (GPR+GPR addressing).

Description: $fd \leftarrow memory[base+index]$

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and placed in FPR *fd*. The contents of GPR *index* and GPR *base* are added to form the effective address.

If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR *fd* is held in an even/odd register pair. The low word is placed in the even register *fd* and the high word is placed in fd+1.

Restrictions:

If fd does not specify an FPR that can contain a doubleword, the result is undefined.

The Region bits of the effective address must be supplied by the contents of *base*. If EffectiveAddress_{63..62} \neq *base*_{63..62}, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{2.0} \neq 0 (not doubleword-aligned).

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

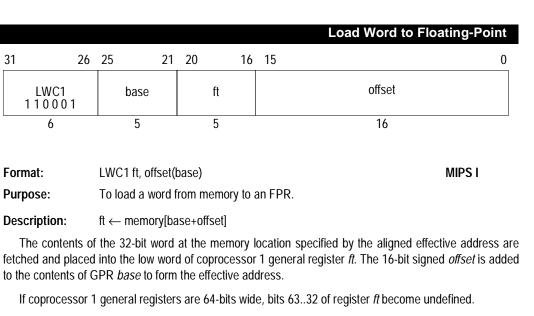
Operation:

Reserved Instruction Coprocessor Unusable

```
vAddr \leftarrow GPR[base] + GPR[index]
     if vAddr<sub>2 0</sub> \neq 0<sup>3</sup> then SignalException(AddressError) endif
     (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD)
     mem 

LoadMemory(unchched, DOUBLEWORD, pAddr, vAddr, DATA)
     if SizeFGR() = 64 then
                                                    /* 64-bit wide FGRs */
          FGR[fd] ← data
     elseif fd_0 = 0 then
                                                    /* valid specifier, 32-bit wide FGRs */
          FGR[fd+1] \leftarrow data_{63..32}
          FGR[fd] \leftarrow data_{31,0}
                                                    /* undefined result for odd 32-bit FGRs */
     else
          UndefinedResult()
     endif
Exceptions:
     TLB Refill, TLB Invalid
     Address Error
```





Restrictions:

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An Address Error exception occurs if EffectiveAddress_{1.0} \neq 0 (not word-aligned).

MIPS IV: The low-order 2 bits of the offset field must be zero. If they are not, the result of the instruction is undefined.

Operation: 32-bit Processors /* "mem" is aligned 64-bits from memory. Pick out correct bytes. */ I: vAddr \leftarrow sign_extend(offset) + GPR[base] if vAddr_{1.0} \neq 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) mem \leftarrow LoadMemory(uncached, WORD, pAddr, vAddr, DATA) I+1: FGR[ft] \leftarrow mem **Operation:** 64-bit Processors /* "mem" is aligned 64-bits from memory. Pick out correct bytes. */ vAddr \leftarrow sign_extend(offset) + GPR[base] if vAddr_{1 0} \neq 0² then SignalException(AddressError) endif (pAddr, uncached) ← AddressTranslation (vAddr, DATA, LOAD) pAddr \leftarrow pAddr_{PSIZE-1..3} || (pAddr_{2..0} xor (ReverseEndian || 0²)) mem LoadMemory(uncached, WORD, pAddr, vAddr, DATA) bytesel \leftarrow vAddr_{2 0} xor (BigEndianCPU || 0²) if SizeFGR() = 64 then /* 64-bit wide FGRs */ $FGR[ft] \leftarrow undefined^{32} || mem_{31+8*bytesel..8*bytesel}$ /* 32-bit wide FGRs */ else $FGR[ft] \leftarrow mem_{31+8*bytesel..8*bytesel}$ endif Exceptions: Coprocessor unusable Reserved Instruction TLB Refill, TLB Invalid Address Error



31	26	25 2	1 20	16	15	11	10	6	5	0
	COP1X 010011	base		index		0	fo	d	LWXC1 000000	
	6	5		5	!	5	5		6	

Format:

LWXC1 fd, index(base)

MIPS IV

Purpose: To load a word from memory to an FPR (GPR+GPR addressing).

Description: $fd \leftarrow memory[base+index]$

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched and placed into the low word of coprocessor 1 general register fd. The contents of GPR index and GPR base are added to form the effective address.

If coprocessor 1 general registers are 64-bits wide, bits 63..32 of register *fd* become undefined.

Restrictions:

The Region bits of the effective address must be supplied by the contents of base. If EffectiveAddress_{63..62} \neq *base*_{63..62}, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{1.0} \neq 0 (not word-aligned).

MIPS IV: The low-order 2 bits of the offset field must be zero. If they are not, the result of the instruction is undefined.

Operation:

operation	
$vAddr \leftarrow GPR[base] + GPR[index]$	
if vAddr _{1.0} \neq 0 ² then SignalException(AddressError) end	if
(pAddr, uncached) ← AddressTranslation (vAddr, DATA,	, LOAD)
pAddr \leftarrow pAddr _{PSIZE-13} (pAddr ₂₀ xor (ReverseEndia	n 0 ²))
/* "mem" is aligned 64-bits from memory. Pick out correct	
mem	DATA)
bytesel \leftarrow vAddr ₂₀ xor (BigEndianCPU 0 ²)	
if SizeFGR() = 64 then	/* 64-bit wide FGRs */
$FGR[fd] \leftarrow undefined^{32} mem_{31+8*bytesel8*bytesel}$	
else	/* 32-bit wide FGRs */
$FGR[fd] \leftarrow mem_{31+8*bytesel8*bytesel}$	
endif	
Exceptions:	
TLB Refill, TLB Invalid	
Address Error	
Reserved Instruction	
Coprocessor Unusable	
5 33	



31	26	25 21	20 16	15 11	10 6	5 3	2 0
	COP1X 0 1 0 0 1 1	fr	ft	fs	fd	MADD 1 0 0	fmt
	6	5	5	5	5	3	3
For	mat:	MIP	S IV				
Pur	pose:	To perform a cor					

Description: $fd \leftarrow (fs \times ft) + fr$

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce a product. The value in FPR *fr* is added to the product. The result sum is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

The accuracy of the result depends which of two alternative arithmetic models is used by the implementation for the computation. The numeric models are explained in the section **Arithmetic Instructions** towards the beginning of this Chapter.

Restrictions:

The fields *fr, fs, ft,* and *fd* must specify FPRs valid for operands of type *fmt.* If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

 $\begin{array}{rcl} \mathsf{vfr} & \leftarrow \mathsf{ValueFPR}(\mathsf{fr}, \mathsf{fmt}) \\ \mathsf{vfs} & \leftarrow \mathsf{ValueFPR}(\mathsf{fs}, \mathsf{fmt}) \\ \mathsf{vft} & \leftarrow \mathsf{ValueFPR}(\mathsf{ft}, \mathsf{fmt}) \\ \mathsf{StoreFPR}(\mathsf{fd}, \mathsf{fmt}, \mathsf{vfr} + \mathsf{vfs}^* \mathsf{vft}) \end{array}$

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation Underflow

RENESAS MFC1

31 2	6 25	21	20	16	15		11	10		0
COP1 010001	0	MF 0 0 0 0	rt			fs			0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
6	!	5	5			5			11	
Format	MEC	1 rtfs							MIDS I	

MFC1 rt, fs Format:

MIPS I

To copy a word from an FPU (CP1) general register to a GPR. Purpose:

Description: rt ← fs

The low word from FPR fs is placed into the low word of GPR rt. If GPR rt is 64 bits wide, then the value is sign extended.

Restrictions:

For MIPS I, MIPS II, and MIPS III the contents of GPR rt are undefined for the instruction immediately following MFC1.

Operation: MIPS I - III

I: word \leftarrow FGR[fs]_{31..0} **I**+1: GPR[rt] ← sign_extend(word)

MIPS IV Operation:

 \leftarrow FGR[fs]_{31..0} word $GPR[rt] \leftarrow sign_extend(word)$

Exceptions:

Coprocessor Unusable



31	26	25	21	20	16	15	11	10	6	5	0
COP1 010001		fmt)) () ()		fs		fd	MOV 0 0 0 1 1 (0
6		5		ļ	5		5		5	6	
Format:		MOV.S f MOV.D		s						MIPS	I
Purpose:	-	To move a	an FP	value be	etween l	FPRs.					
.											

Description: $fd \leftarrow fs$

The value in FPR fs is placed into FPR fd. The source and destination are values in format fmt.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, ValueFPR(fs, fmt))

Exceptions:



									Ν	love Conditi	onal on FP Fal	se
31	26	25	21	20	18	17	16	15	11	10 6	5	0
SPECIAL		rs			C	0	tf	rd		0	MOVCI	
000000)					0	0			00000	000001	
б		5			3	1	1	5		5	6	
- .												
Format:		MOVF	rd, r				da +k	on conditio	onallı		MIPS IV	
Purpose:							ue tr		unany	y move a GPR.		
Description:		if (cc = (
If the floa	iting	-point cond	dition	code	e spe	ecifie	d by	<i>cc</i> is zero	, ther	n the contents of	GPR rs are placed	d ir
Restrictions												
None	•											
Operation:												
	– FC	CC[cc] = tf										
if active												
	R[rd	$d] \leftarrow GPR[$	rs]									
endif												
Exceptions:												
		struction										
Coproce	esso	r Unusable	•									



31 26	25 21	20 18	17	16	15 11	10 6	5	0
COP1 010001	fmt	сс	0 0	tf O	fs	fd	MOVCF 0 1 0 0 0 1	
б	5	3	1	1	5	5	6	
Format:	MOVF.S fo MOVF.D	l, fs, cc fd, fs, c	сс				MIPS IV	
Purpose:	To test an FF	ondition ?	1 COC	le th	en conditionally	move an FP val	ue.	
Description:	if (cc = 0) the	n fd \leftarrow fs						

If the floating-point condition code specified by *cc* is zero, then the value in FPR *fs* is placed into FPR *fd*. The source and destination are values in format *fmt*.

If the condition code is not zero, then FPR *fs* is not copied and FPR *fd* contains its previous value in format *fmt*. If *fd* did not contain a value either in format *fmt* or previously unused data from a load or move-to operation that could be interpreted in format *fmt*, then the value of *fd* becomes undefined.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

```
if FCC[cc] = tf then
    StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
    StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif
```

Exceptions:



31	26 25	21	20	16	15 1 [°]	1 10	6	5	0
COP1 010001		mt	rt		fs	fd		MOVN 0 1 0 0 1 1	
6		5	5		5	5		6	
Format: Purpose:	MO	VN.D	, fs, rt fd, fs, rt ? then conditi	ionall	y move an FP	^r value.		MIPS IV	

Description: if $(rt \neq 0)$ then fd \leftarrow fs

If the value in GPR *rt* is not equal to zero then the value in FPR *fs* is placed in FPR *fd*. The source and destination are values in format *fmt*.

If GPR *rt* contains zero, then FPR *fs* is not copied and FPR *fd* contains its previous value in format *fmt*. If *fd* did not contain a value either in format *fmt* or previously unused data from a load or move-to operation that could be interpreted in format *fmt*, then the value of *fd* becomes undefined.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

Restrictions:

The fields *fs* and *fd* must s.pecify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

```
if GPR[rt] ≠ 0 then
StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif
```

Exceptions:



								al on FP True
31 26	25	21 20 18	17	16	15 ⁻	11 10	6 5	0
SPECIAL 0 0 0 0 0 0 0	rs	сс	0	tf 1	rd	00000)	MOVCI 0 0 0 0 0 1
6	5	3	1	1	5	5		6
Format: Purpose:	MOVT To test a	rd, rs, cc n FP conditic	n coo	de th	en condition	ally move a GI	PR.	MIPS IV
Description:	if (cc = 1)) then rd \leftarrow r	S					
If the floating GPR rd.	g-point condi	tion code spe	ecifie	d by	cc is one th	en the conten	ts of GP F	rs are placed in
Restrictions:								
None								
Operation: if FCC[cc] : GPR[r endif	= tf then ˈd] ← GPR[r:	s]						
Exceptions: Reserved I Coprocess	nstruction or Unusable							



31 26	25 2	1_20	18	17	16	15 11	10 6	5	0
COP1 010001	fmt	с	С	0 0	tf 1	fs	fd	MOVCF 0 1 0 0 0 1	
6	5		3	1	1	5	5	6	
Format:	MOVT.S f MOVT.D			C				MIPS IV	
Purpose:	To test an F	Pcor	nditio	n coo	de th	en conditionally	move an FP val	ue.	
Description:	if (cc = 1) th	en fd	← fs	5					

If the floating-point condition code specified by *cc* is one then the value in FPR *fs* is placed into FPR *fd*. The source and destination are values in format *fmt*.

