



# **MIPS® Architecture for Programmers**

## **Volume II-B: The microMIPS32™**

### **Instruction Set**

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# About This Book

The MIPS® Architecture for Programmers Volume II-B: The microMIPS32™ Instruction Set comes as part of a multi-volume set.

- Volume I-A describes conventions used throughout the document set, and provides an introduction to the MIPS32® Architecture
- Volume I-B describes conventions used throughout the document set, and provides an introduction to the microMIPS32™ Architecture
- Volume II-A provides detailed descriptions of each instruction in the MIPS32® instruction set
- Volume II-B provides detailed descriptions of each instruction in the microMIPS32™ instruction set
- Volume III describes the MIPS32® and microMIPS32™ Privileged Resource Architecture which defines and governs the behavior of the privileged resources included in a MIPS® processor implementation
- Volume IV-a describes the MIPS16e™ Application-Specific Extension to the MIPS32® Architecture. Beginning with Release 3 of the Architecture, microMIPS is the preferred solution for smaller code size.
- Volume IV-b describes the MDMX™ Application-Specific Extension to the MIPS64® Architecture and microMIPS64™. It is not applicable to the MIPS32® document set nor the microMIPS32™ document set. With Release 5 of the Architecture, MDMX is deprecated. MDMX and MSA can not be implemented at the same time.
- Volume IV-c describes the MIPS-3D® Application-Specific Extension to the MIPS® Architecture
- Volume IV-d describes the SmartMIPS® Application-Specific Extension to the MIPS32® Architecture and the microMIPS32™ Architecture .
- Volume IV-e describes the MIPS® DSP Module to the MIPS® Architecture
- Volume IV-f describes the MIPS® MT Module to the MIPS® Architecture
- Volume IV-h describes the MIPS® MCU Application-Specific Extension to the MIPS® Architecture
- Volume IV-i describes the MIPS® Virtualization Module to the MIPS® Architecture
- Volume IV-j describes the MIPS® SIMD Architecture Module to the MIPS® Architecture

## 1.1 Typographical Conventions

This section describes the use of *italic*, **bold** and `courier` fonts in this book.

### 1.1.1 Italic Text

- is used for *emphasis*
- is used for *bits*, *fields*, *registers*, that are important from a software perspective (for instance, address bits used by software, and programmable fields and registers), and various *floating point instruction formats*, such as *S*, *D*, and *PS*
- is used for the memory access types, such as *cached* and *uncached*

### 1.1.2 Bold Text

- represents a term that is being **defined**
- is used for **bits** and **fields** that are important from a hardware perspective (for instance, **register** bits, which are not programmable but accessible only to hardware)
- is used for ranges of numbers; the range is indicated by an ellipsis. For instance, **5..1** indicates numbers 5 through 1
- is used to emphasize **UNPREDICTABLE** and **UNDEFINED** behavior, as defined below.

### 1.1.3 Courier Text

Courier fixed-width font is used for text that is displayed on the screen, and for examples of code and instruction pseudocode.

## 1.2 UNPREDICTABLE and UNDEFINED

The terms **UNPREDICTABLE** and **UNDEFINED** are used throughout this book to describe the behavior of the processor in certain cases. **UNDEFINED** behavior or operations can occur only as the result of executing instructions in a privileged mode (i.e., in Kernel Mode or Debug Mode, or with the CP0 usable bit set in the Status register). Unprivileged software can never cause **UNDEFINED** behavior or operations. Conversely, both privileged and unprivileged software can cause **UNPREDICTABLE** results or operations.

### 1.2.1 UNPREDICTABLE

**UNPREDICTABLE** results may vary from processor implementation to implementation, instruction to instruction, or as a function of time on the same implementation or instruction. Software can never depend on results that are **UNPREDICTABLE**. **UNPREDICTABLE** operations may cause a result to be generated or not. If a result is generated, it is **UNPREDICTABLE**. **UNPREDICTABLE** operations may cause arbitrary exceptions.

**UNPREDICTABLE** results or operations have several implementation restrictions:

- Implementations of operations generating **UNPREDICTABLE** results must not depend on any data source (memory or internal state) which is inaccessible in the current processor mode
- **UNPREDICTABLE** operations must not read, write, or modify the contents of memory or internal state which is inaccessible in the current processor mode. For example, **UNPREDICTABLE** operations executed in user mode must not access memory or internal state that is only accessible in Kernel Mode or Debug Mode or in another process

- **UNPREDICTABLE** operations must not halt or hang the processor

### 1.2.2 UNDEFINED

**UNDEFINED** operations or behavior may vary from processor implementation to implementation, instruction to instruction, or as a function of time on the same implementation or instruction. **UNDEFINED** operations or behavior may vary from nothing to creating an environment in which execution can no longer continue. **UNDEFINED** operations or behavior may cause data loss.

**UNDEFINED** operations or behavior has one implementation restriction:

- **UNDEFINED** operations or behavior must not cause the processor to hang (that is, enter a state from which there is no exit other than powering down the processor). The assertion of any of the reset signals must restore the processor to an operational state

### 1.2.3 UNSTABLE

**UNSTABLE** results or values may vary as a function of time on the same implementation or instruction. Unlike **UNPREDICTABLE** values, software may depend on the fact that a sampling of an **UNSTABLE** value results in a legal transient value that was correct at some point in time prior to the sampling.

**UNSTABLE** values have one implementation restriction:

- Implementations of operations generating **UNSTABLE** results must not depend on any data source (memory or internal state) which is inaccessible in the current processor mode

## 1.3 Special Symbols in Pseudocode Notation

In this book, algorithmic descriptions of an operation are described as pseudocode in a high-level language notation resembling Pascal. Special symbols used in the pseudocode notation are listed in [Table 1.1](#).

**Table 1.1 Symbols Used in Instruction Operation Statements**

Symbol	Meaning
$\leftarrow$	Assignment
$=, \neq$	Tests for equality and inequality
$\parallel$	Bit string concatenation
$x^y$	A $y$ -bit string formed by $y$ copies of the single-bit value $x$
$b\#n$	A constant value $n$ in base $b$ . For instance 10#100 represents the decimal value 100, 2#100 represents the binary value 100 (decimal 4), and 16#100 represents the hexadecimal value 100 (decimal 256). If the "b#" prefix is omitted, the default base is 10.
0bn	A constant value $n$ in base 2. For instance 0b100 represents the binary value 100 (decimal 4).
0xn	A constant value $n$ in base 16. For instance 0x100 represents the hexadecimal value 100 (decimal 256).
$x_{y..z}$	Selection of bits $y$ through $z$ of bit string $x$ . Little-endian bit notation (rightmost bit is 0) is used. If $y$ is less than $z$ , this expression is an empty (zero length) bit string.
$+, -$	2's complement or floating point arithmetic: addition, subtraction

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**Table 1.1 Symbols Used in Instruction Operation Statements (Continued)**

Symbol	Meaning
$\ast, \times$	2's complement or floating point multiplication (both used for either)
div	2's complement integer division
mod	2's complement modulo
/	Floating point division
<	2's complement less-than comparison
>	2's complement greater-than comparison
$\leq$	2's complement less-than or equal comparison
$\geq$	2's complement greater-than or equal comparison
nor	Bitwise logical NOR
xor	Bitwise logical XOR
and	Bitwise logical AND
or	Bitwise logical OR
not	Bitwise inversion
$\&\&$	Logical (non-Bitwise) AND
$\ll$	Logical Shift left (shift in zeros at right-hand-side)
$\gg$	Logical Shift right (shift in zeros at left-hand-side)
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. In Release 2 of the Architecture, $GPR[x]$ is a short-hand notation for $SGPR[SRSCtl_{CSS}, x]$ .
$SGPR[s,x]$	In Release 2 of the Architecture and subsequent releases, multiple copies of the CPU general-purpose registers may be implemented. $SGPR[s,x]$ refers to GPR set $s$ , register $x$ .
$FPR[x]$	Floating Point operand register $x$
$FCC[CC]$	Floating Point condition code CC. $FCC[0]$ has the same value as $COC[1]$ .
$FPR[x]$	Floating Point (Coprocessor unit 1), general register $x$
$CPR[z,x,s]$	Coprocessor unit $z$ , general register $x$ , select $s$
$CP2CPR[x]$	Coprocessor unit 2, general register $x$
$CCR[z,x]$	Coprocessor unit $z$ , control register $x$
$CP2CCR[x]$	Coprocessor unit 2, control register $x$
$COC[z]$	Coprocessor unit $z$ condition signal
$Xlat[x]$	Translation of the MIPS16e GPR number $x$ into the corresponding 32-bit GPR number
BigEndianMem	Endian mode as configured at chip reset (0 → Little-Endian, 1 → Big-Endian). Specifies the endianness of the memory interface (see LoadMemory and StoreMemory pseudocode function descriptions), and the endianness of Kernel and Supervisor mode execution.
BigEndianCPU	The endianness for load and store instructions (0 → Little-Endian, 1 → Big-Endian). In User mode, this endianness may be switched by setting the $RE$ bit in the $Status$ register. Thus, BigEndianCPU may be computed as ( $BigEndianMem \text{ XOR } ReverseEndian$ ).
ReverseEndian	Signal to reverse the endianness of load and store instructions. This feature is available in User mode only, and is implemented by setting the $RE$ bit of the $Status$ register. Thus, ReverseEndian may be computed as ( $SR_{RE}$ and User mode).

**Table 1.1 Symbols Used in Instruction Operation Statements (Continued)**

Symbol	Meaning						
<i>LLbit</i>	Bit of <b>virtual</b> state used to specify operation for instructions that provide atomic read-modify-write. <i>LLbit</i> is set when a linked load occurs and is tested 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.						
<b>I:</b> , <b>I+n:</b> , <b>I-n:</b>	This occurs as a prefix to <i>Operation</i> description lines and functions as a label. It indicates the instruction time during which the pseudocode appears to “execute.” 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 <b>I</b> . Sometimes effects of an instruction appear to occur either earlier or later — that is, during the instruction time of another instruction. When this happens, the instruction operation is written in sections labeled with the instruction time, relative to the current instruction <b>I</b> , 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 has the portion of the instruction operation description that writes the result register in a section labeled <b>I+1</b> . The effect of pseudocode statements for the current instruction labelled <b>I+1</b> appears to occur “at the same time” as the effect of pseudocode statements labeled <b>I</b> for the following instruction. Within one pseudocode sequence, the effects of the statements take place in order. However, between sequences of statements for different instructions that occur “at the same time,” there is no defined order. Programs must not depend on a particular order of evaluation between such sections.						
<b>PC</b>	The <i>Program Counter</i> 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 <b>PC</b> during an instruction time. If no value is assigned to <b>PC</b> during an instruction time by any pseudocode statement, it is automatically incremented by either 2 (in the case of a 16-bit MIPS16e instruction) or 4 before the next instruction time. A taken branch assigns the target address to the <b>PC</b> during the instruction time of the instruction in the branch delay slot. In the MIPS Architecture, the PC value is only visible indirectly, such as when the processor stores the restart address into a GPR on a jump-and-link or branch-and-link instruction, or into a Coprocessor 0 register on an exception. The PC value contains a full 32-bit address all of which are significant during a memory reference.						
<b>ISA Mode</b>	In processors that implement the MIPS16e Application Specific Extension or the microMIPS base architectures, the <i>ISA Mode</i> is a single-bit register that determines in which mode the processor is executing, as follows: <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>Encoding</th> <th>Meaning</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>The processor is executing 32-bit MIPS instructions</td> </tr> <tr> <td>1</td> <td>The processor is executing MIIPS16e or microMIPS instructions</td> </tr> </tbody> </table> In the MIPS Architecture, the ISA Mode value is only visible indirectly, such as when the processor stores a combined value of the upper bits of PC and the ISA Mode into a GPR on a jump-and-link or branch-and-link instruction, or into a Coprocessor 0 register on an exception.	Encoding	Meaning	0	The processor is executing 32-bit MIPS instructions	1	The processor is executing MIIPS16e or microMIPS instructions
Encoding	Meaning						
0	The processor is executing 32-bit MIPS instructions						
1	The processor is executing MIIPS16e or microMIPS instructions						
<b>PABITS</b>	The number of physical address bits implemented is represented by the symbol <b>PABITS</b> . As such, if 36 physical address bits were implemented, the size of the physical address space would be $2^{\text{PABITS}} = 2^{36}$ bytes.						
<b>FP32RegistersMode</b>	Indicates whether the FPU has 32-bit or 64-bit floating point registers (FPRs). It is optional if the FPU has 32 64-bit FPRs in which 64-bit data types are stored in any FPR.  microMIPS64 implementations have a compatibility mode in which the processor references the FPRs as if it were a microMIPS32 implementation. In such a case <b>FP32RegisterMode</b> is computed from the FR bit in the <i>Status</i> register. If this bit is a 0, the processor operates as if it had 32 32-bit FPRs. If this bit is a 1, the processor operates with 32 64-bit FPRs. The value of <b>FP32RegistersMode</b> is computed from the FR bit in the <i>Status</i> register.						

**Table 1.1 Symbols Used in Instruction Operation Statements (Continued)**

Symbol	Meaning
InstructionInBranchDelaySlot	Indicates whether the instruction at the Program Counter address was executed in the delay slot of a branch or jump. This condition reflects the <i>dynamic</i> state of the instruction, not the <i>static</i> state. That is, the value is false if a branch or jump occurs to an instruction whose PC immediately follows a branch or jump, but which is not executed in the delay slot of a branch or jump.
SignalException(exception, argument)	Causes an exception to be signaled, using the exception parameter as the type of exception and the argument parameter as an exception-specific argument). Control does not return from this pseudocode function—the exception is signaled at the point of the call.

## 1.4 For More Information

Various MIPS RISC processor manuals and additional information about MIPS products can be found at the MIPS URL: <http://www.mips.com>

For comments or questions on the MIPS32® Architecture or this document, send Email to [support@mips.com](mailto:support@mips.com).

## Guide to the Instruction Set

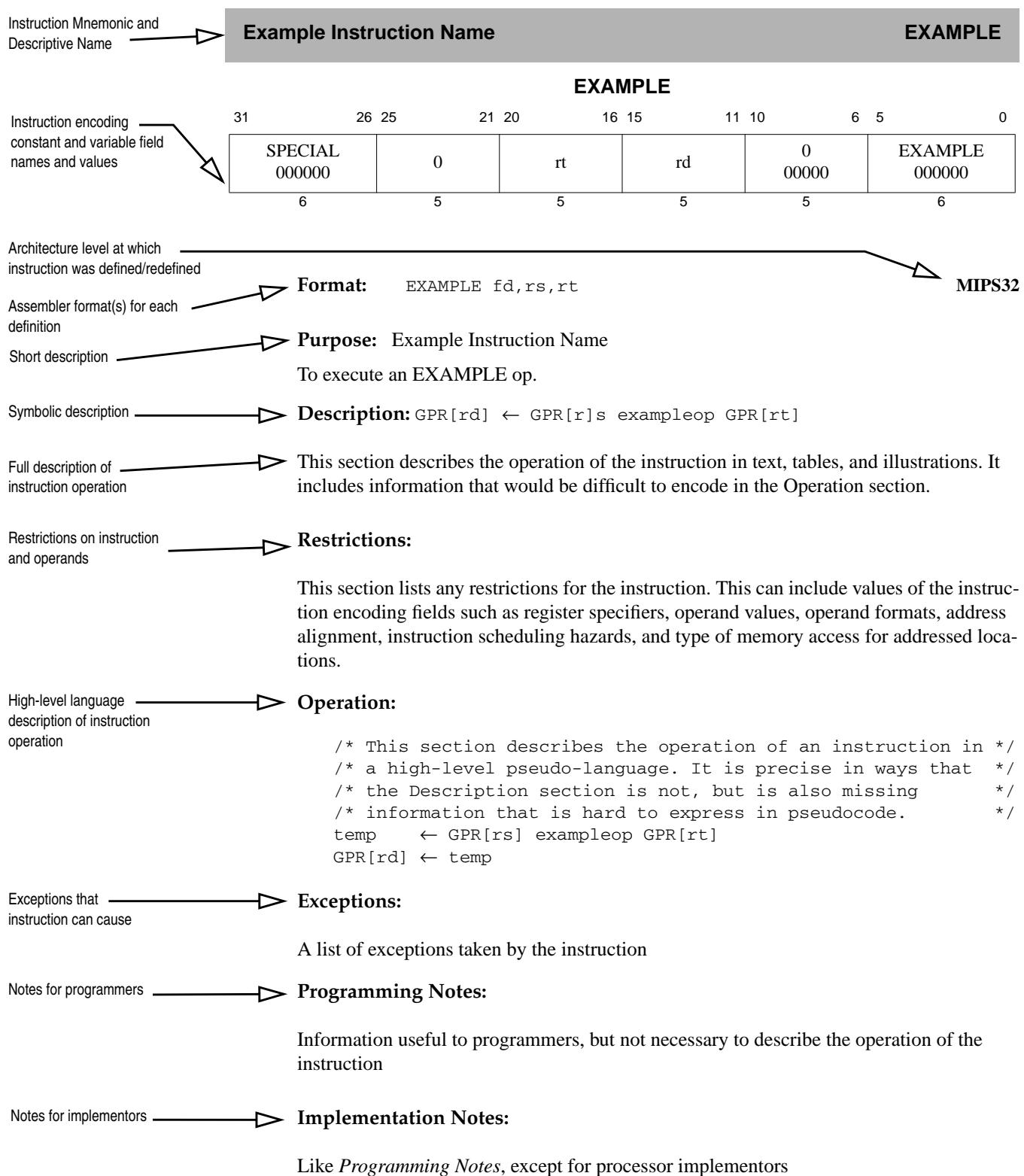
This chapter provides a detailed guide to understanding the instruction descriptions, which are listed in alphabetical order in the tables at the beginning of the next chapter.

### 2.1 Understanding the Instruction Fields

Figure 2.1 shows an example instruction. Following the figure are descriptions of the fields listed below:

- “Instruction Fields” on page 25
- “Instruction Descriptive Name and Mnemonic” on page 25
- “Format Field” on page 25
- “Purpose Field” on page 26
- “Description Field” on page 26
- “Restrictions Field” on page 26
- “Operation Field” on page 27
- “Exceptions Field” on page 27
- “Programming Notes and Implementation Notes Fields” on page 28

Figure 2.1 Example of Instruction Description



### 2.1.1 Instruction Fields

Fields encoding the instruction word are shown in register form at the top of the instruction description. The following rules are followed:

- The values of constant fields and the *opcode* names are listed in uppercase (SPECIAL and ADD in Figure 2.2). Constant values in a field are shown in binary below the symbolic or hexadecimal value.
- All variable fields are listed with the lowercase names used in the instruction description (*rs*, *rt*, and *rd* in Figure 2.2).
- Fields that contain zeros but are not named are unused fields that are required to be zero (bits 10:6 in Figure 2.2). If such fields are set to non-zero values, the operation of the processor is **UNPREDICTABLE**.

**Figure 2.2 Example of Instruction Fields**

31	26 25	21 20	16 15	11 10	6 5	0
SPECIAL 000000	rs	rt	rd	0 00000	ADD 100000	
6	5	5	5	5	6	

### 2.1.2 Instruction Descriptive Name and Mnemonic

The instruction descriptive name and mnemonic are printed as page headings for each instruction, as shown in Figure 2.3.

**Figure 2.3 Example of Instruction Descriptive Name and Mnemonic**

Add Word	ADD
----------	-----

### 2.1.3 Format Field

The assembler formats for the instruction and the architecture level at which the instruction was originally defined are given in the *Format* field. 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 their order of extension (for an example, see [C.cond.fmt](#)). 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.

**Figure 2.4 Example of Instruction Format**

<b>Format:</b>	ADD fd,rs,rt	MIPS32
----------------	--------------	--------

The assembler format is shown with literal parts of the assembler instruction printed in uppercase characters. The variable parts, the operands, are shown as the lowercase names of the appropriate fields. The architectural level at which the instruction was first defined, for example “MIPS32” is shown at the right side of the page.

There can be more than one assembler format for each architecture level. 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 lists both ADD.S and ADD.D.

The assembler format lines sometimes include parenthetical comments to help explain variations in the formats (once again, see C.cond(fmt)). These comments are not a part of the assembler format.

The term *decoded\_immediate* is used if the immediate field is encoded within the binary format but the assembler format uses the decoded value. The term *left\_shifted\_offset* is used if the offset field is encoded within the binary format but the assembler format uses value after the appropriate amount of left shifting.

### 2.1.4 Purpose Field

The *Purpose* field gives a short description of the use of the instruction.

**Figure 2.5 Example of Instruction Purpose**

**Purpose:** Add Word

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

### 2.1.5 Description Field

If a one-line symbolic description of the instruction is feasible, it appears 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.

**Figure 2.6 Example of Instruction Description**

**Description:** GPR[rd]  $\leftarrow$  GPR[rs] + GPR[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, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rd*.

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 /Status* register.

### 2.1.6 Restrictions Field

The *Restrictions* field documents any possible restrictions that may affect the instruction. Most restrictions fall into one of the following six categories:

- Valid values for instruction fields (for example, see floating point ADD.fmt)

- ALIGNMENT requirements for memory addresses (for example, see [LW](#))
- Valid values of operands (for example, see [ALNV.PS](#))
- Valid operand formats (for example, see floating point [ADD\(fmt\)](#))
- Order of instructions necessary to guarantee correct execution. These ordering constraints avoid pipeline hazards for which some processors do not have hardware interlocks (for example, see [MUL](#)).
- Valid memory access types (for example, see [LL/SC](#))

**Figure 2.7 Example of Instruction Restrictions****Restrictions:**

None

**2.1.7 Operation Field**

The *Operation* field describes the operation of the instruction as pseudocode in a high-level language notation resembling Pascal. 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 are omitted for legibility.

**Figure 2.8 Example of Instruction Operation****Operation:**

```

temp ← (GPR[rs]31||GPR[rs]31..0) + (GPR[rt]31||GPR[rt]31..0)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rd] ← temp
endif

```

See [2.2 “Operation Section Notation and Functions”](#) on page [28](#) for more information on the formal notation used here.

**2.1.8 Exceptions Field**

The *Exceptions* field lists the exceptions that can be caused by *Operation* of the instruction. It omits exceptions that can be caused by the instruction fetch, for instance, TLB Refill, and also omits exceptions that can be caused by asynchronous external events such as an Interrupt. Although a 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 dependent upon the implementation.

**Figure 2.9 Example of Instruction Exception**

**Exceptions:**

Integer Overflow

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

### 2.1.9 Programming Notes and Implementation Notes Fields

The *Notes* 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.

**Figure 2.10 Example of Instruction Programming Notes**

**Programming Notes:**

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

## 2.2 Operation Section Notation and Functions

In an instruction description, the *Operation* section uses a high-level language notation to describe the operation performed by each instruction. Special symbols used in the pseudocode are described in the previous chapter. Specific pseudocode functions are described below.

This section presents information about the following topics:

- “Instruction Execution Ordering” on page 28
- “Pseudocode Functions” on page 28

### 2.2.1 Instruction Execution Ordering

Each of the high-level language statements in the *Operations* section are executed sequentially (except as constrained by conditional and loop constructs).

### 2.2.2 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. These functions are defined in this section, and include the following:

- “Coprocessor General Register Access Functions” on page 29
- “Memory Operation Functions” on page 30
- “Floating Point Functions” on page 33
- “Miscellaneous Functions” on page 36

### 2.2.2.1 Coprocessor General Register Access Functions

Defined coprocessors, except for CP0, 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 functions described in this section.

#### **COP\_LW**

The COP\_LW function defines the action taken by coprocessor *z* when supplied with a word from memory during a load word operation. The action is coprocessor-specific. The typical action would be to store the contents of memword in coprocessor general register *rt*.

**Figure 2.11 COP\_LW Pseudocode Function**

```
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

  /* Coprocessor-dependent action */

endfunction COP_LW
```

#### **COP\_LD**

The COP\_LD function defines the action taken by coprocessor *z* when supplied with a doubleword from memory during a load doubleword operation. The action is coprocessor-specific. The typical action would be to store the contents of memdouble in coprocessor general register *rt*.

**Figure 2.12 COP\_LD Pseudocode Function**

```
COP_LD (z, rt, memdouble)
  z: The coprocessor unit number
  rt: Coprocessor general register specifier
  memdouble: 64-bit doubleword value supplied to the coprocessor.

  /* Coprocessor-dependent action */

endfunction COP_LD
```

#### **COP\_SW**

The COP\_SW function defines the action taken by coprocessor *z* to supply a word of data during a store word operation. The action is coprocessor-specific. The typical action would be to supply the contents of the low-order word in coprocessor general register *rt*.

**Figure 2.13 COP\_SW Pseudocode Function**

```
dataword ← COP_SW (z, rt)
  z: The coprocessor unit number
  rt: Coprocessor general register specifier
  dataword: 32-bit word value

  /* Coprocessor-dependent action */
```

```
endfunction COP_SW
```

### COP\_SD

The COP\_SD function defines the action taken by coprocessor  $z$  to supply a doubleword of data during a store doubleword operation. The action is coprocessor-specific. The typical action would be to supply the contents of the low-order doubleword in coprocessor general register  $rt$ .

**Figure 2.14 COP\_SD Pseudocode Function**

```
datadouble ← COP_SD (z, rt)
    z: The coprocessor unit number
    rt: Coprocessor general register specifier
    datadouble: 64-bit doubleword value

    /* Coprocessor-dependent action */

endfunction COP_SD
```

### CoprocessorOperation

The CoprocessorOperation function performs the specified Coprocessor operation.

**Figure 2.15 CoprocessorOperation Pseudocode Function**

```
CoprocessorOperation (z, cop_fun)

/* z:          Coprocessor unit number */
/* cop_fun:    Coprocessor function from function field of instruction */

/* Transmit the cop_fun value to coprocessor z */

endfunction CoprocessorOperation
```

## 2.2.2.2 Memory Operation Functions

Regardless of byte ordering (big- or little-endian), the address of a halfword, word, or doubleword is the smallest byte address of the bytes that form 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* pseudocode for load and store operations, the following functions summarize the handling of virtual addresses and the access of 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 2.1](#). The bytes within the addressed unit of memory (word for 32-bit processors or doubleword for 64-bit processors) that are used can be determined directly from the *AccessLength* and the two or three low-order bits of the address.

### AddressTranslation

The AddressTranslation function translates a virtual address to a physical address and its cacheability and coherency attribute, describing the mechanism used to resolve the memory reference.

Given the virtual address  $vAddr$ , and whether the reference is to Instructions or Data (*IorD*), find the corresponding physical address ( $pAddr$ ) and the cacheability and coherency attribute (*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 or fixed mapping MMU

determines 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.

**Figure 2.16 AddressTranslation Pseudocode Function**

```
(pAddr, CCA) ← AddressTranslation (vAddr, IorD, LorS)

/* pAddr: physical address */
/* CCA: Cacheability&Coherency Attribute, the method used to access caches*/
/* and memory and resolve the reference */

/* vAddr: virtual address */
/* IorD: Indicates whether access is for INSTRUCTION or DATA */
/* LorS: Indicates whether access is for LOAD or STORE */

/* See the address translation description for the appropriate MMU */
/* type in Volume III of this book for the exact translation mechanism */

endfunction AddressTranslation
```

### **LoadMemory**

The LoadMemory function loads a value from memory.

This action uses cache and main memory as specified in both the Cacheability and Coherency Attribute (CCA) and the access (*IorD*) to find the contents of *AccessLength* memory bytes, starting at physical location *pAddr*. The data is returned in a fixed-width naturally aligned memory element (*MemElem*). The low-order 2 (or 3) bits of the address and the *AccessLength* indicate which of the bytes within *MemElem* need to be passed to the processor. If the memory access type of the reference is *uncached*, only the referenced bytes are read from memory and marked as valid within the memory element. If the access type is *cached* but 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, this block is the entire memory element.

**Figure 2.17 LoadMemory Pseudocode Function**

```
MemElem ← LoadMemory (CCA, AccessLength, pAddr, vAddr, IorD)

/* 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: Cacheability&CoherencyAttribute=method used to access caches */
/* and memory and resolve the reference */

/* AccessLength: Length, in bytes, of access */
/* pAddr: physical address */
/* vAddr: virtual address */
/* IorD: Indicates whether access is for Instructions or Data */

endfunction LoadMemory
```

### **StoreMemory**

The StoreMemory function stores a value to memory.

The specified data is stored into the physical location *pAddr* using the memory hierarchy (data caches and main memory) as specified by the Cacheability and Coherency Attribute (*CCA*). The *MemElem* contains the data for an aligned, fixed-width memory element (a word for 32-bit processors, a doubleword for 64-bit processors), though only the bytes that are actually stored to memory need be valid. The low-order two (or three) bits of *pAddr* and the *AccessLength* field indicate which of the bytes within the *MemElem* data should be stored; only these bytes in memory will actually be changed.

**Figure 2.18 StoreMemory Pseudocode Function**

```
StoreMemory (CCA, AccessLength, MemElem, pAddr, vAddr)

/* CCA:      Cacheability&Coherency Attribute, the method used to access */
/*           caches and memory and resolve the reference. */
/* AccessLength: Length, in bytes, of access */
/* MemElem:    Data in the width and alignment of a memory element. */
/*             The width is the same size as the CPU general */
/*             purpose register, either 4 or 8 bytes, */
/*             aligned on a 4- or 8-byte boundary. For a */
/*             partial-memory-element store, only the bytes that will be*/
/*             stored must be valid.*/
/* pAddr:     physical address */
/* vAddr:     virtual address */

endfunction StoreMemory
```

### Prefetch

The Prefetch function prefetches data from memory.

Prefetch is an advisory instruction for which an implementation-specific action is taken. The action taken may increase performance but must not change the meaning of the program or alter architecturally visible state.

**Figure 2.19 Prefetch Pseudocode Function**

```
Prefetch (CCA, pAddr, vAddr, DATA, hint)

/* CCA:      Cacheability&Coherency Attribute, the method used to access */
/*           caches and memory and resolve the reference. */
/* pAddr:     physical address */
/* vAddr:     virtual address */
/* DATA:      Indicates that access is for DATA */
/* hint:      hint that indicates the possible use of the data */

endfunction Prefetch
```

Table 2.1 lists the data access lengths and their labels for loads and stores.

**Table 2.1 AccessLength Specifications for Loads/Stores**

AccessLength Name	Value	Meaning
DOUBLEWORD	7	8 bytes (64 bits)
SEPTIBYTE	6	7 bytes (56 bits)
SEXTIBYTE	5	6 bytes (48 bits)
QUINTIBYTE	4	5 bytes (40 bits)

**Table 2.1 AccessLength Specifications for Loads/Stores**

AccessLength Name	Value	Meaning
WORD	3	4 bytes (32 bits)
TRIPLEBYTE	2	3 bytes (24 bits)
HALFWORD	1	2 bytes (16 bits)
BYTE	0	1 byte (8 bits)

### **SyncOperation**

The SyncOperation function orders loads and stores to synchronize shared memory.

This action makes the effects of the synchronizable loads and stores indicated by *stype* occur in the same order for all processors.

**Figure 2.20 SyncOperation Pseudocode Function**

```
SyncOperation(stype)

/* stype: Type of load/store ordering to perform. */

/* Perform implementation-dependent operation to complete the */
/* required synchronization operation */

endfunction SyncOperation
```

#### **2.2.2.3 Floating Point Functions**

The pseudocode shown below 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**

The ValueFPR function returns a formatted value from the floating point registers.

**Figure 2.21 ValueFPR Pseudocode Function**

```
value ← ValueFPR(fpr, fmt)

/* value: The formatted value from the FPR */

/* fpr: The FPR number */
/* fmt: The format of the data, one of: */
/*      S, D, W, L, PS, */
/*      OB, QH, */
/*      UNINTERPRETED_WORD, */
/*      UNINTERPRETED_DOUBLEWORD */
/* The UNINTERPRETED values are used to indicate that the datatype */
/* is not known as, for example, in SWC1 and SDC1 */

case fmt of
  S, W, UNINTERPRETED_WORD:
    valueFPR ← FPR[fpr]
```

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```
D, UNINTERPRETED_DOUBLEWORD:  
    if (FP32RegistersMode = 0)  
        if (fpr0 ≠ 0) then  
            valueFPR ← UNPREDICTABLE  
        else  
            valueFPR ← FPR[fpr+1]31..0 || FPR[fpr]31..0  
        endif  
    else  
        valueFPR ← FPR[fpr]  
    endif  
  
L, PS:  
    if (FP32RegistersMode = 0) then  
        valueFPR ← UNPREDICTABLE  
    else  
        valueFPR ← FPR[fpr]  
    endif  
  
DEFAULT:  
    valueFPR ← UNPREDICTABLE  
  
endcase  
endfunction ValueFPR
```

The pseudocode shown below specifies the way 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 move-from instructions. Once an FPR receives a value from the StoreFPR(), it is not valid to interpret the value with ValueFPR() in a different format.

### StoreFPR

**Figure 2.22 StoreFPR Pseudocode Function**

```
StoreFPR (fpr, fmt, value)  
  
/* fpr: The FPR number */  
/* fmt: The format of the data, one of: */  
/*      S, D, W, L, PS, */  
/*      OB, QH, */  
/*      UNINTERPRETED_WORD, */  
/*      UNINTERPRETED_DOUBLEWORD */  
/* value: The formattted value to be stored into the FPR */  
  
/* The UNINTERPRETED values are used to indicate that the datatype */  
/* is not known as, for example, in LWC1 and LDC1 */  
  
case fmt of  
    S, W, UNINTERPRETED_WORD:  
        FPR[fpr] ← value  
  
    D, UNINTERPRETED_DOUBLEWORD:  
        if (FP32RegistersMode = 0)  
            if (fpr0 ≠ 0) then  
                UNPREDICTABLE  
            else  
                FPR[fpr] ← UNPREDICTABLE32 || value31..0
```

```

        FPR[fpr+1] ← UNPREDICTABLE32 || value63..32
    endif
else
    FPR[fpr] ← value
endif

L, PS:
if (FP32RegistersMode = 0) then
    UNPREDICTABLE
else
    FPR[fpr] ← value
endif

endcase

endfunction StoreFPR

```

The pseudocode shown below checks for an enabled floating point exception and conditionally signals the exception.

### **CheckFPEException**

**Figure 2.23 CheckFPEException Pseudocode Function**

```

CheckFPEException()

/* A floating point exception is signaled if the E bit of the Cause field is a 1 */
/* (Unimplemented Operations have no enable) or if any bit in the Cause field */
/* and the corresponding bit in the Enable field are both 1 */

if ( (FCSR17 = 1) or
     ((FCSR16..12 and FCSR11..7) ≠ 0)) ) then
    SignalException(FloatingPointException)
endif

endfunction CheckFPEException

```

### **FPCConditionCode**

The FPCConditionCode function returns the value of a specific floating point condition code.

**Figure 2.24 FPCConditionCode Pseudocode Function**

```

tf ← FPCConditionCode(cc)

/* tf: The value of the specified condition code */

/* cc: The Condition code number in the range 0..7 */

if cc = 0 then
    FPCConditionCode ← FCSR23
else
    FPCConditionCode ← FCSR24+cc
endif

endfunction FPCConditionCode

```

### ***SetFPCConditionCode***

The SetFPCConditionCode function writes a new value to a specific floating point condition code.

**Figure 2.25 SetFPCConditionCode Pseudocode Function**

```
SetFPCConditionCode(cc, tf)
    if cc = 0 then
        FCSR ← FCSR31..24 || tf || FCSR22..0
    else
        FCSR ← FCSR31..25+cc || tf || FCSR23+cc..0
    endif

endfunction SetFPCConditionCode
```

#### **2.2.2.4 Miscellaneous Functions**

This section lists miscellaneous functions not covered in previous sections.

### ***SignalException***

The SignalException function signals an exception condition.

This action results in an exception that aborts the instruction. The instruction operation pseudocode never sees a return from this function call.

**Figure 2.26 SignalException Pseudocode Function**

```
SignalException(Exception, argument)

/* Exception:      The exception condition that exists. */
/* argument:       A exception-dependent argument, if any */

endfunction SignalException
```

### ***SignalDebugBreakpointException***

The SignalDebugBreakpointException function signals a condition that causes entry into Debug Mode from non-Debug Mode.

This action results in an exception that aborts the instruction. The instruction operation pseudocode never sees a return from this function call.

**Figure 2.27 SignalDebugBreakpointException Pseudocode Function**