If the condition code is not one, then FPR *fs* is not copied and FPR *fd* contains its previous value in format *fmt*. If *fd* did not contain a value either in format *fmt* or previously unused data from a load or move-to operation that could be interpreted in format *fmt*, then the value of *fd* becomes undefined.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

```
if FCC[cc] = tf then
    StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
    StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif
```

Exceptions:

RENESAS MOVZ.fmt

31	26	25	21	20	16	15	11	10	6	5		0
COP1 01000	1	fmt		rt		fs		fd		0	MOVZ 10010	
6		5		5		5		5			6	
Format:		Movz.s Movz.	D f	d, fs, rt							MIPS IV	
Purpose:		To test a	GPR	then cond	itionall	y move an	FP v	value.				
Description	:	if (rt = 0)	then	$fd \leftarrow fs$								

If the value in GPR *rt* is equal to zero then the value in FPR *fs* is placed in FPR *fd*. The source and destination are values in format *fmt*.

If GPR *rt* is not zero, then FPR *fs* is not copied and FPR *fd* contains its previous value in format *fmt*. If *fd* did not contain a value either in format *fmt* or previously unused data from a load or move-to operation that could be interpreted in format *fmt*, then the value of *fd* becomes undefined.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

```
if GPR[rt] = 0 then
    StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
    StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif
```

Exceptions:



31	26	25 21	20 16	15 11	10 6	53	2 0
COP1X 0 1 0 0 1		fr	ft	fs	fd	MSUB 1 0 1	fmt
6		5	5	5	5	3	3
Format:		MSUB.S fd, fr, MSUB.D fd,				MIP	S IV
Purpose:		To perform a co	mbined multiply-t	hen-subtract of	FP values.		

Description: $fd \leftarrow (fs \times ft) - fr$

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. The value in FPR *fr* is subtracted from the product. The subtraction result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

The accuracy of the result depends which of two alternative arithmetic models is used by the implementation for the computation. The numeric models are explained in the section **Arithmetic Instructions** earlier on in this Chapter.

Restrictions:

The fields *fr, fs, ft,* and *fd* must specify FPRs valid for operands of type *fmt.* If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

 $\begin{array}{rcl} vfr & \leftarrow ValueFPR(fr, fmt) \\ vfs & \leftarrow ValueFPR(fs, fmt) \\ vft & \leftarrow ValueFPR(ft, fmt) \\ StoreFPR(fd, fmt, (vfs * vft) - vfr) \end{array}$

Exceptions:

Reserved Instruction Coprocessor Unusable Floating-Point Inexact Invalid Operation Underflow

RENESAS MTC1

Move Word to Floating-Point

								nove word to	loading i on
31	26	25	21	20	16	15	11	10	
C(0 1 (OP1 0001	MT 0010	00	rt			fs		0 0 0 0 0 0 0
	6	5		5			5	1	1
Format:		MTC1 rt,	fs						MIPS I
Purpose	:			from a Gl	PR to a	n FPU	CP1) ge	eneral register.	
Descript	ion:	fs ← rt							
								nt (coprocessor 1) ter <i>fs</i> become und	
Restricti	ons:								
For M following		PS II, and	MIPS	III the v	value o	f FPR i	's is und	lefined for the ins	truction immedi
Operatio	n:	MIPS I - II	I						
I: I+1:	if SizeFG	GPR[rt] ₃₁₀ R() = 64 th R[fs] ← un	en	d ³² dət		64-bit w	ide FGR	s */	
	else			u uat	a	/* 32-	bit wide	FGRs */	
	FGR endif	R[fs] ← da	ta						
Operatio	n:	MIPS IV							
		GPR[rt] ₃₁₀			1*	()		o */	
		R() = 64 th የ[fs] ← un		d ³² dat		54-dit w	ide FGR	S /	
	else					/* 32·	bit wide	FGRs */	
	FGR	$R[fs] \leftarrow da$	ta						
Exceptio									
-	rocessor l	Jnusable							



31	26	25 2	21	20	16	15	11	10	6	5	0
COP1 010001		fmt		ft		fs		fo	t	MUL 0 0 0 0 1 0	
6		5		5		5		Ę	5	6	
Format: Purpose:		MUL.S fd, f MUL.D fd To multiply F	l, fs	s, ft						MIPS I	

Description: $fd \leftarrow fs \times ft$

The value in FPR *fs* is multiplied by the value in FPR *ft*. The result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) * ValueFPR(ft, fmt))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation Underflow



31	26	25	21	20	16	15		11	10		6	5		0
COP1 010001			fmt	0 0	0 000		fs			fd			NEG 0 0 0 1 1 1	
6			5		5		5			5			6	
Format:			fd, fs D fd, fs	6									MIPS I	
Purpose:	-	To neg	ate an FF	value										
			<i>(</i> ,)											

Description: $fd \leftarrow - (fs)$

The value in FPR *fs* is negated and placed into FPR *fd*. The value is negated by changing the sign bit value. The operand and result are values in format *fmt*.

This operation is arithmetic; a NaN operand signals invalid operation.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, Negate(ValueFPR(fs, fmt)))

Exceptions:



31	26	25 21	20 16	15 11	10 6	5 3	2 0
0	COP1X 010011	fr	ft	fs	fd	NMADD 110	fmt
	6	5	5	5	5	3	3
Form	nat:	NMADD.S fd, fi NMADD.D fi				MIP	S IV
Purp	ose:	To negate a com	bined multiply-t	hen-add of FP v	alues.		

Description: $fd \leftarrow -((fs \times ft) + fr)$

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. The value in FPR *fr* is added to the product. The result sum is calculated to infinite precision, rounded according to the current rounding mode in FCSR, negated by changing the sign bit, and placed into FPR *fd*. The operands and result are values in format *fmt*.

The accuracy of the result depends which of two alternative arithmetic models is used by the implementation for the computation.

Restrictions:

The fields *fr, fs, ft,* and *fd* must specify FPRs valid for operands of type *fmt.* If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

 $\begin{array}{rcl} vfr & \leftarrow ValueFPR(fr, fmt) \\ vfs & \leftarrow ValueFPR(fs, fmt) \\ vft & \leftarrow ValueFPR(ft, fmt) \\ StoreFPR(fd, fmt, -(vfr + vfs * vft)) \end{array}$

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation Underflow



31	26	25	21	20	16	15	11	10	6	5	3	2	0
COP1X 0 1 0 0 1		fr			ft		fs		fd	NMSUI 111	3	fmt	
6		5			5		5		5	3		3	
Format: Purpose:		NMSUB. NMSUE To negat	B.D fo	d, fr, 1		ien-sul	otract of F	P value	es.	Μ	IIP	S IV	

Description: $fd \leftarrow -((fs \times ft) - fr)$

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. The value in FPR *fr* is subtracted from the product. The result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, negated by changing the sign bit, and placed into FPR *fd*. The operands and result are values in format *fmt*.

The accuracy of the result depends which of two alternative arithmetic models is used by the implementation for the computation. The numeric models are explained in the section **Arithmetic Instructions** earlier on in this Chapter.

Restrictions:

The fields *fr, fs, ft,* and *fd* must specify FPRs valid for operands of type *fmt.* If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

 $\begin{array}{rcl} vfr & \leftarrow ValueFPR(fr, fmt) \\ vfs & \leftarrow ValueFPR(fs, fmt) \\ vft & \leftarrow ValueFPR(ft, fmt) \\ StoreFPR(fd, fmt, -((vfs * vft) - vfr)) \end{array}$

Exceptions:

Reserved Instruction Coprocessor Unusable Floating-Point Inexact Invalid Operation Underflow



31	26	25	21	20	16	15		11	10	6	5	0
COP1X 0 1 0 0 1 1		base		index			hint		0 0 0 0 0 0		PREFX 0 0 1 1 1 1	
6		5		5	I		5		5		6	
Format:		PREFX h	int, ir	ndex(base)							MIPS IV	

Purpose: To prefetch locations from memory (GPR+GPR addressing).

Description: prefetch_memory[base+index]

PREFX adds the contents of GPR *index* to the contents of GPR *base* to form an effective byte address. It advises that data at the effective address may be used in the near future. The *hint* field supplies information about the way that the data is expected to be used.

PREFX is an advisory instruction. It may change the performance of the program. For all *hint* values, it neither changes architecturally-visible state nor alters the meaning of the program. An implementation may do nothing when executing a PREFX instruction.

If MIPS IV instructions are supported and enabled and Coprocessor 1 is enabled (allowing access to CP1X), PREFX does not cause addressing-related exceptions. If it raises an exception condition, the exception condition is ignored. If an addressing-related exception condition is raised and ignored, no data will be prefetched. Even if no data is prefetched in such a case, some action that is not architecturally-visible, such as writeback of a dirty cache line, might take place.

PREFX will never generate a memory operation for a location with an uncached memory access type.

If PREFX results in a memory operation, the memory access type used for the operation is determined by the memory access type of the effective address, just as it would be if the memory operation had been caused by a load or store to the effective address.

PREFX enables the processor to take some action, typically prefetching the data into cache, to improve program performance. The action taken for a specific PREFX instruction is both system and context dependent. Any action, including doing nothing, is permitted that does not change architecturally-visible state or alter the meaning of a program. It is expected that implementations will either do nothing or take an action that will increase the performance of the program.

For a cached location, the expected, and useful, action is for the processor to prefetch a block of data that includes the effective address. The size of the block, and the level of the memory hierarchy it is fetched into are implementation specific.

The *hint* field supplies information about the way the data is expected to be used. No *hint* value causes an action that modifies architecturally-visible state. A processor may use a *hint* value to improve the effectiveness of the prefetch action. The defined *hint* values and the recommended prefetch action are shown in the table below. The *hint* table may be extended in future implementations.

Value	Name	Data use and desired prefetch action
0	load	Data is expected to be loaded (not modified). Fetch data as if for a load.
1	store	Data is expected to be stored or modified. Fetch data as if for a store.
2-3		Not yet defined.
4	load_streamed	Data is expected to be loaded (not modified) but not reused extensively; it will "stream" through cache. Fetch data as if for a load and place it in the cache so that it will not displace data prefetched as "retained".
5	store_streamed	Data is expected to be stored or modified but not reused extensively; it will "stream" through cache. Fetch data as if for a store and place it in the cache so that it will not displace data prefetched as "retained".
6	load_retained	Data is expected to be loaded (not modified) and reused extensively; it should be "retained" in the cache. Fetch data as if for a load and place it in the cache so that it will not be displaced by data prefetched as "streamed".
7	store_retained	Data is expected to be stored or modified and reused extensively; it should be "retained" in the cache. Fetch data as if for a store and place it in the cache so that will not be displaced by data prefetched as "streamed".
8-31		Not yet defined.

Table 0-1 Values of Hint Field for Prefetch Instruction

Restrictions:

The Region bits of the effective address must be supplied by the contents of *base*. If EffectiveAddress_{63..62} \neq *base*_{63..62}, the result of the instruction is undefined.

Operation:

vAddr ← GPR[base] + GPR[index] (pAddr, uncached) ← AddressTranslation(vAddr, DATA, LOAD) Prefetch(uncached, pAddr, vAddr, DATA, hint)

Exceptions:

Reserved Instruction Coprocessor Unusable

Programming Notes:

Prefetch can not prefetch data from a mapped location unless the translation for that location is present in the TLB. Locations in memory pages that have not been accessed recently may not have translations in the TLB, so prefetch may not be effective for such locations.