```
SignalDebugBreakpointException()

endfunction SignalDebugBreakpointException
```

### ***SignalDebugModeBreakpointException***

The SignalDebugModeBreakpointException function signals a condition that causes entry into Debug Mode from Debug Mode (i.e., an exception generated while already running in Debug Mode).

This action results in an exception that aborts the instruction. The instruction operation pseudocode never sees a return from this function call.

**Figure 2.28 SignalDebugModeBreakpointException Pseudocode Function**

```
SignalDebugModeBreakpointException()
endfunction SignalDebugModeBreakpointException
```

***NullifyCurrentInstruction***

The NullifyCurrentInstruction function nullifies the current instruction.

The instruction is aborted, inhibiting not only the functional effect of the instruction, but also inhibiting all exceptions detected during fetch, decode, or execution of the instruction in question. For branch-like instructions, nullification kills the instruction in the delay slot of the branch likely instruction.

**Figure 2.29 NullifyCurrentInstruction PseudoCode Function**

```
NullifyCurrentInstruction()
endfunction NullifyCurrentInstruction
```

***JumpDelaySlot***

The JumpDelaySlot function is used in the pseudocode for the PC-relative instructions in the MIPS16e ASE. The function returns TRUE if the instruction at *vAddr* is executed in a jump delay slot. A jump delay slot always immediately follows a JR, JAL, JALR, or JALX instruction.

**Figure 2.30 JumpDelaySlot Pseudocode Function**

```
JumpDelaySlot (vAddr)
/* vAddr:Virtual address */
endfunction JumpDelaySlot
```

***PolyMult***

The PolyMult function multiplies two binary polynomial coefficients.

**Figure 2.31 PolyMult Pseudocode Function**

```
PolyMult(x, y)
    temp ← 0
    for i in 0 .. 31
        if  $x_i = 1$  then
            temp ← temp xor ( $y_{(31-i)..0} \parallel 0^i$ )
        endif
    endfor

    PolyMult ← temp

endfunction PolyMult
```

## 2.3 Op and Function Subfield Notation

In some instructions, the instruction subfields *op* and *function* can have constant 5- or 6-bit values. When reference is made to these instructions, uppercase mnemonics are used. For instance, in the floating point ADD instruction, *op*=COP1 and *function*=ADD. In other cases, a single field has both fixed and variable subfields, so the name contains both upper- and lowercase characters.

## 2.4 FPU Instructions

In the detailed description of each FPU instruction, all variable subfields in an instruction format (such as *fs*, *ft*, *immediate*, and so on) are shown in lowercase. The instruction name (such as ADD, SUB, and so on) is shown in uppercase.

For the sake of clarity, an alias is sometimes used for a variable subfield in the formats of specific instructions. For example, *rs*=*base* in the format for load and store instructions. Such an alias is always lowercase since it refers to a variable subfield.

Bit encodings for mnemonics are given in Volume I, in the chapters describing the CPU, FPU, MDMX, and MIPS16e instructions.

See “Op and Function Subfield Notation” on page 38 for a description of the *op* and *function* subfields.



# Introduction

In today's market, the lowest price/performance points must be satisfied, especially for deeply-embedded applications such as microcontroller applications. Moreover, customers require efficient solutions that can be turned into products quickly. To meet this need, the MIPS® instruction set has been optimized and re-encoded into a new variable-length scheme. This solution is called microMIPS™.

microMIPS minimizes the resulting code footprint of applications and it therefore reduces the cost of memory, which is particularly high for embedded memory. Simultaneously, the high performance of MIPS cores is maintained. Using this technology, the customer can generate best results without spending time to profile its application. The smaller code footprint typically leads to reduced power consumption per executed task because of the smaller number of memory accesses.

microMIPS is the preferred replacement for the existing MIPS16e™ ASE. MIPS16e could only be used for usermode programs which did not use floating-point nor any of the Application Specific Extensions (ASEs). microMIPS does not have these limitations - it can be used for kernelmode code as well as usermode programs; it can be used for programs which use floating-point; it can be used with the available ASEs.

microMIPS is also an alternative to the MIPS32® instruction encoding and can be implemented in parallel or stand-alone. The microMIPS equivalent of MIPS32 is named microMIPS32™ and the microMIPS equivalent of MIPS64 is microMIPS64™.

Overview of changes vs. existing MIPS32 ISA:

- 16-bit and 32-bit opcodes
- Optimized opcode/operand field definitions based on statistics
- Branch and jump delay slots will be kept for maximum compatibility and lowest risk
- Removal of branch likely instructions, emulation by assembler
- Fine-tuned register allocation algorithm in the compiler for lowest code size

## 3.1 Release 3 of the MIPS Architecture

Enhancements included in Release 3 of the MIPS Architecture (also known as MIPSr3™) are:

- microMIPS: The MIPS Release 3 Architecture (also known as MIPSr3™) supports both the MIPS32 instruction set and microMIPS32™ instruction set. Both can be implemented either in parallel or stand-alone. For the first implementations, microMIPS will be primarily implemented together with MIPS32 encoded instruction execution.
- microMIPS is the preferred replacement for MIPS16e. Therefore these two schemes never co-exist within the same processor core.

- Branch likely instructions are phased out in microMIPS and are emulated by the assembler. They remain available in the MIPS32 encoding.

Unless otherwise described in this document, all other aspects of the microMIPS32 architecture are identical to MIPS32 Release 2.

## 3.2 Default ISA Mode

The instruction sets which are available within an implementation are reported by the *Config3<sub>ISA</sub>* register field (bits 15:14). *Config1<sub>CA</sub>* (bit 2) is not used for microMIPS32.

For implementations that support both microMIPS32 and MIPS32, the selected ISA mode following reset is determined by the setting of the *Config3<sub>ISA</sub>* register field., which is a read-only field set by a hardware signal external to the processor core.

For implementations that support both microMIPS32 and MIPS32, the selected ISA mode upon handling an exception is determined by the setting of the *Config3<sub>ISAOnExc</sub>* register field (bit 16). The *Config3<sub>ISAOnExc</sub>* register field is writeable by software and has a reset value that is set by a hardware signal external to the processor core. This register field allows privileged software to change the ISA mode to be used for subsequent exceptions. This capability is for all exception types whose vectors are offsets of the *EBASE* register.

For implementations that support both microMIPS32 and MIPS32, the selected ISA mode when handling a debug exception is determined by the setting of the *ISAOnDebug* register field in the *EJTAG TAP Control* register. This register field is writeable by EJTAG probe software and has a reset value that is set by a hardware signal external to the processor core.

For CPU cores supporting the MT ASE and multiple VPEs, the ISA mode for exceptions can be selected on a per-VPE basis.

## 3.3 Software Detection

Software can determine if microMIPS32 ISA is implemented by checking the state of the ISA (Instruction Set Architecture) field in the *Config3 CP0* register. *Config1<sub>CA</sub>* (bit 2) is not used for microMIPS32.

Software can determine if the MIPS32 ISA is implemented by checking the state of the ISA (Instruction Set Architecture) register field in the *Config3 CP0* register.

Software can determine which ISA is used when handling an exception by checking the state of the *ISAOnExc* (ISA on Exception) field in the *Config3 CP0* register.

Debug Probe Software can determine which ISA is used when handling a debug exception by checking the state of the *ISAOnDebug* field in the *EJTAG TAP Control* register.

## 3.4 Compliance and Subsetting

This document does not change the instruction subsets as defined by the other MIPS architecture reference manuals, including the subsets defined by the various ASEs.

## 3.5 ISA Mode Switch

The MIPS Release 3 architecture defines an ISA mode for each processor. An ISA mode value of 0 indicates MIPS32 instruction decoding. In processors implementing microMIPS32, an ISA mode value of 1 selects microMIPS32 instruction decoding. In processors implementing the MIPS16e ASE, an ISA mode value of 1 selects the decoding of instructions as MIPS16e.

The ISA mode is not directly visible to usermode software. Upon an exception, the ISA mode of the faulting/interrupted instruction is recorded in the least significant address bit within the appropriate return address register - either EPC or ErrorEPC or DebugEPC depending on the exception type.

For the rest of this section, the following definitions are used:

**Jump-and-Link-Register instructions:** For the MIPS32 ISA, this means the JALR and JALR.HB instructions. For the microMIPS32 ISA, this means the JALR, JALR.HB, JALR16, JALRS, JALRS16 and JALRS.HB instructions.

**Jump-Register instructions:** For the MIPS32 ISA, this means the JR and JR.HB instructions. For the microMIPS32 ISA, this means the instructions JR, JR.HB, JR16, JRC and JRADDIUSP instructions.

Mode switching between MIPS32 and microMIPS32 uses the same mechanism used by MIPS16e, namely, the JALX, Jump-and-Link-Register and Jump-Register instructions, as described below.

- The JALX instruction executes a JAL and switches to the other mode.
- The Jump-and-Link-Register and Jump-Register instructions interpret bit 0 of the source registers as the target ISA mode (0=MIPS32, 1=microMIPS32) and therefore set the ISA Mode bit according to the contents of bit 0 of the source register. For the actual jump operation, the PC is loaded with the value of the source register with bit 0 set to 0. The Jump-and-Link-Register instructions save the ISA mode into bit 0 of the destination register.
- When exceptions or interrupts occur and the processor writes to *EPC*, *DEPC*, or *ErrorEPC*, the ISA Mode bit is saved into bit 0 of these registers. Then the ISA Mode bit is set according to the *Config3<sub>ISA</sub>* register field. On return from an exception, the processor loads the ISA Mode bit based on the value from either *EPC*, *DEPC*, or *ErrorEPC*.

If only one ISA mode exists (either MIPS32 or microMIPS32) then this mode switch mechanism does not exist, but the ISA Mode bit is still maintained and has a fixed value (0=MIPS32, 1=microMIPS32). This is to maintain code compatibility between devices which implement both ISA modes and devices which implement only one ISA mode. Executing the JALX instruction will cause a Reserved Instruction exception. Jump-Register and Jump-and-Link-Register instructions cause an Address exception on the target instruction fetch when bit 0 of the source register is different from the fixed ISA mode. Exception handlers must use the instruction set binary format supported by the processor. The Jump-and-Link-Register instructions must still save the fixed ISA mode into bit 0 of the destination register.

## 3.6 Branch and Jump Offsets

In the MIPS32 architecture, because instructions are always 32 bits in size, the jump and branch target addresses are word (32-bit) aligned. Jump/branch offset fields are shifted left by two bits to create a word-aligned effective address.

In the microMIPS32 architecture, because instructions can be either 16 or 32 bits in size, the jump and branch target addresses are halfword (16-bit) aligned. Branch/jusmp offset fields are shifted left by only one bit to create halfword-aligned effective addresses.

To maintain the existing MIPS32 ABIs, link unit/object file entry points are restricted to 32-bit word alignments. In the future, a microMIPS32-only ABI can be created to remove this restriction.

## 3.7 Coprocessor Unusable Behavior

If an instruction associated with a non-implemented coprocessor is executed, it is implementation specific whether a processor executing in microMIPS32 mode raises an RI exception or a coprocessor unusable exception. This behavior is different from the MIPS32 behavior in which coprocessor unusable exception is signalled for such cases.

If the microMIPS32 implementation chooses to use RI exception in such cases, the microMIPS32 RI exception handler must check for coprocessor instructions being executed while the associated coprocessor is implemented but has been disabled ( $Status_{CUx}$  set to zero).

## Instruction Formats

This chapter defines the formats of microMIPS instructions. The microMIPS variable-length encoding comprises 16-bit and 32-bit wide instructions. The 6-bit major opcode is left-aligned within the instruction encoding. Instructions can have 0 to 4 register fields. For 32-bit instructions, the register field width is 5 bits, while for most 16-bit instructions, the register field width is 3 bits, utilizing instruction-specific register encoding. All 5-bit register fields are located at a constant position within the instruction encoding.

The immediate field is right-aligned in the following instructions:

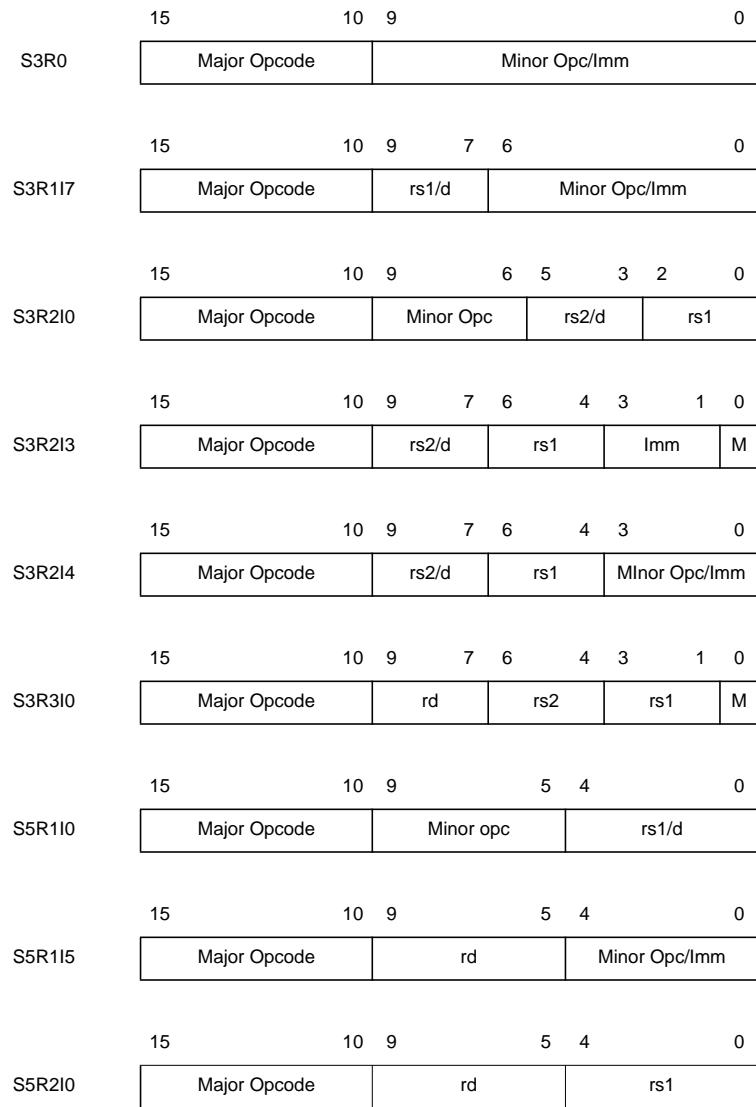
- some 16-bit instructions with 3-bit register fields
- 32-bit instructions with 16-bit or 26-bit immediate field

The name ‘immediate field’ as used here includes the address offset field for branches and load/store instructions as well as the jump target field.

Other instruction-specific fields are typically located between the immediate and minor opcode fields. Instructions that have multiple “other” fields are listed in alphabetical order according to the name of the field, with the first name of the order located at the lower bit position. An empty bit field that is not explicitly shown in the instruction format is located next to the minor opcode field.

[Figure 4.1](#) and [Figure 4.2](#) show the 16-bit and 32-bit instruction formats.

**Figure 4.1 16-Bit Instruction Formats**



## Instruction Formats

**Figure 4.2 32-Bit Instruction Formats**

R0	31                  26 25	0				
	Major Opcode	Immediate/Minor Opcode/Other				
R1	31                  26 25                  21 20                  16 15	0				
	Major Opcode	Imm/Other	rs/fs/base	Immediate/Minor Opcode/Other		
R2	31                  26 25                  21 20                  16 15	0				
	Major Opcode	rt/ft/index	rs/fs/base	Immediate/Minor Opcode/Other		
R3	31                  26 25                  21 20                  16 15                  11 10	0				
	Major Opcode	rt/ft/index	rs/fs/base	rd/fd	Immediate/Minor Opcode/Other	
R4	31                  26 25                  21 20                  16 15                  11 10                  6 5	0				
	Major Opcode	rt/ft	rs/fs	rd/fd	rr/fr	Minor Opcode/Other

**Figure 4.3 Immediate Fields within 32-Bit Instructions**

32-bit instruction formats with 26-bit immediate fields:

R0I26	31                  26 25	0	
	Major Opcode	Immediate	
R0I16	31                  26 25                  16 15	0	
	Major Opcode	Minor Opcode/Other	Immediate

32-bit instruction formats with 16-bit immediate fields:

R1I16	31                  26 25                  21 20                  16 15	0		
	Major Opcode	Minor Opcode/Other	rs/fs	Immediate
R2I16	31                  26 25                  21 20                  16 15	0		
	Major Opcode	rt/ft	rs/fs	Immediate

32-bit instruction formats with 12-bit immediate fields:

R1I12	31                  26 25                  21 20                  16 15                  12 11	0			
	Major Opcode	Other	rs/fs	Minor Opcode	Immediate
R2I12	31                  26 25                  21 20                  16 15                  12 11	0			
	Major Opcode	rt/ft	rs/fs	Minor Opcode	Immediate

The instruction size can be completely derived from the major opcode. For 32-bit instructions, the major opcode also defines the position of the minor opcode field and whether or not the immediate field is right-aligned.

Instructions formats are named according to the number of the register fields and the size of the immediate field. The names have the structure R<x>I<y>. For example, an instruction based on the format R2I16 has 2 register fields and a 16-bit immediate field.

Table 4.1 shows all formats. The 16-bit formats refer to either 3-bit or 5-bit register fields. To visualize this, a 16-bit format name starts with the prefix S3 or S5 respectively.

**Table 4.1 microMIPS Opcode Formats**

32-bit Instruction Formats (existing instructions)	32-bit Instruction Formats (additional format(s) for new instructions)	16-bit Instruction Formats
R0I0	R2I12	S3R0I0
R0I8		S3R0I10
R0I16		S3R1I7
R0I26		S3R2I0
R1I0		S3R2I3
R1I2		S3R2I4
R1I7		S3R3I1
R1I8		S5R1I0
R1I10		S5R1I4
R1I16		S5R2I0
R2I0		
R2I2		
R2I3		
R2I4		
R2I5		
R2I10		
R2I16		
R3I0		
R3I3		
R4I0		

## 4.1 Instruction Stream Organization and Endianness

16-bit instructions are placed within the 32-bit (or 64-bit) memory element according to system endianness.

- On a 32-bit processor in big-endian mode, the first instruction is read from bits 31..16, and the second instruction is read from bits 15..0.

## Instruction Formats

- On a 32-bit processor in little-endian mode, the first instruction is read from bits 15..0, and the second instruction is read from bits 31..16.

The above rule also applies to the halfwords of 32-bit instructions. This means that a 32-bit instruction is not treated as a word data type; instead, the halfwords are treated in the same way as individual 16-bit instructions. The halfword containing the major opcode is always the first in the sequence.

Example:

```
SRL r1, r1, 7      binary opcode fields: 000000 00001 00001 00111 00001 000000
                           hex representation:    0021 3840

                           Address:   3   2   1   0
LittleEndian:          Data:       38 40 00 21

                           Address:   0   1   2   3
BigEndian:            Data:       00 21 38 40
```

Instructions are placed in memory such that they are in-order with respect to the address.



## microMIPS Re-encoded Instructions

This chapter lists all microMIPS re-encoded instructions, sorted into 16-bit and 32-bit categories.

In the 16-bit category:

- Frequent MIPS32 instructions and macros, re-encoded as 16-bit. Register and immediate fields are reduced in size by using encodings of frequently occurring values.

In the 32-bit category:

- All MIPS32 instructions, including all application-specific extensions except MIPS16e, re-encoded: MIPS32, MIPS-3D ASE, MIPS DSP ASE, MIPS MT ASE, and SmartMIPS ASE.
- Opcode space for user-defined instructions (UDIs).
- New instructions designed primarily to reduce code size.

To differentiate between 16-bit and 32-bit encoded instructions, the instruction mnemonic can be optionally extended with the suffix “16” or “32” respectively. This suffix is placed at the end of the instruction before the first ‘.’ if there is one. For example:

ADD16, ADD32, ADD32.PS

If these suffixes are omitted, the assembler automatically chooses the smallest instruction size.

For each instruction, the tables in this chapter provide all necessary information about the bit fields. The formats of the instructions are defined in [Chapter 4, “Instruction Formats” on page 44](#). Together with the major and minor opcode encodings, which can be derived from the tables in [Chapter 6, “Opcode Map” on page 494](#), the complete instruction encoding is provided.

Most register fields have a width of 5 bits. 5-bit register fields use linear encoding ( $r0='00000'$ ,  $r1='00001'$ , etc.). For 16-bit instructions, whose register field size is variable, the register field width is explicitly stated in the instruction table ([Table 5.1](#) and [Table 5.2](#)), and the individual register and immediate encodings are shown in [Table 5.3](#). The ‘other fields’ are defined by the respective column, with the order of these fields in the instruction encoding defined by the order in the tables.

## 5.1 16-Bit Category

### 5.1.1 Frequent MIPS32 Instructions

These are frequent MIPS32 instructions with reduced register and immediate fields containing frequently used registers and immediate values.

MOVE is a very frequent instruction. It therefore supports full 5-bit unrestricted register fields for maximum efficiency. In fact, MOVE used to be a simplified macro of an existing MIPS32 instruction.

There are 2 variants of the LW and SW instructions. One variant implicitly uses the SP register to allow for a larger offset field. The value in the offset field is shifted left by 2 before it is added to the base address.

There are four variants of the ADDIU instruction:

1. A variant with one 5-bit register specifier that allows any GPR to be the source and destination register
2. A variant that uses the stack pointer as the implicit source and destination register
3. A variant that has separate 3-bit source and destination register specifiers
4. A variant that has the stack pointer as the implicit source register and one 3-bit destination register specifier

A 16-bit NOP instruction is needed because of the new 16-bit instruction alignment and the need in specific cases to align instructions on a 32-bit boundary. It can save code size as well. NOP is not shown in the table because it is realized as a macro (as is NEGU).

```
NOP16 = MOVE16 r0, r0
NEGU16 rt, rs = SUBU16 rt, r0, rs
```

Because microMIPS instructions are 16-bit aligned, the 16-bit branch instructions support 16-bit aligned branch target addresses. The offset field is left shifted by 1 before it is added to the PC.

The compact instruction JRC is to be used instead of JR, when the jump delay slot after JR cannot be filled. This saves code size. Because JRC may execute as fast as JR with a NOP in the delay slot, JR is preferred if the delay slot can be filled.

The breakpoint instructions, BREAK and SDBBP, include a 16-bit variant that allows a breakpoint to be inserted at any instruction address without overwriting more than a single instruction.

**Table 5.1 16-Bit Re-encoding of Frequent MIPS32 Instructions**

Instruction	Major Opcode Name	Number of Register Fields	Immediate Field Size (bit)	Register Field Width (bit)	Total Size of Other Fields	Empty 0 Field Size (bit)	Minor Opcode Size (bit)	Comment
ADDIUS5	POOL16D	5bit:1	4	5		0	1	Add Immediate Unsigned Word Same Register

## microMIPS Re-encoded Instructions

**Table 5.1 16-Bit Re-encoding of Frequent MIPS32 Instructions (Continued)**

Instruction	Major Opcode Name	Number of Register Fields	Immediate Field Size (bit)	Register Field Width (bit)	Total Size of Other Fields	Empty 0 Field Size (bit)	Minor Opcode Size (bit)	Comment
ADDIUSP	POOL16D	0	9	0		0	1	Add Immediate Unsigned Word to Stack Pointer
ADDIUR2	POOL16E	2	3	3		0	1	Add Immediate Unsigned Word Two Registers
ADDIUR1SP	POOL16E	1	6	3		0	1	Add Immediate Unsigned Word One Registers and Stack Pointer
ADDU16	POOL16A	3	0	3		0	1	Add Unsigned Word
AND16	POOL16C	2	0	3		0	4	AND
ANDI16	ANDI16	2	4	3		0	0	AND Immediate
B16	B16	0	10			0	0	Branch
BREAK16	POOL16C	0	0		4	0	6	Cause Breakpoint Exception
JALR16	POOL16C	1	0	5		0	5	Jump and Link Register, 32-bit delay-slot
JALRS16	POOL16C	1	0	5		0	5	Jump and Link Register, 16-bit delay-slot
JR16	POOL16C	1	0	5		0	5	Jump Register
LBU16	LBU16	2	4	3		0	0	Load Byte Unsigned
LHU16	LHU16	2	4	3		0	0	Load Halfword
LI16	LI16	1	7	3		0	0	Load Immediate
LW16	LW16	2	4	3		0	0	Load Word
LWGP	LWGP16	1	7	3		0	0	Load Word GP
LWSP	LWSP16	5bit:1	5	5		0	0	Load Word SP
MFHI16	POOL16C	1	0	5		0	5	Move from HI Register
MFLO16	POOL16C	1	0	5		0	5	Move from LO Register
MOVE16	MOVE16	2	0	5		0	0	Move
NOT16	POOL16C	2	0	3		0	4	NOT
OR16	POOL16C	2	0	3		0	4	OR
SB16	SB16	2	4	3		0	0	Store Byte
SDBBP16	POOL16C	0	0		4	0	6	Cause Debug Breakpoint Exception
SH16	SH16	2	4	3		0	0	Store Halfword

**Table 5.1 16-Bit Re-encoding of Frequent MIPS32 Instructions (Continued)**

Instruction	Major Opcode Name	Number of Register Fields	Immediate Field Size (bit)	Register Field Width (bit)	Total Size of Other Fields	Empty 0 Field Size (bit)	Minor Opcode Size (bit)	Comment
SLL16	POOL16B	2	3	3		0	1	Shift Word Left Logical
SRL16	POOL16B	2	3	3		0	1	Shift Word Right Logical
SUBU16	POOL16A	3	0	3		0	1	Sub Unsigned
SW16	SW16	2	4	3		0	0	Store Word
SWSP	SWSP16	5bit:1	5	5		0	0	Store Word SP
XOR16	POOL16C	2	0	3		0	4	XOR

### 5.1.2 Frequent MIPS32 Instruction Sequences

These 16-bit instructions are equivalent to frequently-used short sequences of MIPS32 instructions. The instruction-specific register and immediate value selection are shown in [Table 5.3](#).

**Table 5.2 16-Bit Re-encoding of Frequent MIPS32 Instruction Sequences**

Instruction	Major Opcode Name	Number of Register Fields	Immediate Field Size (bit)	Register Field Width (bit)	Total Size of Other Fields	Empty 0 Field Size (bit)	Minor Opcode Size (bit)	Comment
BEQZ16	BEQZ16	1	7	3		0	0	Branch on Equal Zero
BNEZ16	BNEZ16	1	7	3		0	0	Branch on Not Equal Zero
JRADDIUSP	POOL16C	0	5				5	Jump Register; ADDIU SP
JRC	POOL16C	1	0	5		0	5	Jump Register Compact
LWM16	POOL16C	0	4		2	0	4	Load Word Multiple
MOVEP	POOL16F	3 (encoded)	0	3(encoded)		0	1	Move Register Pair
SWM16	POOL16C	0	4		2	0	4	Store Word Multiple

### 5.1.3 Instruction-Specific Register Specifiers and Immeidiate Field Encodings

**Table 5.3 Instruction-Specific Register Specifiers and Immediate Field Values**

Instruction	Number of Register Fields	Immediate Field Size (bit)	Register 1 Decoded Value	Register 2 Decoded Value	Register 3 Decoded Value	Immediate Field Decoded Value
ADDIUS5	5bit:1	4	rd: 5 bit field			-8..0..7
ADDIUSP	0	9				(-258..-3, 2..257) << 2
ADDIUR2	2	3	rs1:2-7,16, 17	rd:2-7,16, 17		-1, 1, 4, 8, 12, 16, 20, 24
ADDIUR1SP	1	6	rd:2-7,16, 17			(0..63) << 2
ADDU16	3	0	rs1:2-7,16, 17	rs2:2-7,16, 17	rd:2-7,16, 17	
AND16	2	0	rs1:2-7,16, 17	rd:2-7,16, 17		
ANDI16	2	4	rs1:2-7,16, 17	rd:2-7,16, 17		1, 2, 3, 4, 7, 8, 15, 16, 31, 32, 63, 64, 128, 255, 32768, 65535
B16	0	10				(-512..511) << 1
BEQZ16	1	7	rs1:2-7,16, 17			(-64..63) << 1
BNEZ16	1	7	rs1:2-7,16, 17			(-64..63) << 1
BREAK16	0	4				0..15
JALR16	5bit:1	0	rs1:5 bit field			
JALRS16	5bit:1	0	rs1:5 bit field			
JRADDIUSP	0	5				(0..31) << 2
JR16	5bit:1	0	rs1:5 bit field			
JRC	5bit:1	0	rs1:5 bit field			
LBU16	2	4	rb:2-7,16,17	rd:2-7,16, 17		-1,0..14
LHU16	2	4	rb:2-7,16,17	rd:2-7,16, 17		(0..15) << 1
LI16	1	7	rd:2-7,16, 17			-1,0..126
LW16	2	4	rb:2-7,16,17	rd:2-7,16, 17		(0..15) << 2
LWM16	2bit list:1	4				(0..15)<<2
LWGP	1	7	rd:2-7,16,17			(-64..63)<<2
LWSP	5bit:1	5	rd:5-bit field			(0..31)<<2
MFHI16	5bit:1	0	rd:5-bit field			
MFLO16	5bit:1	0	rd:5-bit field			
MOVE16	5bit:2	0	rd:5-bit field	rs1:5-bit field		
MOVEP	3	0	rd, re: (5,6),(5,7),(6,7), (4,21),(4,22),(4, 5),(4,6),(4,7)	rt:0,2,7,16-20	rs:0,2,7,16-20	
NOT16	2	0	rs1:2-7,16, 17	rd:2-7,16, 17		
OR16	2	0	rs1:2-7,16, 17	rd:2-7,16, 17		
SB16	2	4	rb:2-7,16,17	rs1:0, 2-7, 17		0..15

**Table 5.3 Instruction-Specific Register Specifiers and Immediate Field Values (Continued)**

Instruction	Number of Register Fields	Immediate Field Size (bit)	Register 1 Decoded Value	Register 2 Decoded Value	Register 3 Decoded Value	Immediate Field Decoded Value
SDBBP16	0	0				0..15
SH16	2	4	rb:2-7,16,17	rs1:0, 2-7, 17		(0..15) << 1
SLL16	2	3	rs1:2-7,16, 17	rd:2-7,16, 17		1..8 (see encoding tables)
SRL16	2	3	rs1:2-7,16, 17	rd:2-7,16, 17		1..8 (see encoding tables)
SUBU16	3	0	rs1:2-7,16, 17	rs2:2-7,16, 17	rd:2-7,16, 17	
SW16	2	4	rb:2-7,16,17	rs1:0, 2-7, 17		(0..15) << 2
SWSP	5bit:1	5	rs1: 5 bit field			(0..31) << 2
SWM16	2 bit list:1	4				(0..15)<<2
XOR16	2	0	rs1:2-7,16, 17	rd:2-7,16, 17		

## 5.2 16-bit Instruction Register Set

Many of the 16-bit instructions use 3-bit register specifiers in their binary encodings. The register set used for most of these 3-bit register specifiers is listed in [Table 5.5](#). The register set used for SB16, SH16, SW16 source register is listed in [Table 5.5](#). These register sets are a true subset of the register set available in 32-bit mode; the 3-bit register specifiers can directly access 8 of the 32 registers available in 32-bit mode (which uses 5-bit register specifiers).

In addition, specific instructions in the 16-bit instruction set implicitly reference the stack pointer register (*sp*), global pointer register (*gp*), the return address register (*ra*), the integer multiplier/divider output registers (*HI/LO*) and the program counter (*PC*). Of these, [Table 5.6](#) lists *sp*, *gp* and *ra*. [Table 5.7](#) lists the microMIPS special-purpose registers, including *PC*, *HI* and *LO*.

## microMIPS Re-encoded Instructions

The microMIPS also contains some 16-bit instructions that use 5-bit register specifiers. Such 16-bit instructions provide access to all 32 general-purpose registers.

**Table 5.4 16-Bit Instruction General-Purpose Registers - \$2-\$7, \$16, \$17**

16-Bit Register Encoding <sup>1</sup>	32-Bit MIPS Register Encoding <sup>2</sup>	Symbolic Name (From <i>ArchDefs.h</i> )	Description
0	16	s0	General-purpose register
1	17	s1	General-purpose register
2	2	v0	General-purpose register
3	3	v1	General-purpose register
4	4	a0	General-purpose register
5	5	a1	General-purpose register
6	6	a2	General-purpose register
7	7	a3	General-purpose register

1. “0-7” correspond to the register’s 16-bit binary encoding and show how that encoding relates to the MIPS registers. “0-7” never refer to the registers, except within the binary microMIPS instructions. From the assembler, only the MIPS names (\$16, \$17, \$2, etc.) or the symbolic names (s0, s1, v0, etc.) refer to the registers. For example, to access register number 17 in the register file, the programmer references \$17 or s1, even though the micro-MIPS binary encoding for this register is 001.
2. General registers not shown in the above table are not accessible through the 16-bit instruction using 3-bit register specifiers. The Move instruction can access all 32 general-purpose registers.

**Table 5.5 SB16, SH16, SW16 Source Registers - \$0, \$2-\$7, \$17**

16-Bit Register Encoding <sup>1</sup>	32-Bit MIPS Register Encoding <sup>2</sup>	Symbolic Name (From <i>ArchDefs.h</i> )	Description
0	0	zero	Hard-wired Zero
1	17	s1	General-purpose register
2	2	v0	General-purpose register
3	3	v1	General-purpose register
4	4	a0	General-purpose register
5	5	a1	General-purpose register
6	6	a2	General-purpose register
7	7	a3	General-purpose register

1. “0-7” correspond to the register’s 16-bit binary encoding and show how that encoding relates to the MIPS registers. “0-7” never refer to the registers, except within the binary microMIPS instructions. From the assembler, only the MIPS names (\$16, \$17, \$2, etc.) or the symbolic names (s0, s1, v0, etc.) refer to the registers. For example, to access register number 17 in the register file, the programmer references \$17 or s1, even though the micro-MIPS binary encoding for this register is 001.
2. General registers not shown in the above table are not accessible through the 16-bit instructions using 3-bit register specifier. The Move instruction can access all 32 general-purpose registers.

**Table 5.6 16-Bit Instruction Implicit General-Purpose Registers**

16-Bit Register Encoding	32-Bit MIPS Register Encoding	Symbolic Name (From ArchDefs.h)	Description
Implicit	28	gp	Global pointer register
Implicit	29	sp	Stack pointer register
Implicit	31	ra	Return address register

**Table 5.7 16-Bit Instruction Special-Purpose Registers**

Symbolic Name	Purpose
PC	Program counter. The PC-relative ADDIU can access this register as an operand.
HI	Contains high-order word of multiply or divide result.
LO	Contains low-order word of multiply or divide result.

## 5.3 32-Bit Category

### 5.3.1 New 32-bit instructions

The following table lists the 32-bit instructions introduced in the microMIPS ISA.

**Table 5.8 32-bit Instructions introduced within microMIPS**

Instruction	Major Opcode Name	Number of Register Fields	Immediate Field Size (bit)	Register Field Width (bit)	Total Size of Other Fields	Empty 0 Field Size (bit)	Minor Opcode Size (bit)	Comment
ADDIUPC	ADDIUPC	1	23	3		0	0	ADDIU PC-Relative
BEQZC	POOL32I	2:5 bit	16	5			0	Branch on Equal to Zero, No Delay Slot
BNEZC	POOL32I	2:5 bit	16	5			0	Branch on Not Equal to Zero, No Delay Slot
JALRS	POOL32A	2:5 bit	0	5			16	Jump and Link Register, Short Delay Slot
JALRS.HB	POOL32A	2:5 bit	0	5			16	Jump and Link Register with Hazard Barrier, Short Delay Slot

**Table 5.8 32-bit Instructions introduced within microMIPS**

<b>Instruction</b>	<b>Major Opcode Name</b>	<b>Number of Register Fields</b>	<b>Immediate Field Size (bit)</b>	<b>Register Field Width (bit)</b>	<b>Total Size of Other Fields</b>	<b>Empty 0 Field Size (bit)</b>	<b>Minor Opcode Size (bit)</b>	<b>Comment</b>
JALS	JALS32	0	26				0	Jump and Link, Short Delay Slot
JALX	JALX		26	5		0	5	Jump and Link Exchange
LWP	POOL32B	2:5 bit	12		5	0	4	Load Word Pair
LWXS	POOL32A	3:5 bit	0	5	0	1	10	Load Word Indexed, Scale
LWM32	POOL32B	1:5bit	12		5	0	4	Load Word Multiple
SWP	POOL32B	2:5 bit	12			0	4	Load Word Pair
SWM32	POOL32B	1:5bits	12		5	0	4	Store Word Multiple

## **5.4 New Instructions**

This section defines all new instructions introduced with microMIPS. Existing instructions and macros are not covered.

31	26 25	23 22	0
ADDIUPC 011110	rs		Immediate

6                    3                    23

**Format:** ADDIUPC rs, left\_shifted\_immediate

microMIPS

**Purpose:** Add Immediate Unsigned Word (PC-Relative)

To add a constant to the program counter.

**Description:** GPR[translated(rs)]  $\leftarrow$  PC + (immediate  $\ll$  2)

The 23-bit *immediate* is left shifted by two bits, sign-extended and added to the address of the ADDIU instruction. Before the addition, the two lower bits of the instruction address are cleared.

The result of the addition is placed in GPR *rs*.

No integer overflow exception occurs under any circumstances.

Unlike the MIPS16 version of this instruction, the program counter value of the ADDIUPC instruction is always used, even when the ADDIUPC instruction is placed in the delay-slot of a jump or branch instruction.

#### Restrictions:

The 3-bit register field can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

```
temp  $\leftarrow$  (PC_GPREN-1..2 || 02) + sign_extend(immediate || 02)
GPR[Xlat(rs)]  $\leftarrow$  temp
```

#### Exceptions:

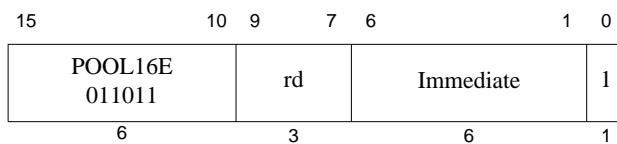
None

#### 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 unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.

The assembler LA (Load Address) pseudo-instruction is implemented as a PC-relative add.

The 25-bit immediate (field shifted by 2 bits) allows addresses within 32MB of the instruction PC location to be generated.



**Format:** ADDIUR1SP rd, decoded\_immediate\_value

microMIPS

**Purpose:** Add Immediate Unsigned Word One Register (16-bit instr size)

To add a constant to a 32-bit integer.

**Description:**  $\text{GPR}[\text{rd}] \leftarrow \text{GPR}[29] + \text{zero\_extend}(\text{immediate} \ll 2)$

The 6-bit *immediate* field is first shifted left by two bits and then zero-extended. This amount is added to the 32-bit value in GPR 29 and the 32-bit arithmetic result is placed into GPR *rd*.

No Integer Overflow exception occurs under any circumstances.

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

```
temp ← GPR[29] + zero_extend(immediate || 02)
GPR[rd] ← temp
```

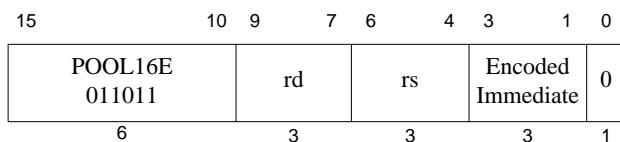
#### Exceptions:

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. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.





**Format:** ADDIUR2 rd, rs1, decoded\_immediate\_value

microMIPS

**Purpose:** Add Immediate Unsigned Word Two Registers (16-bit instr size)

To add a constant to a 32-bit integer.

**Description:**  $GPR[rd] \leftarrow GPR[rs] + \text{sign\_extend}(\text{decoded immediate})$

The encoded immediate field is decoded to obtain the actual immediate value.

The decoded immediate value is sign-extended and then 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.

**Table 5.9 Encoded and Decoded Values of the Immediate Field**

Encoded Value of Instr <sub>3..1</sub> (Decimal)	Encoded Value of Instr <sub>3..1</sub> (Hex)	Decoded Value of Immediate (Decimal)	Decoded Value of Immediate (Hex)
0	0x0	1	0x0001
1	0x1	4	0x0004
2	0x2	8	0x0008
3	0x3	12	0x000c
4	0x4	16	0x0010
5	0x5	20	0x0014
6	0x6	24	0x0018
7	0x7	-1	0xffff

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

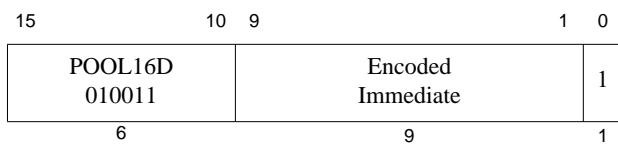
```
temp ← GPR[rs] + sign_extend(decoded immediate)
GPR[rd] ← temp
```

#### 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. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.

**Format:** ADDIUSP decoded\_immediate\_value**microMIPS****Purpose:** Add Immediate Unsigned Word to Stack Pointer(16-bit instr size)

To add a constant to the stack pointer.

**Description:**  $GPR[29] \leftarrow GPR[29] + \text{sign\_extend}(\text{decoded immediate} \ll 2)$ 

The encoded immediate field is decoded to obtain the actual immediate value.

The actual immediate value is first shifted left by two bits and then sign-extended. This amount is added to the 32-bit value in GPR 29, and the 32-bit arithmetic result is placed into GPR 29.

No Integer Overflow exception occurs under any circumstances.

**Table 5.10 Encoded and Decoded Values of Immediate Field**

Encoded Value of Instr <sub>9..1</sub> (Decimal)	Encoded Value of Instr <sub>9..1</sub> (Hex)	Decoded Value of Immediate (Decimal)	Decoded Value of Immediate (Hex)
0	0x0	256	0x0100
1	0x1	257	0x0101
2	0x2	2	0x0002
3	0x3	3	0x0003
...	...	...	...
254	0xfe	254	0x00fe
255	0xff	255	0x00ff
256	0x100	-256	0xff00
257	0x101	-255	0xff01
...	...	...	...
508	0x1fc	-4	0xffffc
509	0x1fd	-3	0xffffd
510	0x1fe	-258	0xfefe
511	0x1ff	-257	0xfeff

**Restrictions:**

None

**Operation:**

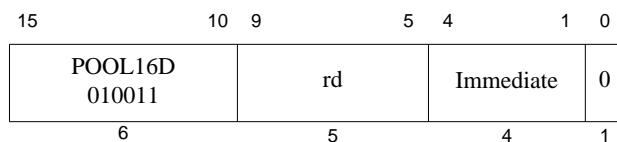
```
temp ← GPR[29] + sign_extend(decoded immediate || 02)
GPR[29] ← temp
```

**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. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.



**Format:** ADDIUS5 rd, decoded\_immediate\_value

microMIPS

**Purpose:** Add Immediate Unsigned Word 5-Bit Register Select (16-bit instr size)

To add a constant to a 32-bit integer

**Description:**  $GPR[rd] \leftarrow GPR[rd] + \text{sign\_extend}(\text{immediate})$

The 4-bit *immediate* field is sign-extended and then added to the 32-bit value in GPR *rd*. The 32-bit arithmetic result is placed into GPR *rd*.

The 5-bit register select allows this 16-bit instruction to use any of the 32 GPRs as the destination register.

No Integer Overflow exception occurs under any circumstances.

**Table 5-1 Encoded and Decoded Values of Signed Immediate Field**

Encoded Value of Instr <sub>4..1</sub> (Decimal)	Encoded Value of Instr <sub>4..1</sub> (Hex)	Decoded Value of Immediate (Decimal)	Decoded Value of Immediate (Hex)
0	0x0	0	0x0000
1	0x1	1	0x0001
2	0x2	2	0x0002
3	0x3	3	0x0003
4	0x4	4	0x0004
5	0x5	5	0x0005
6	0x6	6	0x0006
7	0x7	7	0x0007
8	0x8	-8	0xffff8
9	0x9	-7	0xffff9
10	0xa	-6	0xffffa
11	0xb	-5	0xffffb
12	0xc	-4	0xffffc
13	0xd	-3	0xffffd
14	0xe	-2	0xffffe
15	0xf	-1	0xfffff

**Restrictions:**

None

**Operation:**

```
temp ← GPR[rd] + sign_extend(immediate)
GPR[rd] ← temp
```

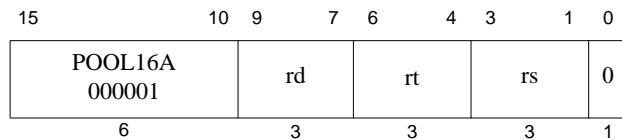
**Exceptions:**

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. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.





**Format:** ADDU16 rd, rs, rt

microMIPS

**Purpose:** Add Unsigned Word (16-bit instr size)

To add 32-bit integers

**Description:**  $\text{GPR}[\text{rd}] \leftarrow \text{GPR}[\text{rs}] + \text{GPR}[\text{rt}]$

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:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

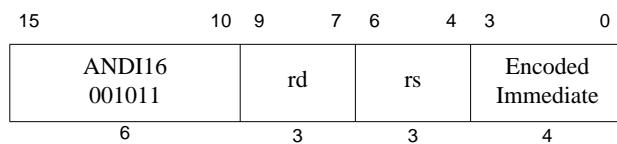
```
temp ← GPR[rs] + GPR[rt]
GPR[rd] ← temp
```

#### 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. This instruction is appropriate for unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.



**Format:** ANDI16 rd, rs, decoded\_immediate\_value

microMIPS

**Purpose:** And Immediate (16-bit instr size)

To do a bitwise logical AND with a constant

**Description:** GPR[rd]  $\leftarrow$  GPR[rs] AND decoded immediate value

The encoded immediate field is decoded to obtain the actual immediate value

The decoded immediate is zero-extended to the left and combined with the contents of GPR rs in a bitwise logical AND operation. The result is placed into GPR rd.

Table 5-2 Encoded and Decoded Values of Immediate Field

Encoded Value of Instr <sub>3..0</sub> (Decimal)	Encoded Value of Instr <sub>3..0</sub> (Hex)	Decoded Value of Immediate (Decimal)	Decoded Value of Immediate (Hex)
0	0x0	128	0x80
1	0x1	1	0x1
2	0x2	2	0x2
3	0x3	3	0x3
4	0x4	4	0x4
5	0x5	7	0x7
6	0x6	8	0x8
7	0x7	15	0xf
8	0x8	16	0x10
9	0x9	31	0x1f
10	0xa	32	0x20
11	0xb	63	0x3f
12	0xc	64	0x40
13	0xd	255	0xff
14	0xe	32768	0x8000
15	0xf	65535	0xffff

**Restrictions:**

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

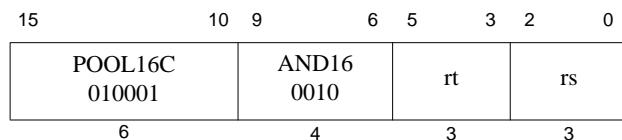
**Operation:**

```
GPR[rd] ← GPR[rs] and zero_extend(decoded immediate)
```

**Exceptions:**

None





**Format:** AND16 rt, rs

microMIPS

#### Purpose: And (16-bit instr size)

To do a bitwise logical AND

**Description:** GPR[rt]  $\leftarrow$  GPR[rs] AND GPR[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 rt.

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

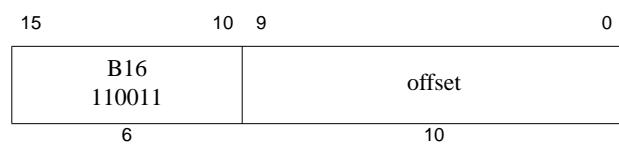
#### Operation:

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

#### Exceptions:

None



**Format:** B16 offset**microMIPS****Purpose:** Unconditional Branch (16-bit instr size)

To do an unconditional branch

**Description: branch**

A 11-bit signed offset (the 10-bit *offset* field shifted left 1 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.

**Restrictions:**

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

```
I:     target_offset ← sign_extend(offset || 01)
I+1:   PC ← PC + target_offset
```

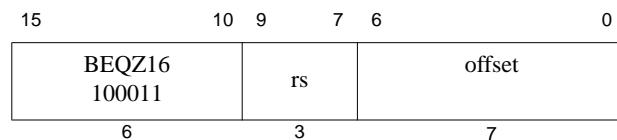
**Exceptions:**

None

**Programming Notes:**

With the 11-bit signed instruction offset, the branch range is  $\pm 1$  Kbytes. Use jump (J) or jump register (JR) or 32-bit branch instructions to branch to addresses outside this range.





**Format:** BEQZ16 rs, offset

microMIPS

**Purpose:** Branch on Equal to Zero (16-bit instr size)

To compare a GPR to zero then do a PC-relative conditional branch

**Description:** if GPR[rs] = 0 then branch

A 8-bit signed offset (the 7-bit *offset* field shifted left 1 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* equals zero, branch to the effective target address after the instruction in the delay slot is executed.

#### Restrictions:

The 3-bit register field can only specify GPRs \$2-\$7, \$16, \$17.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I:      target_offset ← sign_extend(offset || 0)
              condition ← (GPR[rs] == 0)
I+1:    if condition then
                  PC ← PC + target_offset
              endif
  
```

#### Exceptions:

None

#### Programming Notes:

With the 8-bit signed instruction offset, the conditional branch range is  $\pm 64$  Bytes. Use 32-bit branch, jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	16 15	0
POOL32I 010000	BEQZC 00111	rs	offset	

6                    5                    5                    16

**Format:** BEQZC rs, offset**microMIPS****Purpose:** Branch on Equal to Zero, Compact

To test a GPR then do a PC-relative conditional branch.

**Description:** if (GPR[rs] = 0) then branch

The 16-bit *offset* is shifted left 1 bit, sign-extended, and then added to the address of the instruction after the branch to form the target address. If the contents of GPR *rs* is equal to zero, the program branches to the target address, with no delay slot instruction.

**Restrictions:**Processor operation is **UNPREDICTABLE** if the instruction is placed in a delay slot of a branch or jump.**Operation:**

```
I:     tgt_offset ← sign_extend(offset || 0)
      condition ← (GPR[rs] = 0GPRLEN)
      if condition then
          PC ← PC + 4 + tgt_offset
      endif
```

**Exceptions:**

None

**Programming Notes:**

Unlike most MIPS ‘branch’ instructions, BEQZC does not have a delay slot.



31	26 25	21 20	16 15	0
POOL32I 010000	BGEZALS 10011	rs	offset	

6                    5                    5                    16

**Format:** BGEZALS rs, offset

microMIPS

**Purpose:** Branch on Greater Than or Equal to Zero and Link, Short Delay-Slot

To test a GPR then do a PC-relative conditional procedure call

**Description:** if  $GPR[rs] \geq 0$  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 continues after a procedure call.

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of BGEZAL.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when reexecuted. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by reexecuting the branch when an exception occurs in the branch delay slot.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] ≥ 0GPRLEN
      GPR[31] ← PC + 6
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

BGEZALS r0, offset, expressed as BAL offset, is the assembly idiom used to denote a PC-relative branch and link. BAL is used in a manner similar to JAL, but provides PC-relative addressing and a more limited target PC range.



31	26 25	21 20	16 15	0
POOL32I 010000	BLTZALS 10001	rs	offset	

6                    5                    5                    16

**Format:** BLTZALS rs, offset

microMIPS

**Purpose:** Branch on Less Than Zero and Link, Short Delay-Slot

To test a GPR then do a PC-relative conditional procedure call

**Description:** if GPR[rs] < 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 continues after a procedure call.

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of BLTZAL.GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when reexecuted. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by reexecuting the branch when an exception occurs in the branch delay slot.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

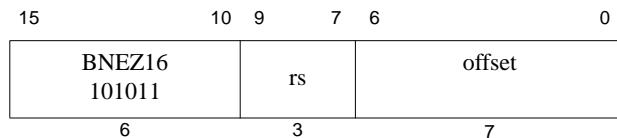
I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] < 0GPRLEN
      GPR[31] ← PC + 6
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.





**Format:** BNEZ16 rs, offset

microMIPS

**Purpose:** Branch on Not Equal to Zero (16-bit instr size)

To compare a GPR to zero then do a PC-relative conditional branch

**Description:** if GPR[rs] != 0 then branch

A 8-bit signed offset (the 7-bit *offset* field shifted left 1 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* does not equal zero, branch to the effective target address after the instruction in the delay slot is executed.