Prefetch does not cause addressing exceptions. It will not cause an exception to prefetch using an address pointer value before the validity of a pointer is determined.

Implementation Notes:

It is recommended that a reserved *hint* field value either cause a default prefetch action that is expected to be useful for most cases of data use, such as the "load" *hint*, or cause the instruction to be treated as a NOP.



3	1 26	25	21	20	16	15	1	1 10		6	5	0
	COP1 010001	fmt		(0 0 0	-		fs		fd		RECIP 0 1 0 1 0 1	
	6	5			5		5		5		6	
Format: RECIP.S fd, fs RECIP.D fd, fs											MIPS IV	
Ρ	urpose:	To approxi	mate	the reci	procal of	an Fl	P value (q	uickly	<i>ı</i>).			

Description: $fd \leftarrow 1.0 / fs$

The reciprocal of the value in FPR *fs* is approximated and placed into FPR *fd*. The operand and result are values in format *fmt*.

The numeric accuracy of this operation is implementation dependent; it does not meet the accuracy specified by the IEEE 754 Floating-Point standard. The computed result differs from the both the exact result and the IEEE-mandated representation of the exact result by no more than one unit in the least-significant place (ulp).

It is implementation dependent whether the result is affected by the current rounding mode in FCSR.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, 1.0 / valueFPR(fs, fmt))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Division-by-zero Overflow

Unimplemented Operation Invalid Operation Underflow



31	26	25 21	20	16	15	11	10	6	5		0	
COP1 010001		fmt	00000	0		fs	fc	ł		ROUND.L 0 0 1 0 0 0		
6		5	5			5	Ę	5		6		
Format:		MIPS III										
Purpose:	rpose: To convert an FP value to 64-bit fixed-point, rounding to nearest.											
Description: $fd \leftarrow convert_and_round(fs)$												

The value in FPR *fs* in format *fmt*, is converted to a value in 64-bit long fixed-point format rounding to nearest/even (rounding mode 0). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{63} to 2^{63} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2⁶³–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2⁶³–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs* and *fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Overflow

Unimplemented Operation Invalid Operation



_	31	26	25 21	20	16	15	11	10	6	5		0
	COP1 010001		fmt	0	0 0 0 0 0		fs	fc	l		ROUND.W 0 0 1 1 0 0	
	6		5		5		5	5)		6	
F	ormat:		MIPS II									
Ρ	urpose:		To convert an	t.								
Description: $fd \leftarrow convert_and_round(fs)$												

The value in FPR *fs* in format *fmt*, is converted to a value in 32-bit word fixed-point format rounding to nearest/even (rounding mode 0). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2³¹ to 2³¹-1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2³¹–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2³¹–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation



31	26	25 21	20 16	15 11	10 6	5 0
	COP1 0 1 0 0 0 1	fmt	0 0 0 0 0 0	fs	fd	RSQRT 0 1 0 1 1 0
	6	5	5	5	5	6
For	mat:	RSQRT.S fd, RSQRT.D f				MIPS IV
Pu	pose:	To approximate	the reciprocal of	the square root	of an FP value (quickly).

Description: $fd \leftarrow 1.0 / sqrt(fs)$

The reciprocal of the positive square root of the value in FPR *fs* is approximated and placed into FPR *fd*. The operand and result are values in format *fmt*.

The numeric accuracy of this operation is implementation dependent; it does not meet the accuracy specified by the IEEE 754 Floating-Point standard. The computed result differs from the both the exact result and the IEEE-mandated representation of the exact result by no more than two units in the least-significant place (ulp).

It is implementation dependent whether the result is affected by the current rounding mode in FCSR.

Restrictions:

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, 1.0 / SquareRoot(valueFPR(fs, fmt)))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Division-by-zero Overflow

Unimplemented Operation Invalid Operation Underflow



31	26	25 21	20 16	15 0
	SDC1 111101	base	ft	offset
	6	5	5	16
			<i>.</i> .	
For	mat:	SDC1 ft, offset	i(base)	MIPS II
Pur	pose:	To store a doubl	eword from an F	PR to memory.

Description: memory[base+offset] \leftarrow ft

The 64-bit doubleword in FPR *ft* is stored in memory at the location specified by the aligned effective address. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR *ft* is held in an even/odd register pair. The low word is taken from the even register *ft* and the high word is from *ft*+1.

Restrictions:

If *ft* does not specify an FPR that can contain a doubleword, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{2.0} \neq 0 (not doubleword-aligned).

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

```
vAddr \leftarrow sign_extend(offset) + GPR[base]
     if vAddr<sub>2.0</sub> \neq 0<sup>3</sup> then SignalException(AddressError) endif
     (pAddr, uncached) ← AddressTranslation(vAddr, DATA, STORE)
     if SizeFGR() = 64 then
                                                   /* 64-bit wide FGRs */
          data ← FGR[ft]
     elseif ft_0 = 0 then
                                                   /* valid specifier, 32-bit wide FGRs */
          data \leftarrow FGR[ft+1] || FGR[ft]
                                                   /* undefined for odd 32-bit FGRs */
     else
          UndefinedResult()
     endif
     StoreMemory(uncached, DOUBLEWORD, data, pAddr, vAddr, DATA)
Exceptions:
     Coprocessor unusable
```

Reserved Instruction TLB Refill, TLB Invalid TLB Modified Address Error



3	l 26	25	21	20	16	15		11	10		6	5	0
	COP1X 010011	base	9	index			fs			0		SDXC 0 0 1 0 0	
	6	5		5			5			5		6	
Fo	ormat:	SDXC1	fs, inc	lex(base)								MIPS	IV

Purpose: To store a doubleword from an FPR to memory (GPR+GPR addressing).

Description: memory[base+index] \leftarrow fs

The 64-bit doubleword in FPR *fs* is stored in memory at the location specified by the aligned effective address. The contents of GPR *index* and GPR *base* are added to form the effective address.

If coprocessor 1 general registers are 32-bits wide (a native 32-bit processor or 32-bit register emulation mode in a 64-bit processor), FPR *fs* is held in an even/odd register pair. The low word is taken from the even register *fs* and the high word is from *fs*+1.

Restrictions:

If *fs* does not specify an FPR that can contain a doubleword, the result is undefined.

The Region bits of the effective address must be supplied by the contents of *base*. If EffectiveAddress_{63.62} \neq *base*_{63.62}, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{2.0} \neq 0 (not doubleword-aligned).

MIPS IV: The low-order 3 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

$vAddr \leftarrow GPR[base] + GPR[index]$	
if vAddr _{2 0} \neq 0 ³ then SignalException(A)	AddressError) endif
(pAddr, uncached) ← AddressTranslat	ion(vAddr, DATA, STORE)
if SizeFGR() = 64 then	/* 64-bit wide FGRs */
data ← FGR[fs]	
elseif fs ₀ = 0 then	/* valid specifier, 32-bit wide FGRs */
data \leftarrow FGR[fs+1] FGR[fs]	
else	/* undefined for odd 32-bit FGRs */
UndefinedResult()	
endif	
StoreMemory(uncached, DOUBLEWO	RD, data, pAddr, vAddr, DATA)
Exceptions:	
TLB Refill, TLB Invalid	
TLB Modified	
Address Error	
Reserved Instruction	
Coprocessor Unusable	



31	26	25	21	20	16	15	11	10	6	5		0
COP1 010001		fmt			0 0 0 0		fs	fd			SQRT 0 0 0 1 0 0	
6		5			5		5	5			6	
Format: SQRT.S fd, fs SQRT.D fd, fs											MIPS II	
Purpose:		To compu	ite the	square	root of a	n FP ۱	alue.					

Description: $fd \leftarrow SQRT(fs)$

The square root of the value in FPR *fs* is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operand and result are values in format *fmt*.

If the value in FPR *fs* corresponds to -0, the result will be -0.

Restrictions:

If the value in FPR *fs* is less than 0, an Invalid Operation condition is raised.

The fields *fs* and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, fmt, SquareRoot(ValueFPR(fs, fmt)))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Unimplemented Operation Invalid Operation Inexact



31	26	25	21	20		16	15		11	10		6	5		0
COP1 010001		fn	nt		ft			fs			fd			SUB 0 0 0 0 0 1	
6			5		5			5			5			6	
Format:	;		fd, fs	s, ft										MIPS I	
Purpose:	-	To subti	act FP v	alues											

Description: $fd \leftarrow fs - ft$

The value in FPR *ft* is subtracted from the value in FPR *fs*. The result is calculated to infinite precision, rounded according to the current rounding mode in FCSR, and placed into FPR *fd*. The operands and result are values in format *fmt*.

Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is undefined.

The operands must be values in format *fmt*. If they are not, the result is undefined and the value of the operand FPRs becomes undefined.

Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) – ValueFPR(ft, fmt))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation Underflow

31	26	25	21 20	16	15	0				
	WC1 1001	base		ft		offset				
	6	5		5		16				
Format:		MIPS I								
Purpose	:	To store a word from an FPR to memory.								
Descript	ion:	memory[base+offset] \leftarrow ft								
					5	pecified by the aligned effect form the effective address.				
Restricti	ions:									
An Ao	dress Erro	or exception o	occurs if E	EffectiveAd	Iress ₁₀ ≠0 (not word	-aligned).				
MIPS is undefi		w-order 2 bits	s of the <i>o</i> i	<i>ffset</i> field m	ust be zero. If they are	not, the result of the instructi				
if v. (pAo data	Addr ₁₀ = ddr, uncac a ← FGR[f	hed) ← Addr [t]	SignalE) essTrans	ception(lation (vAd	AddressError) endi dr, DATA, STORE) /Addr, DATA)	f				
Operatio	on:	64-bit Proces	ssors							
if v. (pAd pAd byte /* th if Si else end	Addr ₁₀ = ddr, uncac dr \leftarrow pAd esel \leftarrow vAi e bytes of zeFGR() = data \leftarrow 0 data \leftarrow 0 if	hed) \leftarrow Addr dr _{PSIZE-13} // ddr ₂₀ xor (Bin the word are 64 then $^{32-8*bytesel} \parallel I$ $^{32-8*bytesel} \parallel I$	SignalE> essTrans (pAddr ₂ gEndian(moved in FGR[ft] ₃₁ FGR[ft]	cception(, lation (vAd o xor (Reve CPU 0 ²) to the corre 0 0 ^{8*byte} 0 ^{8*bytesel}	AddressError) endi dr, DATA, STORE) rseEndian 0 ²)) ect byte lanes */ /* 64-bit wide FGRs * /* top or bottom wd o /* 32-bit wide FGRs * /* top or bottom wd o	*/ f 64-bit data */ */				
Res TLB TLB	ons: processor L erved Inst Refill, TLI Modified ress Error	ruction								



3	31 26	25 21	20 16	15 11	10 6	5 0
	COP1X 010011	base	index	fs	0	SWXC1 001000
	6	5	5	5	5	6

Format: SWXC1 fs, index(base)

MIPS IV

Purpose: To store a word from an FPR to memory (GPR+GPR addressing).

Description: memory[base+index] \leftarrow fs

The low 32-bit word from FPR *fs* is stored in memory at the location specified by the aligned effective address. The contents of GPR *index* and GPR *base* are added to form the effective address.

Restrictions:

The Region bits of the effective address must be supplied by the contents of *base*. If EffectiveAddress_{63.62} \neq *base*_{63.62}, the result is undefined.

An Address Error exception occurs if EffectiveAddress_{1.0} \neq 0 (not word-aligned).

MIPS IV: The low-order 2 bits of the *offset* field must be zero. If they are not, the result of the instruction is undefined.