#### Restrictions:

The 3-bit register field can only specify GPRs \$2-\$7, \$16, \$17.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I:      target_offset ← sign_extend(offset || 0)
              condition ← (GPR[rs] != 0)
I+1:    if condition then
                  PC ← PC + target_offset
              endif
  
```

#### Exceptions:

None

#### Programming Notes:

With the 8-bit signed instruction offset, the conditional branch range is  $\pm 64$  Bytes. Use 32-bit branch, jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	16 15	0
POOL32I 010000	BNEZC 00101	rs	offset	

6                    5                    5                    16

**Format:** BNEZC rs, offset**microMIPS****Purpose:** Branch on Not Equal to Zero, Compact

To test a GPR then do a PC-relative conditional branch.

**Description:** if ( $\text{GPR}[\text{rs}] \neq 0$ ) then branch

The 16-bit *offset* is shifted left 1 bit, sign-extended, and then added to the address of the instruction after the branch to form the target address. If the contents of GPR *rs* is not equal to zero, the program branches to the target address, with no delay slot instruction.

**Restrictions:**Processor operation is **UNPREDICTABLE** if the instruction is placed in a delay slot of a branch or jump.**Operation:**

```
I:     tgt_offset ← sign_extend(offset || 0)
      condition ← ( $\text{GPR}[\text{rs}] \neq 0^{\text{GPRLEN}}$ )
      if condition then
          PC ← PC + 4 + tgt_offset
      endif
```

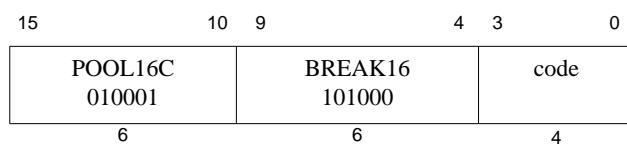
**Exceptions:**

None

**Programming Notes:**

Unlike most MIPS ‘branch’ instructions, BNEZC does not have a delay slot.





**Format:** BREAK16

microMIPS

**Purpose:** Breakpoint

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:**

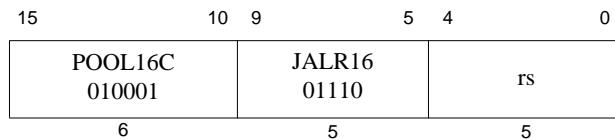
None

**Operation:**

SignalException(Breakpoint)

**Exceptions:**

Breakpoint

**Format:** JALR16 rs**microMIPS****Purpose:** Jump and Link Register (16-bit instr size)

To execute a procedure call to an instruction address in a register

**Description:** GPR[31]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs]

Place the return address link in GPR r31. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.

*For processors that do not implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR rs bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

**Restrictions:**The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JALR16.

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR rs.

For processors which implement MIPS32 and if the ISAMode bit of the target is MIPS32 (bit 0 of GPR rs is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32 ISA, if the intended target ISAMode is MIPS32 (bit 0 of GPR rs is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

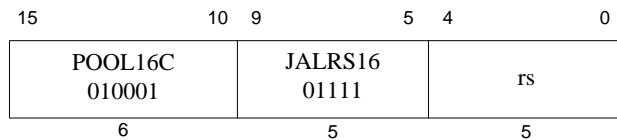
Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I: temp  $\leftarrow$  GPR[rs]
      GPR[31]  $\leftarrow$  PC + 6
I+1:if ConfigISA = 1 then
      PC  $\leftarrow$  temp
    else
      PC  $\leftarrow$  tempGPRLEN-1..1 || 0
      ISAMode  $\leftarrow$  temp0
    endif
  
```

**Exceptions:**

None

**Format:** JALRS16 rs**microMIPS****Purpose:** Jump and Link Register, Short Delay-Slot(16-bit instr size)

To execute a procedure call to an instruction address in a register

**Description:** GPR[31]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs]Place the return address link in GPR *r31*. The return link is the address of the second instruction following the branch, where execution continues after a procedure call.*For processors that do not implement the MIPS32 ISA:*

- Jump to the effective target address in GPR *rs*. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32 ISA:*

- Jump to the effective target address in GPR *rs*. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR *rs* bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

**Restrictions:**The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of JALRS16.If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR *rs*.For processors which implement MIPS32 and if ISAMode bit of the target is MIPS32 (bit 0 of GPR *rs* is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.For processors that do not implement MIPS32 ISA, if the target ISAMode is MIPS32 (bit 0 of GPR *rs* is zero), an Address Error exception occurs when the jump target is fetched as an instruction.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I: temp  $\leftarrow$  GPR[rs]
      GPR[31]  $\leftarrow$  PC + 4
I+1:if ConfigISA = 1 then
      PC  $\leftarrow$  temp
    else
      PC  $\leftarrow$  tempGPRLEN-1..1 || 0
      ISAMode  $\leftarrow$  temp0
    endif
  
```

**Exceptions:**

None

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	JALRS 0100111100	POOL32AXf 111100	6

**Format:** JALRS rs (rt = 31 implied)  
JALRS rt, rs

microMIPS  
microMIPS

**Purpose:** Jump and Link Register, Short Delay Slot

To execute a procedure call to an instruction address in a register

**Description:** GPR[rt]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs]

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

*For processors that do not implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR rs bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

#### Restrictions:

The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of JALRS.

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

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR rs.

For processors which implement MIPS32 and if if ISAMode bit of the target is MIPS32 (bit 0 of GPR rs is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32ISA, if the intended target ISAMode is MIPS32(bit 0 of GPR rs is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I: temp  $\leftarrow$  GPR[rs]
      GPR[rt]  $\leftarrow$  PC + 6
I+1:if Config1CA = 0 then
          PC  $\leftarrow$  temp
      else

```

```
PC ← tempGPRLEN-1..1 || 0
ISAMode ← temp0
endif
```

**Exceptions:**

None

**Programming Notes:**

This branch-and-link instruction can select a register for the return link; 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	16 15	6 5	0
POOL32A 000000	rd	rs	JALRS.HB 0101111100	POOL32AXf 111100	6

**Format:** JALRS.HB rs (rt = 31 implied)  
JALRS.HB rt, rs

microMIPS  
microMIPS

#### Purpose: Jump and Link Register with Hazard Barrier, Short Delay-Slot

To execute a procedure call to an instruction address in a register and clear all execution and instruction hazards

**Description:** GPR[rt]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs], clear execution and instruction hazards

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

*For processors that do not implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR rs bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

JALRS.HB implements a software barrier that resolves all execution and instruction hazards created by Coprocessor 0 state changes (for Release 2 implementations, refer to the SYNCI instruction for additional information on resolving instruction hazards created by writing the instruction stream). The effects of this barrier are seen starting with the instruction fetch and decode of the instruction at the PC to which the JALRS.HB instruction jumps. An equivalent barrier is also implemented by the ERET instruction, but that instruction is only available if access to Coprocessor 0 is enabled, whereas JALRS.HB is legal in all operating modes.

This instruction clears both execution and instruction hazards. Refer to the [EHB](#) instruction description for the method of clearing execution hazards alone.

#### Restrictions:

The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of JALRS.HB.

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

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR rs.

For processors which implement MIPS32 and if ISAMode bit of the target is MIPS32 (bit 0 of GPR rs is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32 ISA, if the intended target ISAMode is MIPS32 (bit 0 of GPR rs is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

After modifying an instruction stream mapping or writing to the instruction stream, execution of those instructions has **UNPREDICTABLE** behavior until the instruction hazard has been cleared with JALR.HB, JALRS.HB, JR.HB, ERET, or DERET. Further, the operation is **UNPREDICTABLE** if the mapping of the current instruction stream is modified.

JALRS.HB does not clear hazards created by any instruction that is executed in the delay slot of the JALRS.HB. Only hazards created by instructions executed before the JALR.HB are cleared by the JALRS.HB.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I: temp ← GPR[rs]
      GPR[rt] ← PC + 6
I+1:if Config1CA = 0 then
      PC ← temp
    else
      PC ← tempGPRLEN-1..1 || 0
      ISAMode ← temp0
    endif
    ClearHazards()
  
```

#### Exceptions:

None

#### Programming Notes:

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

This instruction implements the final step in clearing execution and instruction hazards before execution continues. A hazard is created when a Coprocessor 0 or TLB write affects execution or the mapping of the instruction stream, or after a write to the instruction stream. When such a situation exists, software must explicitly indicate to hardware that the hazard should be cleared. Execution hazards alone can be cleared with the EHB instruction. Instruction hazards can only be cleared with a JR.HB, JALR.HB, JALRS.HB or ERET instruction. These instructions cause hardware to clear the hazard before the instruction at the target of the jump is fetched. Note that because these instructions are encoded as jumps, the process of clearing an instruction hazard can often be included as part of a call (JALR[S][16]) or return (JR) sequence, by simply replacing the original instructions with the HB equivalent.

Example: Clearing hazards due to an ASID change

```

/*
 * Code used to modify ASID and call a routine with the new
 * mapping established.
 *
 * a0 = New ASID to establish
 * a1 = Address of the routine to call
 */
    mfc0    v0, C0_EntryHi      /* Read current ASID */
    li      v1, ~M_EntryHiASID /* Get negative mask for field */
    and    v0, v0, v1          /* Clear out current ASID value */
    or     v0, v0, a0          /* OR in new ASID value */
    mtc0    v0, C0_EntryHi      /* Rewrite EntryHi with new ASID */
    jalr.hb a1                  /* Call routine, clearing the hazard */
    nop
  
```

31	26 25	0
JALS32 011101	instr_index	26

**Format:** JALS target**microMIPS****Purpose:** Jump and Link, Short Delay Slot

To execute a procedure call within the current 128 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, at which location execution continues after a procedure call.

This is a PC-region branch (not PC-relative); the effective target address is in the “current” 128 MB-aligned region. The low 27 bits of the target address is the *instr\_index* field shifted left 1 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 that follows the jump, in the branch delay slot, before executing the jump itself.

**Restrictions:**

The delay-slot instruction must be 16-bits in size. Processor operation is **UNPREDICTABLE** if a 32-bit instruction is placed in the delay slot of JALS.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

**I:** GPR[31]  $\leftarrow$  PC + 6  
**I+1:** PC  $\leftarrow$  PC<sub>GPRLEN-1..27</sub> || instr\_index || 0<sup>1</sup>

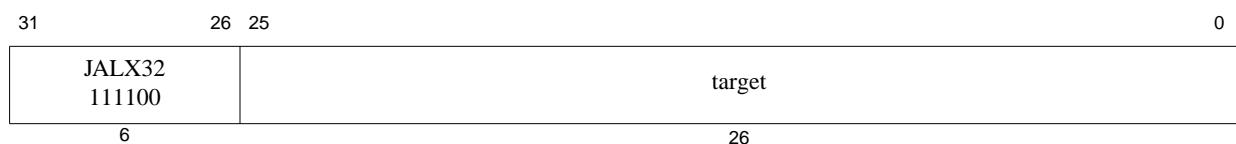
**Exceptions:**

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 128 MB region aligned on a 128 MB boundary. It allows a branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative offset.

This definition creates the following boundary case: When the branch instruction is in the last word of a 128 MB region, it can branch only to the following 128 MB region containing the branch delay slot.

**Format:** JALX target**microMIPS****Purpose:** Jump and Link Exchange (microMIPS Format)

To execute a procedure call within the current 256 MB-aligned region and change the ISA Mode from microMIPS to 32-bit MIPS.

**Description:**

Place the return address link in GPR 31. The return link is the address of the second instruction following the branch, at which location execution continues after a procedure call. The value stored in GPR 31 bit 0 reflects the current value of the *ISA Mode* bit.

This is a PC-region branch (not PC-relative); the effective target address is in the “current” 256 MB-aligned region. The low 26 bits of the target address is the *target* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction following the branch (not the branch itself).

Jump to the effective target address, toggling the *ISA Mode* bit. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself.

**Restrictions:**

The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JALX.

Processor operation is UNPREDICTABLE if a branch or jump instruction is placed in the delay slot of a jump.

If the MIPS32 ISA is not implemented, a Reserved Instruction Exception is initiated.

**Operation:**

```

I:      GPR[31] ← (PC + 8)GPRLEN-1..1 || ISAMode
I+1:    PC ← PCGPRLEN-1..28 || target || 02
          ISAMode ← (not ISAMode)
  
```

**Exceptions:**

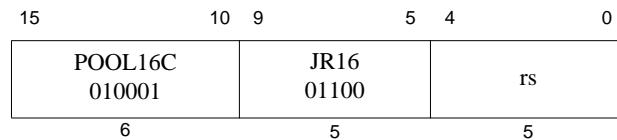
None

**Programming Notes:**

Forming the jump target address by concatenating PC and the 26-bit target address 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 jump 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 jump instruction is in the last word of a 256 MB region and can therefore jump only to the following 256 MB region containing the following instruction.



**Format:** JR16 rs**microMIPS****Purpose:** Jump Register (16-bit instr size)

To execute a branch to an instruction address in a register

**Description:**  $PC \leftarrow GPR[rs]$ Jump to the effective target address in GPR *rs*. Execute the instruction following the jump, in the branch delay slot, before jumping.For processors that implement MIPS32 ISA, set the *ISA Mode* bit to the value in GPR *rs* bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one**Restrictions:**If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR *rs*.For processors which implement MIPS32 and the ISAMode bit of the target address is MIPS32 (bit 0 of GPR *rs* is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.For processors that do not implement MIPS32 ISA, if the intended target ISAMode is MIPS32 (bit 0 of GPR *rs* is zero), an Address Error exception occurs when the jump target is fetched as an instruction.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

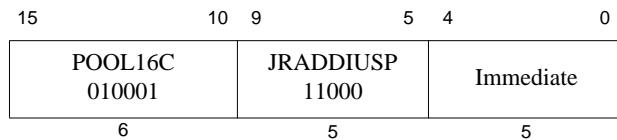
I: temp ← GPR[rs]
I+1: if Config3ISA = 1 then
        PC ← temp
    else
        PC ← tempGPRLEN-1..1 || 0
        ISAMode ← temp0
    endif

```

**Exceptions:**

None





**Format:** JRADDIUSP decoded\_immediate

microMIPS

**Purpose:** Jump Register, Adjust Stack Pointer (16-bit)

To execute a branch to an instruction address in a register and adjust stack pointer

**Description:**  $PC \leftarrow GPR[ra]; SP \leftarrow SP + \text{zero\_extend}(\text{Immediate} \ll 2)$

The program unconditionally jumps to the address specified in GPR 31. If MIPS32 is implemented, the instruction sets the *ISA Mode* bit to the value in GPR 31 bit 0.

Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

The 5-bit *immediate* field is first shifted left by two bits and then zero-extended. This amount is then added to the 32-bit value of GPR 29 and the 32-bit arithmetic result is placed into GPR 29. No Integer Overflow exception occurs under any circumstances for the update of GPR 29.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR *rs*.

For processors which implement MIPS32 and the ISAMode bit of the target address is MIPS32 (bit 0 of GPR *rs* is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32 ISA, if the intended target ISAMode is MIPS32 (bit 0 of GPR *rs* is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

#### Operation:

```

I:
  PC ← GPR[31]GPRLEN-1..1 || 0
  if ( Config3ISA > 1 )
    ISAMode ← GPR[31]0
  endif
I+1:
  temp ← GPR[29] + zero_extend(immediate || 02)
  GPR[29] ← temp

```

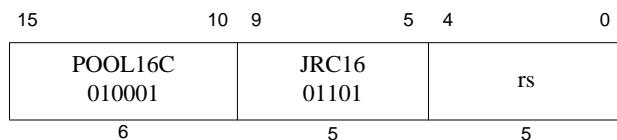
#### Exceptions:

None.

#### Programming Notes:

Unlike most MIPS “jump” instructions, JRADDIUSP does not have a delay slot.



**Format:** JRC rs**microMIPS****Purpose:** Jump Register, Compact (16-bit)

To execute a branch to an instruction address in a register

**Description:**  $\text{PC} \leftarrow \text{GPR}[rs]$ 

The program unconditionally jumps to the address specified in GPR  $rs$ , with no delay slot instruction. If MIPS32 is implemented, the instruction sets the *ISA Mode* bit to the value in GPR  $rs$  bit 0.

If MIPS32 is implemented, bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

#### **Restrictions:**

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 of GPR  $rs$ .

For processors which implement MIPS32 and the ISAMode bit of the target address is MIPS32 (bit 0 of GPR  $rs$  is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32 ISA, if the intended target ISAMode is MIPS32 (bit 0 of GPR  $rs$  is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

#### **Operation:**

```
I: PC ← GPR[rs]GPRLEN-1..1 || 0
    if ( Config3ISA > 1 )
        ISAMode ← GPR[rs1]0
    endif
```

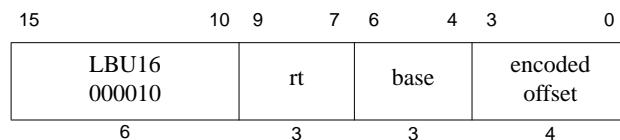
#### **Exceptions:**

None.

#### **Programming Notes:**

Unlike most MIPS “jump” instructions, JRC does not have a delay slot.





**Format:** LBU16 rt, decoded\_offset(base)

microMIPS

**Purpose:** Load Byte Unsigned (16-bit instr size)

To load a byte from memory as an unsigned value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[base] + decoded\_offset]

The encoded offset field is decoded to get the actual offset value. This decoded value is added to the contents of base register to create the effective address. [Table 5.11](#) shows the encoded and decode values of the offset field.

**Table 5.11 Offset Field Encoding Range -1, 0..14**

Encoded Input (Hex)	Decoded Value (Decimal)
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
a	10
b	11
c	12
d	13
e	14
f	-1

The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR *rt*. The 4-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

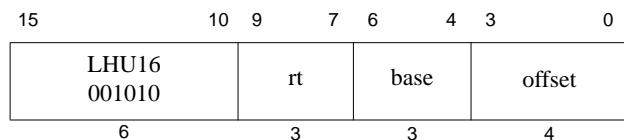
```
decoded_offset  $\leftarrow$  Decode(encoded_offset)
vAddr  $\leftarrow$  sign_extend(decoded_offset) + GPR[base]
```

```
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
memword ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor BigEndianCPU2
GPR[rt] ← zero_extend(memword7+8*byte..8*byte)
```

**Exceptions:**

TLB Refill, TLB Invalid, Address Error, Watch





**Format:** LHU16 rt, left\_shifted\_offset(base)

microMIPS

**Purpose:** Load Halfword Unsigned (16-bit instr size)

To load a halfword from memory as an unsigned value

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[\text{base}] + (\text{offset} \times 2)]$

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 4-bit unsigned *offset* is left shifted by one bit and then added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

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

#### Operation:

```

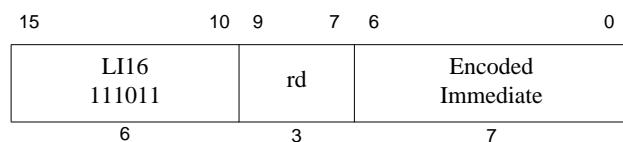
vAddr ← zero_extend(offset || 0) + GPR[base]
if vAddr0 ≠ 0 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword ← LoadMemory (CCA, HALFWORD, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt] ← zero_extend(memword15+8*byte..8*byte)

```

#### Exceptions:

TLB Refill, TLB Invalid, Address Error, Watch





**Format:** LI16 rd, decoded\_immediate

microMIPS

**Purpose:** Load Immediate Word (16-bit instr size)

To load a 6-bit constant into a register.

**Description:** GPR[rd]  $\leftarrow$  decoded\_immediate

The 7-bit encoded Immediate field is decoded to obtain the actual immediate value. Table 5.12 shows the encoded values of the Immeidate field and the actual immediate values.

**Table 5.12 LI16 -1, 0..126 Immediate Field Encoding Range**

Encoded Input (Hex)	Decoded Value (Decimal)
0	0
1	1
2	2
3	3
...	...
7e	126
7f	-1

The actual decoded immediate value is sign-extended and placed into GPR rd.

No Integer Overflow exception occurs under any circumstances.