Operation:

 $\begin{array}{l} \mathsf{vAddr} \leftarrow \mathsf{GPR}[\mathsf{base}] + \mathsf{GPR}[\mathsf{index}] \\ \mathsf{if} \mathsf{vAddr}_{1..0} \neq \mathsf{0}^2 \mathsf{then} \mathsf{SignalException}(\mathsf{AddressError}) \mathsf{endif} \\ (\mathsf{pAddr}, \mathsf{uncached}) \leftarrow \mathsf{AddressTranslation}(\mathsf{vAddr}, \mathsf{DATA}, \mathsf{STORE}) \\ \mathsf{pAddr} \leftarrow \mathsf{pAddr}_{\mathsf{PSIZE-1..3}} \parallel (\mathsf{pAddr}_{2..0} \mathsf{xor} (\mathsf{ReverseEndian} \parallel \mathsf{0}^2)) \\ \mathsf{bytesel} \leftarrow \mathsf{vAddr}_{2..0} \mathsf{xor} (\mathsf{BigEndianCPU} \parallel \mathsf{0}^2) \\ /^* \mathsf{the} \mathsf{bytes} \mathsf{of} \mathsf{the} \mathsf{word} \mathsf{are} \mathsf{moved} \mathsf{into} \mathsf{the} \mathsf{correct} \mathsf{byte} \mathsf{lanes}^* / \\ \mathsf{data} \leftarrow \mathsf{0}^{32\cdot8^*\mathsf{bytesel}} \parallel \mathsf{FGR}[\mathsf{fs}]_{31..0} \parallel \mathsf{0}^{8^*\mathsf{bytesel}} / \mathsf{top} \mathsf{or} \mathsf{bottom} \mathsf{wd} \mathsf{of} \mathsf{64}\mathsf{-bit} \mathsf{data}^* / \\ \mathsf{data} \leftarrow \mathsf{0}^{32\cdot8^*\mathsf{bytesel}} \parallel \mathsf{FGR}[\mathsf{fs}] \parallel \mathsf{0}^{8^*\mathsf{bytesel}} / \mathsf{top} \mathsf{or} \mathsf{bottom} \mathsf{wd} \mathsf{of} \mathsf{64}\mathsf{-bit} \mathsf{data}^* / \\ \mathsf{endif} \\ \mathsf{StoreMemory}(\mathsf{uncached}, \mathsf{WORD}, \mathsf{data}, \mathsf{pAddr}, \mathsf{vAddr}, \mathsf{DATA}) \end{array}$

Exceptions:

TLB Refill, TLB Invalid TLB Modified Address Error Reserved Instruction Coprocessor Unusable



31	26	25	21	20	16	15	11	10	6	5		0
COP1 010001		fm	t		0 0 0 0		fs		fd		TRUNC.L 0 0 1 0 01	
6		5			5		5		5		6	
Format:		TRUNC.L TRUNC		-							MIPS III	
Purpose:		To conve	t an F	P value	to 64-bi	t fixed	-point, rou	Inding	toward ze	ero.		
Description:	1	fd ← con	vert_a	nd_rour	nd(fs)							

The value in FPR *fs* in format *fmt*, is converted to a value in 64-bit long fixed-point format rounding toward zero (rounding mode 1). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2^{63} to 2^{63} -1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2⁶³–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2⁶³–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Invalid Operation

Unimplemented Operation Overflow



31	26	25 21	20	16	15	11	10	6	5		0
COP1 010001		fmt	0000	0 0	f	Ś	fc	i		TRUNC.W 0 0 1 1 0 1	
6		5	5			5	5	5		6	
Format:		TRUNC.W.S f TRUNC.W.D	fd, fs							MIPS II	
Purpose:		To convert an F	P value t	o 32-bil	t fixed-p	point, rou	inding to	ward ze	ero.		
Description:	1	$fd \leftarrow convert_a$	ind_round	d(fs)							

The value in FPR *fs* in format *fmt*, is converted to a value in 32-bit word fixed-point format using rounding toward zero (rounding mode 1)). The result is placed in FPR *fd*.

When the source value is Infinity, NaN, or rounds to an integer outside the range -2³¹ to 2³¹-1, the result cannot be represented correctly and an IEEE Invalid Operation condition exists. The result depends on the FP exception model currently active.

- Precise exception model: The Invalid Operation flag is set in the FCSR. If the Invalid Operation enable bit is set in the FCSR, no result is written to fd and an Invalid Operation exception is taken immediately. Otherwise, the default result, 2³¹–1, is written to fd.
- Imprecise exception model (R8000 normal mode): The default result, 2³¹–1, is written to fd. No FCSR flag is set. If the Invalid Operation enable bit is set in the FCSR, an Invalid Operation exception is taken, imprecisely, at some future time.

Restrictions:

The fields *fs and fd* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed-point. If they are not valid, the result is undefined.

The operand must be a value in format *fmt*. If it is not, the result is undefined and the value of the operand FPR becomes undefined.

Operation:

StoreFPR(fd, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

Exceptions:

Coprocessor Unusable Reserved Instruction Floating-Point Inexact Overflow

Invalid Operation Unimplemented Operation



Floating-Point Truncate to Word Fixed-Point



Floating-Point Truncate to Word Fixed-Point







FPU Instructions Encoding

Notes

An FPU instruction is a single 32-bit aligned word. The distinct FP instruction layouts are shown below. Variable information is in lower-case labels, such as "offset". Upper-case labels and any numbers indicate constant data. A table follows all the layouts that explains the fields used in them. Note that the same field may have different names in different instruction layout pictures. The field name is mnemonic to the function of that field in the instruction layout. The opcode tables and the instruction decode discussion use the canonical field names: opcode, fmt, nd, tf, and function. The other fields are not used for instruction decode.

Immediate: load/store using register + offset addressing.

31		26	25	21	20		16	15	0
	opcode		b	ase		ft		offset	
	6			5		5		16	

Register: 2-register and 3-register formatted arithmetic operations.

31	2	6 2	25 21	20	16	15	11	10	6	5	0
	COP1		fmt	f	ft		fs		fd	fun	ction
	6		5	ļ	5		5		5		6

Register Immediate: data transfer -- CPU ´ FPU register.

31	26	25	21	20		16	15		11	10		0
COP1			sub		rt			fs			0	
6			5		5			5			11	

Condition code, Immediate: conditional branches on FPU cc using PC + offset.

31	26 25	21 20 1	8 17 16 ⁻	15 0
COP1	BO	C CC	nd tf	offset
6	5	3	11	16

Register to Condition Code: formatted FP compare.

31	26	25	21	20	16	15	11	10 8	76	5	0
COP1		fmt		ft		fs		CC	0	function	
6		5		5		5		3	2	4	

Condition Code, Register FP: FPU register move-conditional on FP cc.

_	31	26	25 21	20 18	17	16	15	11	10 é	5	0
	COP1		fmt	СС	0	tf	fs		fd	MOVCF	
	6		5	5	1	1	5		5	6	

31		26	25		21	20	16	15		11	10		6	5		2	(
	COP1X			fr		f	t		fs			fd		0	pp4	ction fm	13
	6			5		Į	5		5			5			3	3	
_																	
-	gister Index	: Lo	ad/stor	e us	sing	-	+ regis	ter ad	Idres	sing.							
31		26	25		21	20	16	15		11	10		6	5			
	COP1X		ba	ase		inc	lex		0			fd			fun	ction	
	6			5		Į	5		5			5				6	
Reg	gister Index	(hint	: Prefe	etch	usin	g regist	er + reg	ister	addre	essing	g.						
31		26	25		21	20	16	15		11	10		6	5			
	COP1X		ba	ase		inc	lex		hint			0			PR	REFX	
	6			5		Į	5		5			5				6	
Con 31	dition Code	e, Re <u>26</u>	-	Inte	ger: 21		gister m 8 17 16		condi	tiona 11	l on F 10	Pcc	6	5			
			-	Inte	-		-		condi			Pcc		5			
31			25	Inte rs	-		-		condi rd			P cc		5	МС	OVCI	
31	dition Code		25		-	20 1	8 17 16							5	MC	DVCI 6	
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	M		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	M		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	M		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	M		
31	dition Code		25	rs	-	20 1 cc	8 17 16 0 tf		rd			0		5	MC		

BC	Branch Conditional instruction subcode (op=COP1)
base	CPU register: base address for address calculations
COP1	Coprocessor 1 primary opcode value in op field.
COP1X	Coprocessor 1 eXtended primary opcode value in op field.
СС	condition code specifier. For architecture levels prior to MIPS IV it must be zero.
fd	FPU register: destination (arithmetic, loads, move-to) or source (stores, move-from)
fmt	destination and/or operand type ("format") specifier
fr	FPU register: source
fs	FPU register: source
ft	FPU register: source (for stores, arithmetic) or destination (for loads)
function	function field specifying a function within a particular op operation code.
function: op4 - fmt3	op4 is a 3-bit function field specifying which 4-register arithmetic operation for COP1X, fmt3 is a 3-bit field specifying the format of the operands and destination. The combinations are shown as several distinct instructions in the opcode tables.
hint	hint field made available to cache controller for prefetch operation
index	CPU register, holds index address component for address calculations
MOVC	Value in function field for conditional move. There is one value for the instruction with op=COP1, another for the instruction with op=SPECIAL.
nd	nullify delay. If set, branch is Likely and delay slot instruction is not executed. This must be zero for MIPS I.
offset	signed offset field used in address calculations
ор	primary operation code (COP1, COP1X, LWC1, SWC1, LDC1, SDC1, SPECIAL)
PREFX	Value in function field for prefetch instruction for op=COP1X
rd	CPU register: destination
rs	CPU register: source
rt	CPU register: source / destination
SPECIAL	SPECIAL primary opcode value in op field.
sub	Operation subcode field for COP1 register immediate mode instructions.
tf	true/false. The condition from FP compare is tested for equality with tf bit.

FPU (CP1) Instruction Opcode Bit Encoding

This section describes the encoding of the Floating-Point Unit (FPU) instructions for the four levels of the MIPS architecture, MIPS I through MIPS IV. Each architecture level includes the instructions in the previous level;¹ MIPS IV includes all instructions in MIPS I, MIPS II, and MIPS III. This section presents eight different views of the instruction encoding.

- Separate encoding tables for each architecture level.
- A MIPS IV encoding table showing the architecture level at which each opcode was originally defined and subsequently modified (if modified).
- Separate encoding tables for each architecture revision showing the changes made during that revision.

Instruction Decode

Instruction field names are printed in **bold** in this section.

^{1.} An exception to this rule is that the reserved, but never implemented, Coprocessor 3 instructions were removed or changed to another use starting in MIPS III.

The primary **opcode** field is decoded first. The **opcode** values LWC1, SWC1, LDC1, and SDC1 fully specify FPU load and store instructions. The **opcode** values *COP1*, *COP1X*, and *SPECIAL* specify instruction classes. Instructions within a class are further specified by values in other fields.

COP1 Instruction Class

The **opcode**=*COP1* instruction class encodes most of the FPU instructions. The class is further decoded by examining the **fmt** field. The **fmt** values fully specify the CPU \leftrightarrow FPU register move instructions and specify the *S*, *D*, *W*, *L*, and *BC* instruction classes.

The **opcode**=*COP1* + **fmt**=*BC* instruction class encodes the conditional branch instructions. The class is further decoded, and the instructions fully specified, by examining the **nd** and **tf** fields.

The **opcode**=*COP1* + **fmt**=(*S*, *D*, *W*, or *L*) instruction classes encode instructions that operate on formatted (typed) operands. Each of these instruction classes is further decoded by examining the **function** field. With one exception the **function** values fully specify instructions. The exception is the *MOVCF* instruction class.

The **opcode**=COP1 + **fmt**=(S or D) + **function**=MOVCF instruction class encodes the MOVT.*fmt* and MOVF.*fmt* conditional move instructions (to move FP values based on FP condition codes). The class is further decoded, and the instructions fully specified, by examining the **tf** field.

COP1X Instruction Class

The **opcode**=*COP1X* instruction class encodes the indexed load/store instructions, the indexed prefetch, and the multiply accumulate instructions. The class is further decoded, and the instructions fully specified, by examining the **function** field.

SPECIAL Instruction Class

The **opcode**=*SPECIAL* instruction class is further decoded by examining the **function** field. The only **function** value that applies to FPU instruction encoding is the *MOVCI* instruction class. The remainder of the **function** values encode CPU instructions.

The **opcode**=*SPECIAL* + **function**=*MOVCI* instruction class encodes the MOVT and MOVF conditional move instructions (to move CPU registers based on FP condition codes). The class is further decoded, and the instructions fully specified, by examining the **tf** field.

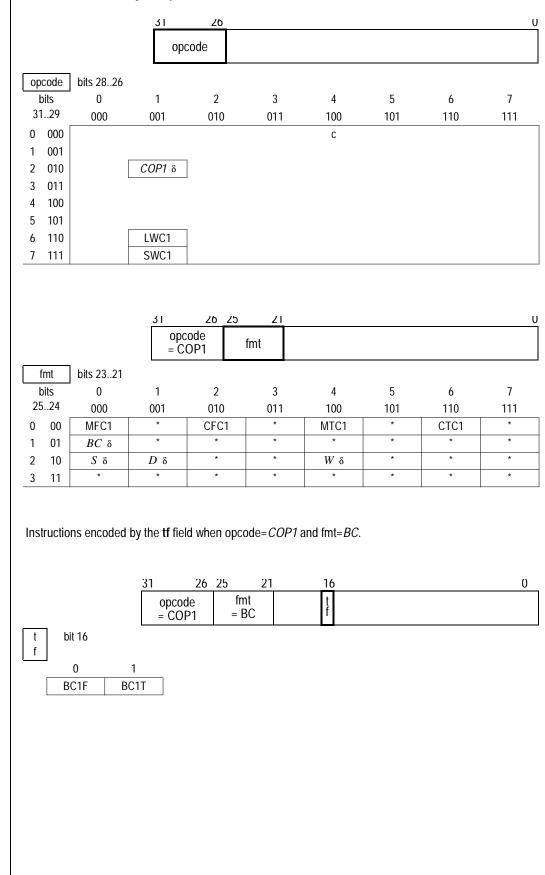
Instruction Subsets of MIPS III and MIPS IV Processors

MIPS III processors, such as the RC4000, RC4200, RC4300, RC4400, and RC4600, have a processor mode in which only the MIPS II instructions are valid. The MIPS II encoding table describes the MIPS II-only mode.

MIPS IV processors, such as the R8000 and R10000, have processor modes in which only the MIPS II or MIPS III instructions are valid. The MIPS II encoding table describes the MIPS III-only mode. The MIPS III encoding table describes the MIPS III-only mode.



Instructions encoded by the **opcode** field.



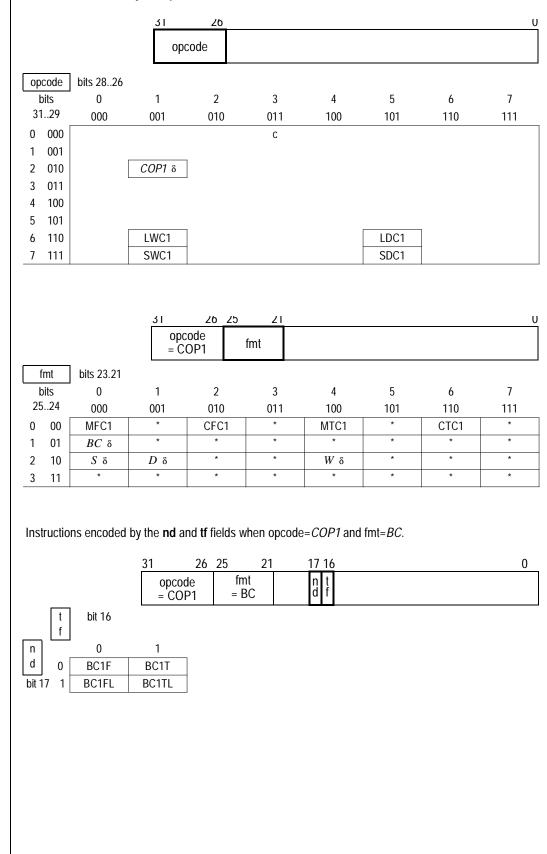


	oding = S	when	3 I opci = C(26 25 ode DP1	fmt = S				function
fun	ction	bits 20							
b	oits	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	ADD	SUB	MUL	DIV	*	ABS	MOV	NEG
1	001	*	*	*	*	*	*	*	*
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	*	CVT.D	*	*	CVT.W	*	*	*
5	101	*	*	*	*	*	*	*	*
6	110	C.F α	C.UN α	C.EQ α	C.UEQ α	C.OLT α	C.ULT α	C.OLE α	C.ULE α
7	111	C.SF α	C.NGLE α	C.SEQ a	C.NGL α	C.LT α	C.NGE α	C.LE α	C.NGT α
	oding = D	when	31 opci = C0	26 25 ode DP1	21 fmt = D				U function
fun	ction	bits 20							
	oits	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	ADD	SUB	MUL	DIV	*	ABS	MOV	NEG
1	001	*	*	*	*	*	*	*	*
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	CVT.S	*	*	*	CVT.W	*	*	*
5	101	*	*	*	*	*	*	*	*
6	110	C.F α	C.UN α	C.EQ α	C.UEQ α	C.OLT α	C.ULT α	C.OLE α	C.ULE α
7	111	C.SF α	C.NGLE α	C.SEQ α	C.NGL α	C.LT α	C.NGE α	C.LE α	C.NGT α
									1
enc	oding	when	31	26 2					
fmt	= W		(pcode COP1	fmt = W				function
fun	iction	bits 20	<u> </u>		L. L.				
Ŀ	oits	0	1	2	3	4	5	6	7
5	53	000	001	010	011	100	101	110	111
0	000	*	*	*	*	*	*	*	*
1	001	*	*	*	*	*	*	*	*
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	CVT.S	CVT.D	*	*	*	*	*	*
	100	*	*	*	*	*	*	*	*
4 5 6	110	*	*	*	*	*	*	*	*

Instructions encoded by the **function** field when opcode=COP1 and fmt = S, D, or W



Instructions encoded by the **opcode** field.



Instruction Subsets of MIPS III and MIPS IV Processors



	coding t = S	y when	opc = C		fmt = S				function
fur	nction	bits 20							
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	ADD	SUB	MUL	DIV	SQRT	ABS	MOV	NEG
1	001	*	*	*	*	ROUND. W	TRUNC.W	CEIL.W	FLOOR.W
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	*	CVT.D	*	*	CVT.W	*	*	*
5	101	*	*	*	*	*	*	*	*
6	110	C.F α	C.UN α	C.EQ α	C.UEQ α	C.OLT a	C.ULT α	C.OLE α	C.ULE α
7	111	C.SF α	C.NGLE α	C.SEQ α	C.NGL α	C.LT α	C.NGE α	C.LE α	C.NGT α
	coding t = D	y when	3 I opc = C	26 25 ode	fmt				
6		1			= D				function
	nction	bits 20			-				
bit	S	0	1	2	3	4	5	6	7
bit 5	s 3	000	1 001	2 010	3 011	100	101	110	7 111
bit	s 3	0	1	2	3	100 SQRT			7
bit 5 0 1	s 3 000 001	0 000 ADD *	1 001 SUB *	2 010 MUL *	3 011 DIV *	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W	7 111 NEG FLOOR.V
bit 5 0 1 2	s 3 000 001 010	0 000 ADD *	1 001 SUB *	2 010 MUL *	3 011 DIV *	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W	7 111 NEG FLOOR.V
bit 5 0 1 2 3	s 3 000 001 010 011	0 000 ADD * *	1 001 SUB * *	2 010 MUL *	3 011 DIV *	100 SQRT ROUND. W *	101 ABS TRUNC.W *	110 MOV CEIL.W *	7 111 NEG FLOOR.V
bit 5 0 1 2 3 4	s 3 000 001 010 011 100	0 000 ADD * * CVT.S	1 001 SUB * *	2 010 MUL * *	3 011 DIV * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W * *	110 MOV CEIL.W * *	7 111 NEG FLOOR.V *
bit 5 0 1 2 3	s 3 000 001 010 011 100 101	0 000 ADD * * CVT.S	1 001 SUB * * *	2 010 MUL * * *	3 011 DIV * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W * * *	110 MOV CEIL.W * *	7 111 NEG FLOOR.V * *
bit 5 0 1 2 3 4	s 3 000 001 010 011 100	0 000 ADD * * CVT.S	1 001 SUB * *	2 010 MUL * *	3 011 DIV * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W * *	110 MOV CEIL.W * *	7 111 NEG FLOOR.W * *

Instructions encoded by the **function** field when opcode=COP1 and fmt = S, D, or W

Instruction Subsets of MIPS III and MIPS IV Processors



encoding fmt = W		op = C	code COP1	fmt = W				function
function	bits 20							
bits	0	1	2	3	4	5	6	7
53	000	001	010	011	100	101	110	111
0 000	*	*	*	*	*	*	*	*
1 001	*	*	*	*	*	*	*	*
2 010 3 011	*	*	*	*	*	*	*	*
4 100	CVT.S	CVT.D	*	*	*	*	*	*
5 101	*	*	*	*	*	*	*	*
6 110	*	*	*	*	*	*	*	*
7 111	*	*	*	*	*	*	*	*
opcode bits	bits 2826 0	1	2	3	4	5	6	7
			2	3	4	5	6	7
3129	000	001	010	011	100	101	110	111
0 000								
1 001			_					
2 010		COP1 δ						
3 011 4 100				С				
4 100 5 101								
6 110		LWC1	7			LDC1		
7 111		SWC1	-			SDC1	-	
	1	1	_!			-		
			26 25) 21				
		op = (code COP1	fmt				
fmt	bits 2321							
fmt bits	0	1	2	3	4	5	6	7
DIIS 2524	000	001	2 010	3 011	4 100	5 101	0 110	, 111
0 00	MFC1	DMFC1	CFC1	*	MTC1	DMTC1	CTC1	*
1 01	ΒС δ	*	*	*	*	*	*	*
	<u> </u>	D δ	*	*	Ψ δ	Lδ	*	*
2 10	5.0							

RENESAS FPU Instructions Encoding

Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.

0

Instructions encoded by the function field when opcode=COP1 and fmt = S, D, W, or L

	coding t = <i>S</i>	j when	31 opc = C0	26 25 ode OP1	fmt = S				0 function
£	otion] hite 2, 0							
	nction	bits 20	4	0	2		-	,	-
bit: 5		0	1	2	3	4	5	6	7
		000	001	010	011	100	101	110	111
0	000	ADD	SUB	MUL	DIV	SQRT	ABS	MOV	NEG
1	001	ROUND.L	TRUNC.L	CEIL.L	FLOOR.L	ROUND. W	TRUNC.W	CEIL.W	FLOOR.W
2	010	*	*	*	*	*	*	*	
3	011	*	*	*	*	*	*	*	*
4	100	*	CVT.D	*	*	CVT.W	CVT.L	*	*
5	101	*	*	*	*	*	*	*	*
6	110	C.F α	C.UN α	C.EQ α	C.UEQ α	C.OLT α	C.ULT α	C.OLE α	C.ULE a
7	111	C.SF α	C.NGLE α	C.SEQ α	C.NGL α	C.LT α	C.NGE α	C.LE α	C.NGT α
	coding t = D	y when	3 I	20 25 ode	21 fmt				U function
fm	t = D	_		ode					U function
fm fur	t = D	bits 20	opc = C(ode OP1	fmt = D				function
fm fur bit	t = D] bits 20 0	opc = C(ode OP1 2	fmt = D	4	5	6	function 7
fm fur bits 5	t = D nction s 3	bits 20 0 000	000 = C0	ode DP1 2 010	fmt = D 3 011	100	101	110	function 7 111
fm fur bit	t = D] bits 20 0	opc = C(ode OP1 2	fmt = D	100 SQRT			function 7
fm fur bits 5	t = D nction s 3	bits 20 0 000	000 = C0	ode DP1 2 010	fmt = D 3 011	100	101	110	function 7 111
fm fur bits 5 0	t = D	bits 20 0 000 ADD	0pc = C0 1 001 SUB	ode DP1 2 010 MUL	fmt = D 3 011 DIV	100 SQRT ROUND.	101 ABS	110 MOV	function 7 111 NEG
fm fur bit: 5 0	t = D	bits 20 0 000 ADD ROUND.L	0pc = Cl 001 SUB TRUNC.L	ode DP1 2 010 MUL CEIL.L	fmt = D 3 011 DIV FLOOR.L	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W	function 7 111 NEG
fm fur bit: 5 0 1	t = D	bits 20 0 000 ADD ROUND.L	0pc = Cl 001 SUB TRUNC.L	ode DP1 2 010 MUL CEIL.L	fmt = D 3 011 DIV FLOOR.L	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W	function 7 111 NEG FLOOR.W
fm fur bit: 5 0 1 2 3	$t = D$ $\frac{1}{2}$ $\frac{1}{2$	bits 20 0 000 ADD ROUND.L *	0pc = Cl 1 001 SUB TRUNC.L *	ode DP1 2 010 MUL CEIL.L *	fmt = D 3 011 DIV FLOOR.L *	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W *	function 7 111 NEG FLOOR.W
fm fur bits 5 0 1 2 3 4	$t = D^{3}$	bits 20 0 000 ADD ROUND.L * CVT.S	0pc = Cl 3001 SUB TRUNC.L * *	ode DP1 2 010 MUL CEIL.L * *	fmt = D 3 011 DIV FLOOR.L * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W * CVT.L	110 MOV CEIL.W * *	function 7 111 NEG FLOOR.W
fm fur bit: 5 0 1 2 3 4 5	$t = D^{3}$	bits 20 0 000 ADD ROUND.L * CVT.S *	opc = CI 1 001 SUB TRUNC.L * *	ode DP1 2 010 MUL CEIL.L * * * C.EQ α	fmt = D 3 011 DIV FLOOR.L * * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W * CVT.L *	110 MOV CEIL.W * *	function 7 111 NEG FLOOR.W