#### Restrictions:

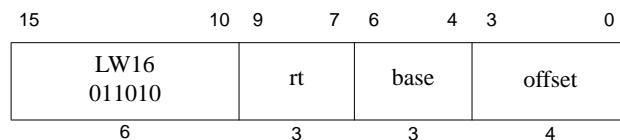
The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

```
decoded_immediate  $\leftarrow$  Decode(encoded_immediate)
temp  $\leftarrow$  sign_extend(decoded_immediate)
GPR[rd]  $\leftarrow$  temp31..0
```

#### Exceptions:

None



**Format:** LW16 rt, left\_shifted\_offset(base)

microMIPS

**Purpose:** Load Word (16-bit instr size)

To load a word from memory as a signed value

**Description:**  $\text{GPR}[rt] \leftarrow \text{memory}[\text{GPR}[base] + (\text{offset} \times 4)]$

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 4-bit signed *offset* is left shifted by two bits and then is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

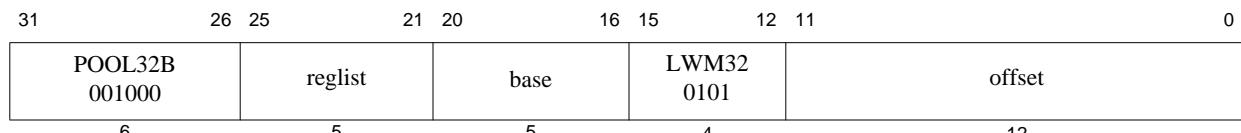
#### Operation:

```
vAddr ← sign_extend(offset || 02) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt] ← memword
```

#### Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch





**Format:** LWM32 {sre16, } {ra}, offset(base)

microMIPS

**Purpose:** Load Word Multiple

To load a sequence of consecutive words from memory

**Description:** {GPR[16], {GPR[17], {GPR[18], {GPR[19], {GPR[20], {GPR[21], {GPR[22], {GPR[23], {GPR[30]} }}}}}}}}{GPR[31]} ←  
memory[GPR[base]+offset], ..., memory[GPR[base]+offset+4\*(fn(reglist))]

The contents of consecutive 32-bit words at the memory location specified by the 32-bit aligned effective address are fetched, sign-extended to the GPR register length if necessary, and placed in the GPRs defined by *reglist*. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The following table shows the encoding of the *reglist* field.

reglist Encoding (binary)	List of Registers Loaded
0 0 0 0 1	GPR[16]
0 0 0 1 0	GPR[16], GPR[17]
0 0 0 1 1	GPR[16], GPR[17], GPR[18]
0 0 1 0 0	GPR[16], GPR[17], GPR[18], GPR[19]
0 0 1 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20]
0 0 1 1 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21]
0 0 1 1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22]
0 1 0 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23]
0 1 0 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[30]
1 0 0 0 0	GPR[31]
1 0 0 0 1	GPR[16], GPR[31]
1 0 0 1 0	GPR[16], GPR[17], GPR[31]
1 0 0 1 1	GPR[16], GPR[17], GPR[18], GPR[31]
1 0 1 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[31]
1 0 1 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[31]
1 0 1 1 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[31]
1 0 1 1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[31]
1 1 0 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[31]

<b>reglist Encoding (binary)</b>	<b>List of Registers Loaded</b>
1 1 0 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[30], GPR[31]
All other combinations	Reserved

The register numbers and the effective addresses are correlated using the order listed in the table, starting with the left-most register on the list and ending with the right-most register on the list. The effective address is incremented for each subsequent register on the list.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of the instruction is **UNPREDICTABLE**, if *base* is included in *reglist*. Reason for this is to allow restartability of the operation if an interrupt or exception has aborted the operation in the middle.

The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

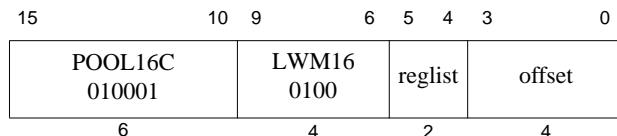
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
for i←0 to fn(reglist)
    (pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
    memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
    GPR[gpr(reglist,i)] ← memword
    vAddr ← vAddr + 4
endfor

function fn(list)
    fn ← (number of entries in list) - 1
endfunction

```

#### Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch



**Format:** LWM16 s0, {s1, {s2, {s3, }}} ra, left\_shifted\_offset(sp)

microMIPS

**Purpose:** Load Word Multiple (16-bit)

To load a sequence of consecutive words from memory

**Description:** GPR[16], {GPR[17], {GPR[18], {GPR[19], }}} GPR[31] ← memory[GPR[29]+(offset<<2)],...,memory[GPR[19]+(offset<<2)+4\*(fn(reglist))]

The contents of consecutive 32-bit words at the memory location specified by the 32-bit aligned effective address are fetched, sign-extended to the GPR register length if necessary, and placed in the GPRs defined by *reglist*. The 4-bit unsigned *offset* is first left shifted by two bits and then added to the contents of GPR *sp* to form the effective address.

The following table shows the encoding of the *reglist* field.

<b>reglist Encoding (binary)</b>	<b>List of Registers Loaded</b>
0 0	GPR[16], GPR[31]
0 1	GPR[16], GPR[17], GPR[31]
1 0	GPR[16], GPR[17], GPR[18], GPR[31]
1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[31]

The register numbers and the effective addresses are correlated using the order listed in the table, starting with the left-most register on the list and ending with the right-most register on the list. The effective address is incremented for each subsequent register on the list.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

vAddr ← zero_extend(offset || 02) + GPR[sp]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
for i←0 to fn(reglist)
    (pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
    memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
    GPR[gpr(reglist,i)] ← memword
    vAddr ← vAddr + 4
endfor

```

```
function fn(list)
    fn ← number of entries in list - 1
endfunction
```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch

31	26 25	21 20	16 15	12 11	0
POOL32B 001000	rd	base	LWP 0001	offset	

**Format:** LWP rd, offset(base)

microMIPS

#### Purpose:

To load two consecutive words from memory

**Description:** GPR[rd], GPR[rd+1]  $\leftarrow$  memory[GPR[base] + offset]

The contents of the two consecutive 32-bit words at the memory location specified by the 32-bit aligned effective address are fetched, sign-extended to the GPR register length if necessary, and placed in GPR *rd* and (*rd+1*). The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of the instructions is **UNPREDICTABLE** if *rd* equals r31.

The behavior of the instruction is **UNPREDICTABLE**, if *base* and *rd* are the same. Reason for this is to allow restartability of the operation if an interrupt or exception has aborted the operation in the middle.

The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

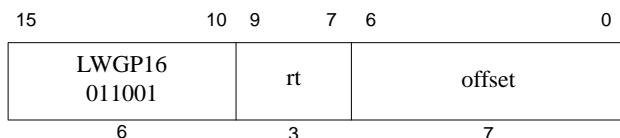
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rd]  $\leftarrow$  memword
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base] + 4
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rd+1]  $\leftarrow$  memword

```

#### Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch





**Format:** LWGP rt, left\_shifted\_offset(gp)

microMIPS

**Purpose:** Load Word from Global Pointer (16-bit instr size)

To load a word from memory as a signed value

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[28] + (\text{offset} \times 4)]$

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 7-bit signed *offset* is left shifted by two bits and then added to the contents of GPR 28 to form the effective address.

#### Restrictions:

The 3-bit register field can only specify GPRs \$2-\$7, \$16, \$17.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

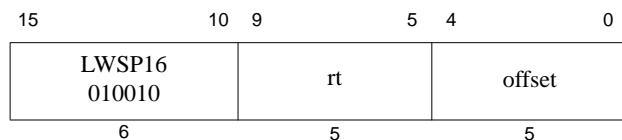
#### Operation:

```
vAddr ← sign_extend(offset || 02) + GPR[28]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt] ← memword
```

#### Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch





**Format:** LWSP rt, left\_shifted\_offset(sp)

microMIPS

**Purpose:** Load Word from Stack Pointer (16-bit instr size)

To load a word from memory as a signed value

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[29] + (\text{offset} \times 4)]$

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 5-bit signed *offset* is left shifted by two bits, zero-extended and then is added to the contents of GPR 29 to form the effective address.

#### Restrictions:

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```

vAddr ← zero_extend(offset || 02) + GPR[29]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt] ← memword

```

#### Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	index	base	rd	0	LWXs 0100011000

6                    5                    5                    5                    1                    10

**Format:** LWXS rd, index(base)

microMIPS

**Purpose:** Load Word Indexed, Scaled

To load a word from memory as a signed value, using scaled indexed addressing.

**Description:** GPR[rd]  $\leftarrow$  memory[GPR[base] + (GPR[index]  $\times$  4)]

The contents of GPR *index* is multiplied by 4 and the result 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 placed in GPR *rd*.

**Restrictions:**

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

**Operation:**

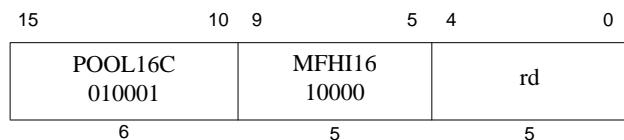
```

vAddr  $\leftarrow$  (GPR[index]29..0 || 02) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rd]  $\leftarrow$  memword

```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error

**Format:** MFHI16 rd**microMIPS****Purpose:** Move From HI Register (16-bit instr size)To copy the special purpose *HI* register to a GPR**Description:** GPR[rd] ← HIThe contents of special register *HI* are loaded into GPR *rd*.**Restrictions:**

None

**Operation:**

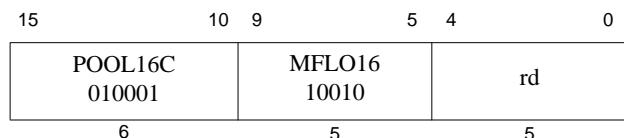
GPR[rd] ← HI

**Exceptions:**

None

**Historical Information:**

In the MIPS I, II, and III architectures, the two instructions which follow the MFHI must not modify the *HI* register. If this restriction is violated, the result of the MFHI is **UNPREDICTABLE**. This restriction was removed in MIPS IV and MIPS32, and all subsequent levels of the architecture.

**Format:** MFLO16 rd**microMIPS****Purpose:** Move From LO RegisterTo copy the special purpose *LO* register to a GPR**Description:** GPR[rd] ← LOThe contents of special register *LO* are loaded into GPR *rd*.**Restrictions:**

None

**Operation:**

GPR[rd] ← LO

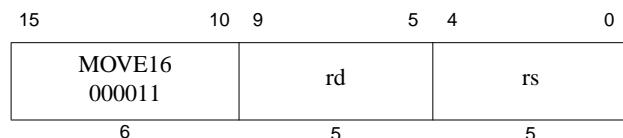
**Exceptions:**

None

**Historical Information:**

In the MIPS I, II, and III architectures, the two instructions which follow the MFHI must not modify the *HI* register. If this restriction is violated, the result of the MFHI is **UNPREDICTABLE**. This restriction was removed in MIPS IV and MIPS32, and all subsequent levels of the architecture.





**Format:** MOVE16 rd, rs

microMIPS

**Purpose:** Move Register (16-bit instr size)

To copy one GPR to another GPR.

**Description:**  $\text{GPR}[rd] \leftarrow \text{GPR}[rs]$

The contents of GPR *rs* are placed into GPR *rd*.

**Restrictions:**

None

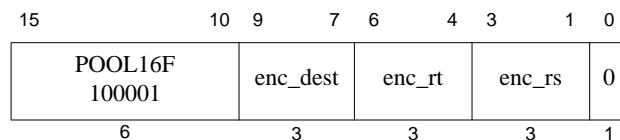
**Operation:**

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

**Exceptions:**

None



**Format:** MOVEP rd, re, rs, rt**microMIPS****Purpose:** Move a Pair of Registers

To copy two GPRs to another two GPRs.

**Description:**  $\text{GPR}[rd] \leftarrow \text{GPR}[rs]; \text{GPR}[re] \leftarrow \text{GPR}[rt];$ The contents of GPR *rs* are placed into GPR *rd*. The contents of GPR *rt* are placed into GPR *re*.The register numbers *rd* and *re* are determined by the encoded *enc\_dest* field:**Table 5.13 Encoded and Decoded Values of the Enc\_Dest Field**

Encoded Value of Instr <sub>9..7</sub> (Decimal)	Encoded Value of Instr <sub>9..7</sub> (Hex)	Decoded Value of <i>rd</i> (Decimal)	Decoded Value of <i>re</i> (Decimal)
0	0x0	5	6
1	0x1	5	7
2	0x2	6	7
3	0x3	4	21
4	0x4	4	22
5	0x5	4	5
6	0x6	4	6
7	0x7	4	7

The register numbers *rs* and *rt* are determined by the encoded *enc\_rs* and *enc\_rt* fields:

**Table 5.14 Encoded and Decoded Values of the Enc\_rs and Enc\_rt Fields**

Encoded Value of Instr <sub>6..4</sub> (or Instr <sub>3..1</sub> ) (Decimal)	Encoded Value of Instr <sub>6..4</sub> (or Instr <sub>3..1</sub> ) (Hex)	Decoded Value of rt (or rs) (Decimal)	Symbolic Name (From ArchDefs.h)
0	0x0	0	zero
1	0x1	17	s1
2	0x2	2	v0
3	0x3	3	v1
4	0x4	16	s0
5	0x5	18	s2
6	0x6	19	s3
7	0x7	20	s4

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The destination register pair field, *enc\_dest*, can only specify the register pairs defined in [Table 5.13](#).

The source register fields *enc\_rs* and *enc\_rt* can only specify GPRs 0,2-3,16-20.

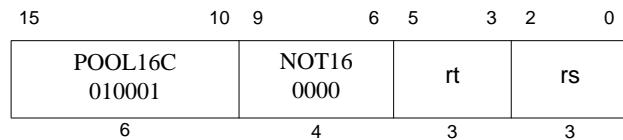
The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

GPR[rd]  $\leftarrow$  GPR[rs]; GPR[re]  $\leftarrow$  GPR[rt]

#### Exceptions:

None

**Format:** NOT16 rt, rs**microMIPS****Purpose:** Invert (16-bit instr size)

To do a bitwise logical inversion.

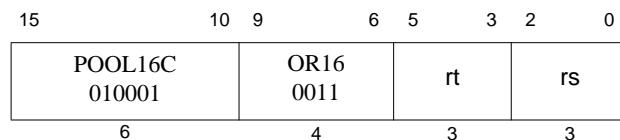
**Description:**  $GPR[rt] \leftarrow GPR[rs] \text{ XOR } 0xffffffff$ Invert the contents of GPR *rs* in a bitwise fashion and place the result into GPR *rt*.**Restrictions:**

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

**Operation:** $GPR[rt] \leftarrow GPR[rs] \text{ xor } 0xffffffff$ **Exceptions:**

None



**Format:** OR16 rt, rs**MIPS32****Purpose:** Or (16-bit instr size)

To do a bitwise logical OR

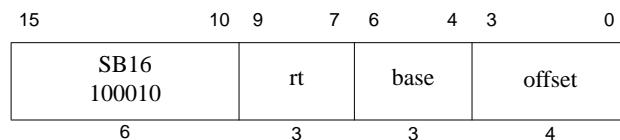
**Description:**  $\text{GPR}[rt] \leftarrow \text{GPR}[rs] \text{ or } \text{GPR}[rt]$ The contents of GPR *rs* are combined with the contents of GPR *rt* in a bitwise logical OR operation. The result is placed into GPR *rt*.**Restrictions:**

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

**Operation:** $\text{GPR}[rt] \leftarrow \text{GPR}[rs] \text{ or } \text{GPR}[rt]$ **Exceptions:**

None





**Format:** SB16 rt, offset(base)

microMIPS

**Purpose:** Store Byte (16-bit instr size)

To store a byte to memory

**Description:**  $\text{memory}[\text{GPR}[\text{base}] + \text{offset}] \leftarrow \text{GPR}[\text{rt}]$

The least-significant 8-bit byte of GPR *rt* is stored in memory at the location specified by the effective address. The 4-bit unsigned *offset* is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit *base* register field can only specify GPRs \$2-\$7, \$16, \$17.

The 3-bit *rt* register field can only specify GPRs \$0, \$2-\$7, \$17.

#### Operation:

```

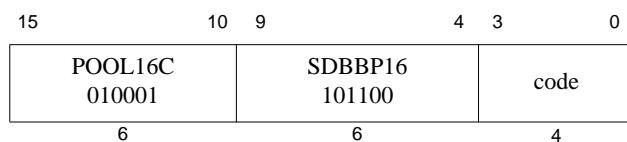
vAddr ← zero_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
bytesel ← vAddr1..0 xor BigEndianCPU2
dataword ← GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, BYTE, dataword, pAddr, vAddr, DATA)

```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error, Watch



**Format:** SDBBP16 code**EJTAG+microMIPS****Purpose:** Software Debug Breakpoint (16-bit instr size)

To cause a debug breakpoint exception

**Description:**

This instruction causes a debug exception, passing control to the debug exception handler. If the processor is executing in Debug Mode when the SDBBP instruction is executed, the exception is a Debug Mode Exception, which sets the DebugDExcCode field to the value 0x9 (Bp). The code field can be used for passing information to the debug exception handler, and is retrieved by the debug exception handler only by loading the contents of the memory word containing the instruction, using the DEPC register. The CODE field is not used in any way by the hardware.

**Restrictions:****Operation:**

```

If DebugDM = 0 then
    SignalDebugBreakpointException()
else
    SignalDebugModeBreakpointException()
endif

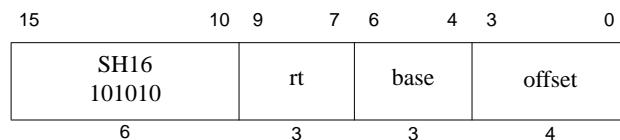
```

**Exceptions:**

Debug Breakpoint Exception

Debug Mode Breakpoint Exception





**Format:** SH16 rt, left\_shifted\_offset(base)

microMIPS

**Purpose:** Store Halfword (16-bit instr size)

To store a halfword to memory

**Description:** `memory[GPR[base] + (offset × 2)] ← GPR[rt]`

The least-significant 16-bit halfword of register *rt* is stored in memory at the location specified by the aligned effective address. The 4-bit unsigned *offset* is left shifted by one bit and then added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit *base* register field can only specify GPRs \$2-\$7, \$16, \$17.

The 3-bit *rt* register field can only specify GPRs \$0, \$2-\$7, \$17.

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

#### Operation:

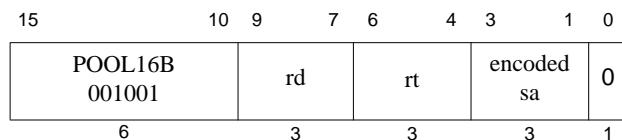
```

vAddr ← zero_extend(offset || 0) + GPR[base]
if vAddr0 ≠ 0 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
bytesel ← vAddr1..0 xor (BigEndianCPU || 0)
dataword ← GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, HALFWORD, dataword, pAddr, vAddr, DATA)

```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



**Format:** SLL16 rd, rt, decoded\_sa

microMIPS

**Purpose:** Shift Word Left Logical (16-bit instr size)

To left-shift a word by a fixed number of bits

**Description:** GPR[rd]  $\leftarrow$  GPR[rt]  $\ll$  decoded\_sa

The contents of the low-order 32-bit word of GPR rt are shifted left, inserting zeros into the emptied bits; the word result is placed in GPR rd. The bit-shift amount is specified by decoding the *encoded\_sa* field. Table 5.15 lists the encoded values of the *encoded\_sa* field and the actual bit shift amount values.