Instruction Subsets of MIPS III and MIPS IV Processors



fmt = W	or L	opc = C	code OP1 =	fmt = W, L				function
function	bits 20		I					
bits	0	1	2	3	4	5	6	7
53	000	001	010	011	100	101	110	111
0 000	*	*	*	*	*	*	*	*
1 001	*	*	*	*	*	*	*	*
2 010	*	*	*	*	*	*	*	*
3 011	*	*	*	*	*	*	*	*
4 100	CVT.S	CVT.D	*	*	*	*	*	*
5 101	*	*	*	*	*	*	*	*
6 110 7 111	*	*	*	*	*	*	*	*
opcode] bits 2826	, L	code	3	Δ	5	6	7
bits	0	1	2	3	4	5	6	7
3129 0 000	000 SPECIAL δ,	001	010	011	100	101	110	111
1 001 2 010 3 011		COP1 δ		COP1X &	δ,λ	С		
4 100 5 101 6 110		LWC1 SWC1				LDC1 SDC1		
4 100 5 101 6 110 7 111 <u>fmt</u> bits	bits 2321	SWC1	26 25 code COP1	fmt 3	4	SDC1	6	7
4 100 5 101 6 110 7 111 fmt bits 2524	0 000	SWC1 31 0pc = C 1 001	2 010	fmt	100	5 101	110	7 111 *
4 100 5 101 6 110 7 111 fmt bits 2524 0 00	0 000 MFC1	SWC1	2 2 2 2 2 2	fmt 3 011		SDC1		111
4 100 5 101 6 110 7 111 fmt bits 2524	0 000	SWC1 31 000 1 001 0MFC1	2 010 CFC1	fmt 3 011 *	100 MTC1	5 101 DMTC1	110 CTC1	111 *

RENESAS FPU Instructions Encoding

Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.

0

Instructions encoded by the function field when opcode=COP1 and fmt = S, D, W, or L

	coding t = <i>S</i>	y when	31 opc = C		21 fmt = S				0 function								
fur	nction	bits 20															
bit	S	0	1	2	3	4	5	6	7								
5	3	000	001	010	011	100	101	110	111								
0	000	ADD	SUB	MUL	DIV	SQRT	ABS	MOV	NEG								
1	001	ROUND.L	TRUNC.L	CEIL.L	FLOOR.L	ROUND. W	TRUNC.W	CEIL.W	FLOOR.W								
2	010	*	MOVCF δ	MOVZ	MOVN	*	RECIP	RSQRT									
3	011	*	*	*	*	*	*	*	*								
4	100	*	CVT.D	*	*	CVT.W	CVT.L	*	*								
5	101	*	*	*	*	*	*	*	*								
6	110	C.F α	C.UN a	C.EQ α	C.UEQ α	C.OLT a	C.ULT α	C.OLE α	C.ULE a								
7	111	C.SF α	C.NGLE α	C.SEQ α	C.NGL α	C.LT α	C.NGE α	C.LE α	C.NGT α								
en	مطابعه																
0.1	coainc	y when	31	20 25	21				U								
	t = D	y when	орс	ode	fmt = D				U function								
fm		_	орс	ode	fmt				-								
fm	t = D	_	орс	ode	fmt	4	5	6	-								
fm fur	t = D nction s	bits 20	opc = C	ode OP1	fmt = D	4 100	5 101	6 110	function								
fm fur bit	t = D nction s] bits 20 0	opc = C	ode OP1 2	fmt = D	•		-	function 7								
fm fur bits 5	t = D nction s 3	bits 20 0 000	000 = C1 001	ode OP1 2 010	fmt = D 3 011	100	101	110	function 7 111								
fm fur bits 5 0	t = D	bits 20 0 000 ADD	000 = Cl 001 SUB	ode OP1 2 010 MUL	fmt = D 3 011 DIV	100 SQRT ROUND.	101 ABS	110 MOV	function 7 111 NEG								
fm fur bit: 5 0	t = D nction s 3 000 001	bits 20 0 000 ADD ROUND.L	0pc = Cu 001 SUB TRUNC.L	ode OP1 2 010 MUL CEIL.L	fmt = D 3 011 DIV FLOOR.L	100 SQRT ROUND. W	101 ABS TRUNC.W	110 MOV CEIL.W	function 7 111 NEG								
fm fur bit: 5 0 1	t = D nction s 3 000 001 010	bits 20 0 000 ADD ROUND.L	opc = CI 001 SUB TRUNC.L MOVCF δ	ode OP1 2 010 MUL CEIL.L MOVZ	fmt = D 3 011 DIV FLOOR.L MOVN	100 SQRT ROUND. W	101 ABS TRUNC.W RECIP	110 MOV CEIL.W RSQRT	function 7 111 NEG FLOOR.W								
fm fur bit: 5 0 1 2 3	t = D $ration$ s 000 001 010 011	bits 20 0 000 ADD ROUND.L *	opc = Cl 001 SUB TRUNC.L MOVCF δ	ode OP1 2 010 MUL CEIL.L MOVZ	fmt = D 3 011 DIV FLOOR.L MOVN	100 SQRT ROUND. W	101 ABS TRUNC.W RECIP	110 MOV CEIL.W RSQRT	function 7 111 NEG FLOOR.W								
fm [*] fur bits 5 0 1 2 3 4	$t = D^{-1}$	bits 20 0 000 ADD ROUND.L * CVT.S	0pc = Cu 1 001 SUB TRUNC.L MOVCF δ *	ode OP1 2 010 MUL CEIL.L MOVZ *	fmt = D 3 011 DIV FLOOR.L MOVN * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W RECIP * CVT.L	110 MOV CEIL.W RSQRT	function 7 111 NEG FLOOR.W								
fm fur bit: 5 0 1 2 3 4 5	t = D action s 000 001 010 011 100 101	bits 20 0 000 ADD ROUND.L * CVT.S *	0pc = Cl 001 SUB TRUNC.L MOVCF δ * *	ode OP1 2 010 MUL CEIL.L MOVZ * * C.EQ α	fmt = D 3 011 DIV FLOOR.L MOVN * *	100 SQRT ROUND. W * CVT.W	101 ABS TRUNC.W RECIP * CVT.L *	110 MOV CEIL.W RSQRT * *	function 7 111 NEG FLOOR.W								

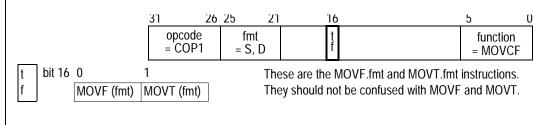


	coding t = W	y when or <i>L</i>		3 I opc = C(26 ode OP1	25 fn = W						U function
fur	nction	bits 20	L									
bit	s	0	1		2	3	3	4		5	6	7
5	3	000	001		010	C)11	100		101	110	111
0	000	*		*	*		*		*	*	*	*
1	001	*		*	*		*		*	*	*	*
2	010	*		*	*		*		*	*	*	*
3	011	*		*	*		*		*	*	*	*
4	100	CVT.S	CVT	.D	*		*	*		*	*	*
5	101	*		*	*		*		*	*	*	*
6	110	*		*	*		*		*	*	*	*
7	111	*		*	*		*		*	*	*	*

Instructions encoded by the **function** field when opcode=*COP1X*.

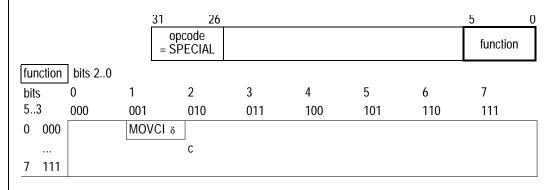
			31	26				_	5 0
				code DP1X					function
fur	nction	bits 20						_	
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	LWXC1	LDXC1	*	*	*	*	*	*
1	001	SWXC1	SDXC1	*	*	*	*	*	PREFX
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	MADD.S	MADD.D	*	*	*	*	*	*
5	101	MSUB.S	MSUB.D	*	*	*	*	*	*
6	110	NMADD.S	NMADD.D	*	*	*	*	*	*
7	111	NMSUB.S	NMSUB.D	*	*	*	*	*	*

Instructions encoded by the tf field when opcode=*COP1*, fmt = *S* or *D*, and function=*MOVCF*.

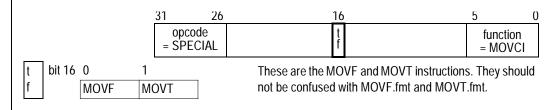




Instruction class encoded by the function field when opcode=SPECIAL.

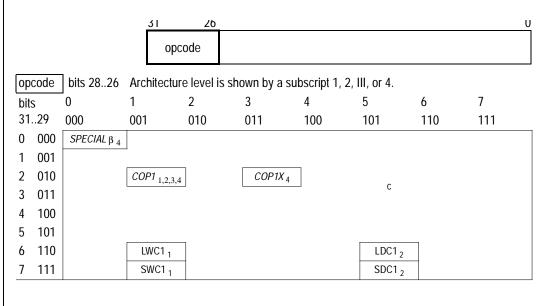


Instructions encoded by the tf field when opcode = SPECIAL and function=MOVCI.



The architecture level in which each MIPS IVencoding was defined is indicated by a subscript 1, 2, 3, or 4 (for architecture level I, II, III, or IV). If an instruction or instruction class was later extended, the extending level is indicated after the defining level.

Instructions encoded by the opcode field.



Instruction Subsets of MIPS III and MIPS IV Processors



			31	26 25	21				U
			code OP1	fmt					
fm	t	bits 2321	Architecture	e level is sho	own by a su	oscript 1, 2, 3	3, or 4.		
bit	S	0	1	2	3	4	5	6	7
25	24	000	001	010	011	100	101	110	111
0	00	MFC1 1	DMFC1 3	CFC1 ₁	* 1	MTC1 ₁	DMTC1 3	CTC1 ₁	* 1
1	01	BC 1,2,4	*1	*1	*1	* 1	*1	*1	*1
2	10	S 1,2,3,4	D 1,2,3,4	*1	*1	W 1,2,3,4	L 3,4	*1	*1
3	11	* 1	* 1	* 1	*1	*1	*1	*1	*1

Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.

31 26	25 21	<u>17 16</u>	0
opcode = COP1	fmt = BC	n t d f	

	t f	bit 16	Architecture
n		0	1
d	0		BC1T 1, 4
bit 1	17 1	BC1FL _{2, 4}	BC1TL 2, 4

Architecture level is shown by a subscript 1, 2, 3, or 4.

Instructions encoded by the **function** field when opcode=COP1 and fmt = S, D, W, or L

encoding when fmt = *S*

31 26	25 21	U
opcode = COP1	fmt = S	function

fur	nction	bits 20	Architecture	e level is sh	own by a su	bscript 1, 2, 3	8, or 4.		
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	ADD 1	SUB 1	MUL ₁	DIV 1	SQRT 2	ABS ₁	MOV ₁	NEG ₁
1	001	ROUND.L	TRUNC.L	CEIL.L 3	FLOOR.L	ROUND.W	TRUNC.W	CEIL.W 2	FLOOR.W
•		3	3	02.2.2.3	3	2	2	2	2
2	010	* 1	MOVCF ₄	MOVZ 4	MOVN ₄	* 1	RECIP ₄	RSQRT ₄	* 1
3	011	*1	*1	*1	*1	*1	*1	*1	*1
4	100	* 1	CVT.D _{1, 3}	*1	*1	CVT.W ₁	CVT.L ₃	*1	*1
5	101	*1	*1	*1	*1	*1	*1	*1	*1
6	110	C.F _{1, 4}		C.EQ _{1, 4}	C.UEQ _{1, 4}		C.ULT _{1, 4}	C.OLE 1, 4	C.ULE 1, 4
7	111	C.SF _{1, 4}	C.NGLE _{1,}	C.SEQ _{1, 4}	C.NGL _{1, 4}	C.LT _{1, 4}	C.NGE _{1, 4}	C.LE _{1, 4}	C.NGT _{1, 4}
			4	, ,	, ,				

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1

* 1



en	codinc	y when	31	26 25	21				U
	t = D		opc = Co	ode OP1	fmt = D				function
fur	nction	bits 20	Architecture	e level is sho	own by a sul	bscript 1, 2, 3	3, or 4.		
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	ADD 1	SUB 1	MUL ₁	DIV ₁	SQRT 2	ABS ₁	MOV ₁	NEG ₁
1	001	ROUND.L	TRUNC.L	CEIL.L 3	FLOOR.L	ROUND.W	TRUNC.W	CEIL.W 2	FLOOR.W
		3	3		3	2	2	-	2
2	010	* 1			MOVN ₄	* 1	RECIP ₄	RSQRT ₄	
3	011	* 1	*1	*1	*1	*1	* 1	*1	* 1
4	100	CVT.S _{1, 3}	*1	*1	* 1	CVT.W ₁	CVT.L ₃	*1	*1
5	101	*1	*1	*1	* 1	*1	*1	*1	*1
6	110	C.F _{1, 4}	C.UN _{1, 4}	C.EQ _{1, 4}	C.UEQ 1, 4	C.OLT _{1, 4}	C.ULT _{1, 4}	C.OLE 1, 4	C.ULE 1, 4
7	111	C.SF _{1, 4}	C.NGLE _{1,} 4	C.SEQ _{1, 4}	C.NGL _{1, 4}	C.LT _{1, 4}	C.NGE _{1, 4}	C.LE _{1, 4}	C.NGT _{1, 4}
en	codinc	y when	31	26 25	21				U
	t = W		opc = C		fmt W, L				function
fur	nction	bits 20	Architecture	e level is she	own by a su	bscript 1, 2, 3	3, or 4.		
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	* 1	* 1	* 1	* 1	* 1	*1	*1	*1
1	001	* 1	* 1	* 1	* 1	* 1	* 1	* 1	*1
n	010	*	*	*	*	*	*	*	*

* 1

* 1

* 1

* 1

* 1

* 1_

* 1

* 1

* 1

* 1

* 1

CVT.S 1, 3 CVT.D 1, 3

* 1

* 1

* 1

* 1

* 1

1 2 010

3 011

4 100

5 101

6 110

7 111

* 1

* 1

* 1

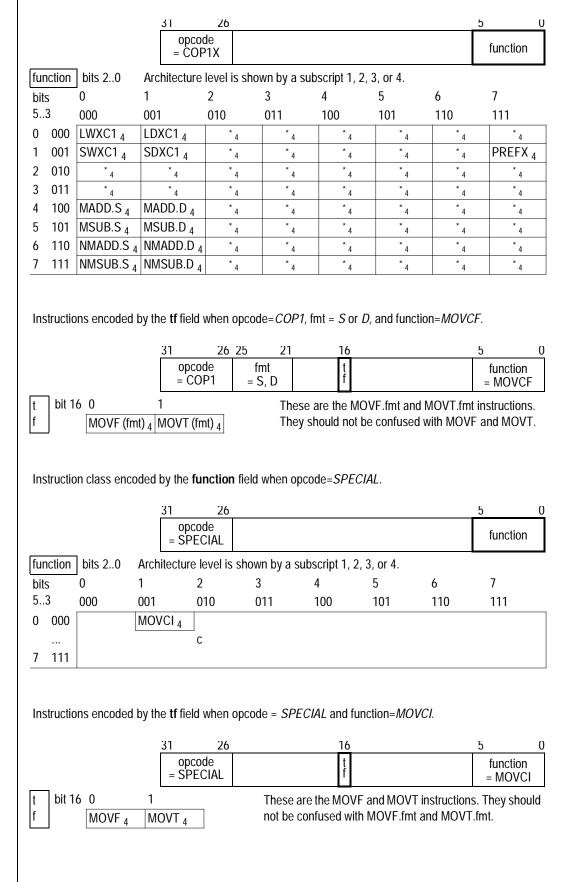
* 1

* 1

* 1



Instructions encoded by the function field when opcode=COP1X.



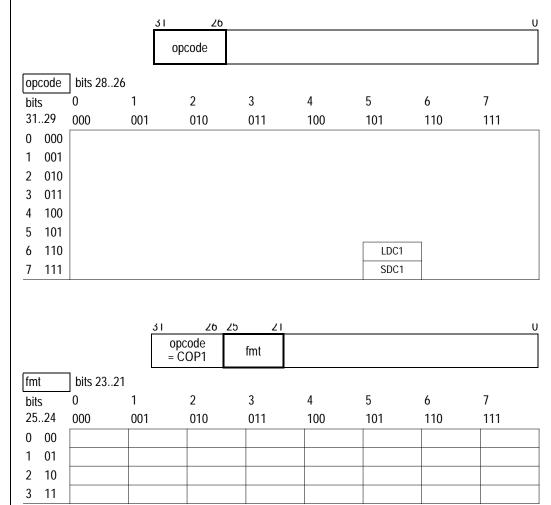
Instruction Subsets of MIPS III and MIPS IV Processors

An instruction encoding is shown if the instruction is added or extended in this architecture revision. An instruction class, like COP1, is shown if the instruction class is added in this architecture revision.

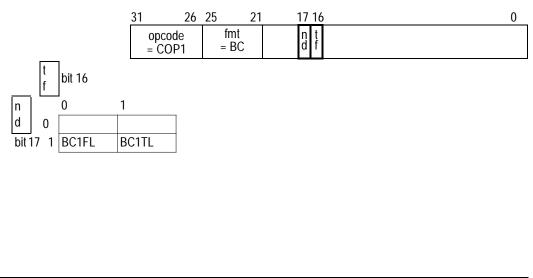
Instructions encoded by the **opcode** field.

RENESAS

FPU Instructions Encoding



Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.



Instruction Subsets of MIPS III and MIPS IV Processors

RENESAS FPU Instructions Encoding

encod	ing when	31	26 Z				- F	
fmt =		-	opcode = COP1	fmt = S				function
functio	on bits 20							
bits	0	1	2	3	4	5	6	7
53	000	001	010	011	100	101	110	111
0 00					SQRT			
1 00	1				ROUND. W	TRUNC.W	CEIL.W	FLOOR.
2 01	0							
3 01	1							
4 10	0							
5 10	1							
6 11	0							
0 1	-							
7 11	1	31	20 2	25 21				
7 11	1 ing when	<u>31</u>	26 z opcode = COP1	25 21 fmt = D				function
7 11 encod	1 ing when D		opcode	fmt				function
7 11 encod fmt = functio bits	1 ing when D		opcode	fmt	4	5	6	function 7
7 11 encod fmt = function bits 53	1 ing when D bits 20 0 000	=	opcode = COP1	fmt = D	100	5 101	6 110	
7 11 encod fmt = functio bits	1 ing when D bits 20 0 000	1	opcode = COP1 2	fmt = D 3	100 SQRT			7
7 11 encod fmt = function bits 53 0 00 1 00	1 ing when D bits 20 0 000 0 1	1	opcode = COP1 2	fmt = D 3	100		110	7 111
7 11 encod fmt = functio bits 53 0 00 1 00 2 01	1 ing when D bits 20 0 000 11 0	1	opcode = COP1 2	fmt = D 3	100 SQRT ROUND.	101	110	7 111
7 11 encod fmt = function function bits 53 0 00 1 00 2 01 3 01	1 ing when D bits 20 0 000 0 1 1 0 1	1	opcode = COP1 2	fmt = D 3	100 SQRT ROUND.	101	110	7 111
7 11 encod fmt = function function bits 53 0 00 1 00 2 01 3 01 4 10	1 ing when D bits 20 0 000 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0	1	opcode = COP1 2	fmt = D 3	100 SQRT ROUND.	101	110	7 111
7 11 encod fmt = function fmt = function fmt = function fmt = function fmt = fmt = fmt = <	1 ing when D bits 20 0 000 0 1 1 0 1 0 1 0 1 1 0 1 1	1	opcode = COP1 2	fmt = D 3	100 SQRT ROUND.	101	110	7 111
7 11 encod fmt = function function bits 53 0 00 1 00 2 01 3 01 4 10	1 ing when D bits 20 0 000 0 1 1 0 1 0 1 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0	1	opcode = COP1 2	fmt = D 3	100 SQRT ROUND.	101	110	7

Instructions encoded by the **function** field when opcode=COP1 and fmt = S, D, or W



en	codinc	y when		31 26	25 21				U
	t = W			opcode = COP1	fmt = W				function
fur	nction	bits 20							
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000								
1	001								
2	010								
3	011								
4	100								
5	101								
6	110								
7	111								

An instruction encoding is shown if the instruction is added or extended in this architecture revision. An instruction class, like COP1, is shown if the instruction class is added in this architecture revision.

Instructions encoded by the opcode field.

			31	26						U
				opcode						
ор	code	bits 28	26							
bit	S	0	1	2	3	4	5	6	7	
31	29	000	001	010	011	100	101	110	111	
0	000									
1	001									
2	010									
3	011									
4	100									
5	101									
6	110									
7	111									

Instructions encoded by the **fmt** field when opcode=*COP1*.

			31	26	25	21						U
			opo = C	ode OP1	fm							
fmt	bits 2321											
bits	0	1		2	3		4	!	5	6	7	
2524	000	001		010	01	1	100		101	110	111	
0 00		DI	MFC1						DMTC1			
1 01												
2 10									<i>L</i> δ			
3 11												
3 11												



RENESAS FPU Instructions Encoding

Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.

	31 26 25	21 <u>17 16</u>	0
	$\begin{array}{ c c } \hline opcode & fmt \\ = COP1 & = BC \end{array}$	n t d f	
	= COPI - BC	ŭ	
t f bit 16			
n 0 1			
d 0			
bit 17 1 BC1FL E	BC1TL		

Instructions encoded by the **function** field when opcode=COP1 and fmt = S, *D*, or *L*.

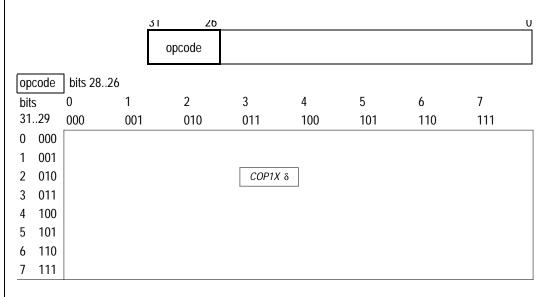
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		coding t = <i>S</i>	j when	31 opc = C	26 25 code OP1	21 fmt = S				U function
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	fur	nction	bits 20							
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	bit	S	0	1	2	3	4	5	6	7
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	5	3	000	001	010	011	100	101	110	111
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	0	000								
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1	001	ROUND.L	TRUNC.L	CEIL.L	FLOOR.L				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $		010								
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	3									
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $								CVT.L		
7 111 Image: style sty										
and the second symbol of the										
encoding withing opcode = COP1 fmt = D function function bits 20 60 1 2 3 4 5 6 7 bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 1 2 3 4 5 6 7 1 001 ROUND.L TRUNC.L CEIL.L FLOOR.L 1 1 1 2 010 1 1 1 1 1 1 1 3 011 1 1 1 1 1 1 1 4 100 1	7	111								
encoding withing opcode = COP1 fmt = D function function bits 20 60 1 2 3 4 5 6 7 bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 1 2 3 4 5 6 7 1 001 ROUND.L TRUNC.L CEIL.L FLOOR.L 1 1 1 2 010 1 1 1 1 1 1 1 3 011 1 1 1 1 1 1 1 4 100 1										
Image: Definition is 20 function bits 20 bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 Image: Complex structure			j when		20 20	21				
bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 Image: Constraint of the stress of the strest of the stress of the stress of the strest of the st	Im			000	ahor	fmt			Ī	
bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 Image: Constraint of the stress of the strest of the stress of the stress of the strest of the st		l = D		opc = C	code OP1					
53 000 001 010 011 100 101 110 111 0 000 Image: Constraint of the state of	fur		bits 20	opo = C	code OP1					
1 001 ROUND.L TRUNC.L CEIL.L FLOOR.L 2 010 3 011 </td <td>_</td> <td>nction</td> <td></td> <td>= C</td> <td>OP1</td> <td>= D</td> <td>4</td> <td>5</td> <td>6</td> <td>function</td>	_	nction		= C	OP1	= D	4	5	6	function
2 010	bit	nction s	0	= C	OP1 2	= D 3				function 7
3 011	bit 5	nction s 3	0	= C	OP1 2	= D 3				function 7
4 100 CVT.L 5 101 CVT.L 6 110 CVT.L	bit: 5 0	nction s 3 000	0 000	1 001	0P1 2 010	= D 3 011				function 7
5 101 6 110	bit: 5 0 1	nction s 3 000 001	0 000	1 001	0P1 2 010	= D 3 011				function 7
6 110	bit: 5 0 1 2	nction s 3 000 001 010	0 000	1 001	0P1 2 010	= D 3 011				function 7
	bit: 5 0 1 2 3	nction s 3 000 001 010 011	0 000	1 001	0P1 2 010	= D 3 011		101		function 7
7 111	bit: 5 0 1 2 3 4	nction s 3 000 001 010 011 100	0 000	1 001	0P1 2 010	= D 3 011		101		function 7
	bit: 5 0 1 2 3 4 5	nction s 3 000 001 010 011 100 101	0 000	1 001	0P1 2 010	= D 3 011		101		function 7



en	codinc	ywhen		31	26	25	21						 U
	t = L	,		орс = С(ode OP1		fmt = L						function
fur	nction	bits 20											
bit	S	0	1		2		3	4		5		6	7
5	3	000	001		010		011	1	00	10	1	110	111
0	000	*		*	*		*		*		*	*	*
1	001	*		*	*		*		*		*	*	*
2	010	*		*	*		*		*		*	*	*
3	011	*		*	*		*		*		*	*	*
4	100	CVT.S	CVI	.D	*		*	*		*		*	*
5	101	*		*	*		*		*		*	*	*
6	110	*		*	*		*		*		*	*	*
7	111	*		*	*		*		*		*	*	*
			-									1	J

An instruction encoding is shown if the instruction is added or extended in this architecture revision. An instruction class, like COP1X, is shown if the instruction class is added in this architecture revision.

Instructions encoded by the opcode field.



Instructions encoded by the **fmt** field when opcode=*COP1*.

				31 26	25 21					U
				opcode = COP1	fmt					
fm	t	bits 2321								
bit		0	1	2	3	4	5	6	7	
25	24	000	001	010	011	100	101	110	111	
0	00									
1	01									
2	10									
3	11									
3	11									



Instructions encoded by the **nd** and **tf** fields when opcode=*COP1* and fmt=*BC*.

		31 26	25 21	<u>17 16</u>	0
		opcode = COP1	fmt = BC	n t d f	
t f	bit 16				
n	0	1			
d 0	BC1F	BC1T			
bit 17 1	BC1FL	BC1TL			
	•				

Table 6-15 (cont.)

Instructions encoded by the **function** field when opcode=*COP1* and fmt = *S*, *D*, *W*, or *L*.

$\begin{tabular}{ c c c c c c c c c c c c c c c c c c c$		coding t = <i>S</i>	j when	3 I opc = C	26 25 ode OP1	21 fmt = S				U function
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	fur	nction	bits 20							
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	bit	S	0	1	2	3	4	5	6	7
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	5	3	000	001	010	011	100	101	110	111
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	0	000								
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	1	001								
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	2	010		MOVCF δ	MOVZ	MOVN		RECIP	RSQRT	
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	3	011								
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	-									
7 111 C.SF C.NGLE C.SEQ C.NGL C.LT C.NGE C.LE C.NGT encoding when fmt = D 31 20 25 21 U U $0pcode$ fmt = COP1 = D function function function bits 20 bits 20 U function function bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 1 001 2 010 MOVCF δ MOVZ MOVN RECIP RSQRT 3 011 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>										
and the second of the second										
encoding within $0pcode = COP1$ fmt = D function function bits 20 60 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 000 010 011 100 101 110 111 0 000 000 010 011 100 101 110 111 0 0000 0000 0000	7	111	C.SF	C.NGLE	C.SEQ	C.NGL	C.LT	C.NGE	C.LE	C.NGT
bits 0 1 2 3 4 5 6 7 53 000 001 010 011 100 101 110 111 0 000 101 110 111 0 000										
53 000 001 010 011 100 101 110 111 0 000 010 011 100 101 110 111 0 000 010 011 100 101 110 111 1 001 010 011 100 101 110 111 2 010 MOVCF δ MOVZ MOVN RECIP RSQRT 101 3 011 0100 010 010 <t< td=""><td></td><td></td><td>y when</td><td>орс</td><td>ode</td><td>fmt</td><td></td><td></td><td></td><td></td></t<>			y when	орс	ode	fmt				
0 000 Image: Constraint of the constraint of	fm	t = D	_	орс	ode	fmt				
1 001 MOV MOV RECIP RSQRT 2 010 MOVCF δ MOVZ MOVN RECIP RSQRT 3 011 4 100 5 101 6 110 C.F C.UN C.EQ C.UEQ C.OLT C.ULT C.OLE C.ULE	fm fur	t = D	bits 20	opc = C	ode OP1	fmt = D	4	5	6	function
2 010 MOVCF δ MOVZ MOVN RECIP RSQRT 3 011	fm fur bit	t = D nction s] bits 20 0	opc = C	ode OP1 2	fmt = D	•			function 7
3 011	fm fur bit 5	t = D nction s 3] bits 20 0	opc = C	ode OP1 2	fmt = D	•			function 7
4 100	fm fur bit 5	t = D $nction$ s 3 000] bits 20 0	opc = C	ode OP1 2	fmt = D	•			function 7
5 101 C.F C.UN C.EQ C.UEQ C.OLT C.ULT C.OLE C.ULE	fm fur bit 5 0 1	t = D nction s 3 000 001] bits 20 0	0pc = C1 001	ode OP1 2 010	fmt = D 3 011	•	101	110	function 7
6 110 C.F C.UN C.EQ C.UEQ C.OLT C.ULT C.OLE C.ULE	fm fur bit 5 0 1 2	t = D nction s 3 000 001 010] bits 20 0	0pc = C1 001	ode OP1 2 010	fmt = D 3 011	•	101	110	function 7
	fm fur 5 0 1 2 3	t = D nction s 3 000 001 010 011] bits 20 0	0pc = C1 001	ode OP1 2 010	fmt = D 3 011	•	101	110	function 7
7 111 C.SF C.NGLE C.SEQ C.NGL C.LT C.NGE C.LE C.NGT	fm fur 5 0 1 2 3 4	t = D nction s 3 000 001 010 011 100] bits 20 0	0pc = Cl 001 MOVCF δ	ode OP1 2 010	fmt = D 3 011	•	101	110 RSQRT	function 7 111
	fm fur bit 5 0 1 2 3 4 5 6	t = D action s 3 000 001 010 011 100 101 110	bits 20 0 000 C.F	0pc = C 001 ΜΟVCF δ	ode OP1 2 010 MOVZ C.EQ	fmt = D 3 011 MOVN 6 	100 100 	101 RECIP	110 RSQRT	function 7 111

Instruction Subsets of MIPS III and MIPS IV Processors



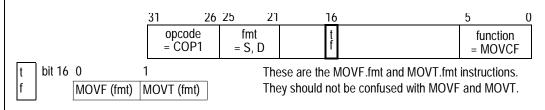
encoding when fmt = <i>W</i> or <i>L</i>				25 21				0	
			opcode = COP1	= W, L				function	
fur	nction	bits 20							
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000								
1	001								
2	010								
3	011								
4	100								
5	101								
6	110								
7	111								

Table 6-15 (cont.) FPU Instruction Encoding Changes - MIPS IV Revision.

Instructions encoded by the **function** field when opcode=*COP1X*.

			31	26					5 0
			opo = C0	code OP1X					function
fur	nction	bits 20							
bit	S	0	1	2	3	4	5	6	7
5	3	000	001	010	011	100	101	110	111
0	000	LWXC1	LDXC1	*	*	*	*	*	*
1	001	SWXC1	SDXC1	*	*	*	*	*	PREFX
2	010	*	*	*	*	*	*	*	*
3	011	*	*	*	*	*	*	*	*
4	100	MADD.S	MADD.D	*	*	*	*	*	*
5	101	MSUB.S	MSUB.D	*	*	*	*	*	*
6	110	NMADD.S	NMADD.D	*	*	*	*	*	*
7	111	NMSUB.S	NMSUB.D	*	*	*	*	*	*

Instructions encoded by the **tf** field when opcode=*COP1*, fmt = *S* or *D*, and function=*MOVCF*.





26 0 31 5 opcode function = SPECIAL function bits 2..0 1 2 3 4 5 6 7 bits 0 5..3 000 001 010 011 100 101 110 111 0 000 MOVCI 8 С . . . 7 111 Instructions encoded by the tf field when opcode = SPECIAL and function=MOVCI. 31 26 16 5 0 opcode function = SPECIAL = MOVCI bit 16 0 1 These are the MOVF and MOVT instructions. They should It not be confused with MOVF.fmt and MOVT.fmt. f MOVF MOVT Key to all FPU (CP1) instruction encoding tables: This opcode is reserved for future use. An attempt to execute it causes either a Reserved Instruction exception or a Floating Point Unimplemented Operation Exception. The choice of exception is implementation specific. The table shows 16 compare instructions with values named C.condition where α "condition" is a comparison condition such as "EQ". These encoding values are all documented in the instruction description titled "C.cond.fmt". ß The SPECIAL instruction class was defined in MIPS I for CPU instructions. An FPU instruction was first added to the instruction class in MIPS IV. δ (also italic opcode name) This opcode indicates an instruction class. The instruction word must be further decoded by examining additional tables that show values for another instruction field. λ The COP1X opcode in MIPS IV was the COP3 opcode in MIPS I and II and a reserved instruction in MIPS III. These opcodes are not FPU operations. For further information on them, look χ in the CPU Instruction Encoding information Chapter 3. (fmt) This opcode is a conditional move of formatted FP registers - either MOVF.D, MOVF.S, MOVT.D, or MOVT.S. It should not be confused with the similarlynamed MOVF or MOVT instruction that moves CPU registers.



Key to all FPU (CP1) instruction encoding tables:

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