**Table 5.15 Shift Amount Field Encoding**

Encoded Input (Hex)	Decoded Value (Decimal)
0	8
1	1
2	2
3	3
4	4
5	5
6	6
7	7

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

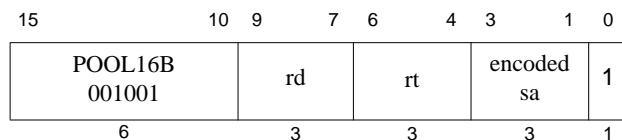
#### Operation:

```
decoded_sa  $\leftarrow$  DECODE(encoded_sa)
s  $\leftarrow$  decoded_sa
temp  $\leftarrow$  GPR[rt](31-s)... || 0s
GPR[rd]  $\leftarrow$  temp
```

#### Exceptions:

None

#### Programming Notes:



**Format:** SRL16 rd, rt, decoded\_sa

microMIPS

**Purpose:** Shift Word Right Logical (16-bit instr size)

To execute a logical right-shift of a word by a fixed number of bits

**Description:**  $\text{GPR}[rd] \leftarrow \text{GPR}[rt] \gg \text{decoded\_sa}$  (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 amount is specified by *s* by decoding the *encoded\_sa* field. Table 5.16 lists the encoded values of the *encoded\_sa* field and the actual bit shift amount values.

**Table 5.16 Shift Amount Field Encoding**

Encoded Input (Hex)	Decoded Value (Decimal)
0	8
1	1
2	2
3	3
4	4
5	5
6	6
7	7

#### Restrictions:

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

#### Operation:

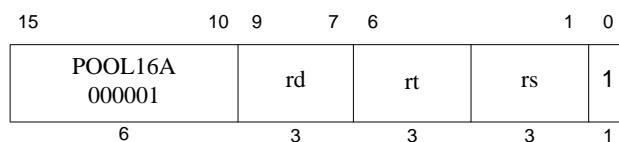
```

decoded_sa <- DECODE(encoded_sa)
s <- decoded_sa
temp <- 0s || GPR[rt]31..s
GPR[rd] <- temp

```

#### Exceptions:

None

**Format:** SUBU16 rd, rs, rt**microMIPS****Purpose:** Subtract Unsigned Word (16-bit instr size)

To subtract 32-bit integers

**Description:**  $GPR[rd] \leftarrow GPR[rs] - GPR[rt]$ 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:**

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

**Operation:**

```
temp ← GPR[rs] - GPR[rt]
GPR[rd] ← temp
```

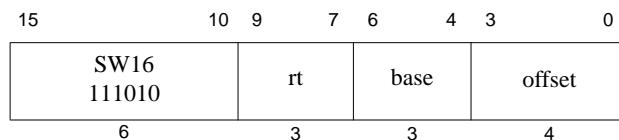
**Exceptions:**

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 unsigned arithmetic, such as address arithmetic, or integer arithmetic environments that ignore overflow, such as C language arithmetic.





**Format:** SW16 rt, left\_shifted\_offset(base)

microMIPS

**Purpose:** Store Word (16-bit instr size)

To store a word to memory

**Description:** `memory[GPR[base] + (offset × 4)] ← GPR[rt]`

The least-significant 32-bit word of GPR *rt* is stored in memory at the location specified by the aligned effective address. The 4-bit unsigned *offset* is left-shifted by two bits and then added to the contents of GPR *base* to form the effective address.

#### Restrictions:

The 3-bit *base* register field can only specify GPRs \$2-\$7, \$16, \$17.

The 3-bit *rt* register field can only specify GPRs \$0, \$2-\$7, \$17.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

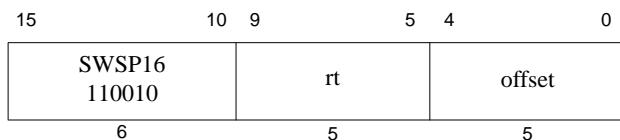
#### Operation:

```
vAddr ← zero_extend(offset || 02) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rt]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch





**Format:** SWSP rt, left\_shifted\_offset(base)

microMIPS

**Purpose:** Store Word to Stack Pointer (16-bit instr size)

To store a word to memory

**Description:** `memory[GPR[29] + (offset × 4)] ← GPR[rt]`

The least-significant 32-bit word of GPR *rt* is stored in memory at the location specified by the aligned effective address. The 5-bit signed *offset* is left shifted by two bits, zero-extended and then is added to the contents of GPR 29 to form the effective address.

#### Restrictions:

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr ← zero_extend(offset || 02) + GPR[29]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rt]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



31	26 25	21 20	16 15	12 11	0
POOL32B 001000	reglist	base	SWM 1101	offset	

6                    5                    5                    4                    12

**Format:** SWM32 {sregs, } {ra}, offset(base)

microMIPS

**Purpose:** Store Word Multiple

To store a sequence of consecutive words to memory

**Description:** `memory[GPR[base]+offset], ..., memory[GPR[base]+offset+4*(fn(reglist))]` ← `{GPR[16], {GPR[17], {GPR[18], {GPR[19], {GPR[20], {GPR[21], {GPR[22], {GPR[23], {GPR[30]} }}}}}}}{GPR[31]}`

The least-significant 32-bit words of the GPRs defined by *reglist* are stored in memory at the location specified by the aligned effective address. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The following table shows the encoding of the *reglist* field.

<b>reglist Encoding (binary)</b>	<b>List of Registers Loaded</b>
0 0 0 0 1	GPR[16]
0 0 0 1 0	GPR[16], GPR[17]
0 0 0 1 1	GPR[16], GPR[17], GPR[18]
0 0 1 0 0	GPR[16], GPR[17], GPR[18], GPR[19]
0 0 1 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20]
0 0 1 1 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21]
0 0 1 1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22]
0 1 0 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23]
0 1 0 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[30]
1 0 0 0 0	GPR[31]
1 0 0 0 1	GPR[16], GPR[31]
1 0 0 1 0	GPR[16], GPR[17], GPR[31]
1 0 0 1 1	GPR[16], GPR[17], GPR[18], GPR[31]
1 0 1 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[31]
1 0 1 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[31]
1 0 1 1 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[31]
1 0 1 1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[31]
1 1 0 0 0	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[31]
1 1 0 0 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[20], GPR[21], GPR[22], GPR[23], GPR[30], GPR[31]

<i>reglist</i> Encoding (binary)	List of Registers Loaded
All other combinations	Reserved

The register numbers and the effective addresses are correlated using the order listed in the table, starting with the left-most register on the list and ending with the right-most register on the list. The effective address is incremented for each subsequent register on the list.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

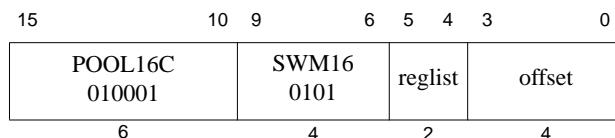
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
for i←0 to fn(reglist)
    (pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
    dataword ← GPR[gpr(reglist,i)]
    StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
    vAddr ← vAddr + 4
endfor

function fn(list)
    fn ← (number of entries in list) - 1
endfunction

```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



**Format:** SWM16 s0, {s1, {s2, {s3, }}} ra, left\_shifted\_offset(sp)

microMIPS

**Purpose:** Store Word Multiple (16-bit)

To store a sequence of consecutive words to memory

**Description:** `memory[GPR[29]], ..., memory[GPR[29]+(offset<<2)+4*(2+fn(reglist))] ← GPR[16], {GPR[17], {GPR[18], {GPR[19], }}} GPR[31]`

The least-significant 32-bit words of the GPRs defined by *reglist* are stored in memory at the location specified by the aligned effective address. The 4-bit unsigned *offset* is added to the contents of GPR *sp* to form the effective address.

The following table shows the encoding of the *reglist* field.

<b>reglist Encoding (binary)</b>	<b>List of Registers Stored</b>
0 0	GPR[16], GPR[31]
0 1	GPR[16], GPR[17], GPR[31]
1 0	GPR[16], GPR[17], GPR[18], GPR[31]
1 1	GPR[16], GPR[17], GPR[18], GPR[19], GPR[31]

The register numbers and the effective addresses are correlated using the order listed in the table, starting with the left-most register on the list and ending with the right-most register on the list. The effective address is incremented for each subsequent register on the list.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of this instruction is **UNPREDICTABLE**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

vAddr ← zero_extend(offset || 02) + GPR[sp]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
for i←0 to fn(reglist)
    (pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
    dataword ← GPR[gpr(reglist,i)]
    StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
    vAddr ← vAddr + 4
endfor

```

```
function fn(list)
    fn ← number of entries in list - 1
endfunction
```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

31	26 25	21 20	16 15	12 11	0
POOL32B 001000	rs1	base	SWP 1001	offset	

**Format:** SWP rs1, offset(base)

microMIPS

#### Purpose:

To store two consecutive words to memory

**Description:**  $\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{GPR}[rs1], \text{GPR}[rs1+1]$

The least-significant 32-bit words of GPR *rs1* and GPR *rs1+1* are stored in memory at the location specified by the aligned effective address. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

It is implementation-specific whether interrupts are disabled during the sequence of operations generated by this instruction.

#### Restrictions:

The effective address must be 32-bit aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

The behavior of the instructions is **UNDEFINED** if *rd* equals \$31.

The behavior of this instruction is **UNDEFINED**, if it is placed in a delay slot of a jump or branch.

#### Operation:

```

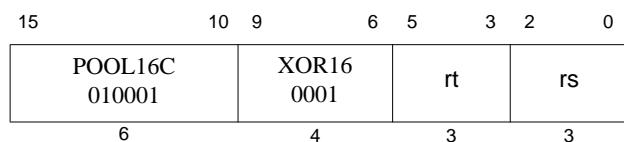
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rs1]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)

vAddr ← sign_extend(offset) + GPR[base] + 4
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rs1+1]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)

```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

**Format:** XOR16 rt, rs**microMIPS****Purpose:** Exclusive OR (16-bit instr size)

To do a bitwise logical Exclusive OR

**Description:**  $GPR[rt] \leftarrow GPR[rs] \text{ xor } GPR[rt]$ Combine the contents of GPR *rs* and GPR *rt* in a bitwise logical Exclusive OR operation and place the result into GPR *rt*.**Restrictions:**

The 3-bit register fields can only specify GPRs \$2-\$7, \$16, \$17.

**Operation:** $GPR[rt] \leftarrow GPR[rs] \text{ xor } GPR[rt]$ **Exceptions:**

None



## 5.5 Recoded 32-Bit Instructions

This section defines the recoded instructions of the existing instruction sets.



31	26 25	21 20	16 15 14 13 12	6 5	0
POOL32F 010101	ft	fs	0 fmt	ABS 0001101	POOL32FXf 111011

6                    5                    5                    1                    2                    7                    6

**Format:** ABS.fmt  
 ABS.S ft, fs  
 ABS.D ft, fs  
 ABS.PS ft, fs

microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Absolute Value

**Description:** FPR[ft]  $\leftarrow \text{abs}(\text{FPR}[fs])$

The absolute value of the value in FPR *fs* is placed in FPR *ft*. The operand and result are values in format *fmt*. ABS.PS takes the absolute value of the two values in FPR *fs* independently, and ORs together any generated exceptions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

If *FIR*<sub>Has2008</sub>=0 or *FCSR*<sub>ABS2008</sub>=0 then this operation is arithmetic. For this case , any NaN operand signals invalid operation.

If *FCSR*<sub>ABS2008</sub>=1 then this operation is non-arithmetic. For this case, both regular floating point numbers and NAN values are treated alike, only the sign bit is affected by this instruction. No IEEE exception can be generated for this case.

#### Restrictions:

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of ABS.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
StoreFPR(ft, fmt, AbsoluteValue(ValueFPR(fs, fmt)))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation, Invalid Operation



31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	ADD 0100010000

6                    5                    5                    5                    1                    10

**Format:** ADD rd, rs, rt**microMIPS****Purpose:** Add Word

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

**Description:**  $GPR[rd] \leftarrow GPR[rs] + GPR[rt]$ 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, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rd*.

**Restrictions:**

None

**Operation:**

```

temp ← (GPR[rs]31 || GPR[rs]31..0) + (GPR[rt]31 || GPR[rt]31..0)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rd] ← temp
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	11 10 9 8 7	0
POOL32F 010101	ft	fs	fd	0 fmt	ADD 00110000

6                    5                    5                    5                    1                    2                    8

**Format:** ADD fmt  
 ADD.S fd, fs, ft  
 ADD.D fd, fs, ft  
 ADD.PS fd, fs, ft

microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Add

To add floating point values

**Description:** FPR[fd]  $\leftarrow$  FPR[fs] + FPR[ft]

The value in FPR *ft* is added to the value in FPR *fs*. The result is calculated to infinite precision, rounded by using to the current rounding mode in *FCSR*, and placed into FPR *fd*. The operands and result are values in format *fmt*. ADD.PS adds the upper and lower halves of FPR *fs* and FPR *ft* independently, and ORs together any generated exceptions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

#### Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of ADD.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) +<sub>fmt</sub> ValueFPR(ft, fmt))

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation, Invalid Operation, Inexact, Overflow, Underflow



31	26 25	21 20	16 15	0
ADDI32 000100	rt	rs	immediate	

6                    5                    5                    16

**Format:** ADDI rt, rs, immediate**microMIPS****Purpose:** Add Immediate Word

To add a constant to a 32-bit integer. If overflow occurs, then trap.

**Description:**  $GPR[rt] \leftarrow GPR[rs] + \text{immediate}$ 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, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rt*.

**Restrictions:**

None

**Operation:**

```

temp ← (GPR[rs]31 || GPR[rs]31..0) + sign_extend(immediate)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rt] ← temp
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
ADDIU32 001100	rt	rs	immediate	

6                    5                    5                    16

**Format:** ADDIU rt, rs, immediate**microMIPS****Purpose:** Add Immediate Unsigned Word

To add a constant to a 32-bit integer

**Description:**  $GPR[rt] \leftarrow GPR[rs] + \text{immediate}$ 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:**

None

**Operation:**

```

temp ← GPR[rs] + sign_extend(immediate)
GPR[rt] ← 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. This instruction is appropriate for unsigned arithmetic, 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	0
POOL32A 000000	rt	rs	rd	0	ADDU 0101010000

**Format:** ADDU rd, rs, rt

microMIPS

**Purpose:** Add Unsigned Word

To add 32-bit integers

**Description:**  $GPR[rd] \leftarrow GPR[rs] + GPR[rt]$

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:

None

#### Operation:

```
temp ← GPR[rs] + GPR[rt]
GPR[rd] ← 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. This instruction is appropriate for unsigned arithmetic, 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
POOL32F 010101	ft	fs	fd	rs	ALNV.PS 011001	
6	5	5	5	5	6	

**Format:** ALNV.PS fd, fs, ft, rs

microMIPS

**Purpose:** Floating Point Align Variable

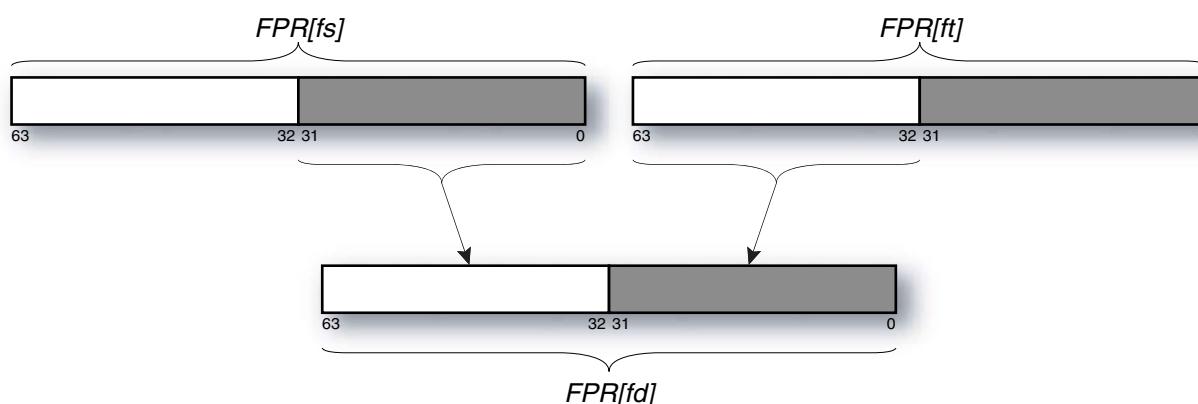
To align a misaligned pair of paired single values

**Description:**  $FPR[fd] \leftarrow \text{ByteAlign}(GPR[rs]_{2..0}, FPR[fs], FPR[ft])$

FPR  $fs$  is concatenated with FPR  $ft$  and this value is funnel-shifted by GPR  $rs_{2..0}$  bytes, and written into FPR  $fd$ . If GPR  $rs_{2..0}$  is 0, FPR  $fd$  receives FPR  $fs$ . If GPR  $rs_{2..0}$  is 4, the operation depends on the current endianness.

Figure 3-1 illustrates the following example: for a big-endian operation and a byte alignment of 4, the upper half of FPR  $fd$  receives the lower half of the paired single value in  $fs$ , and the lower half of FPR  $fd$  receives the upper half of the paired single value in FPR  $ft$ .

**Figure 5.1 Example of an ALNV.PS Operation**



The move is non arithmetic; it causes no IEEE 754 exceptions.

#### Restrictions:

The fields  $fs$ ,  $ft$ , and  $fd$  must specify FPRs valid for operands of type  $PS$ . If they are not valid, the result is **UNPREDICTABLE**.

If GPR  $rs_{1..0}$  are non-zero, the results are **UNPREDICTABLE**.

The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```

if GPR[rs]_{2..0} = 0 then
    StoreFPR(fd, PS, ValueFPR(fs, PS))
else if GPR[rs]_{2..0} ≠ 4 then
    UNPREDICTABLE
else if BigEndianCPU then
    StoreFPR(fd, PS, ValueFPR(fs, PS)_{31..0} || ValueFPR(ft, PS)_{63..32})
else
    StoreFPR(fd, PS, ValueFPR(ft, PS)_{31..0} || ValueFPR(fs, PS)_{63..32})
endif

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Programming Notes:**

ALNV.PS is designed to be used with LUXC1 to load 8 bytes of data from any 4-byte boundary. For example:

```
/* Copy T2 bytes (a multiple of 16) of data T0 to T1, T0 unaligned, T1 aligned.
   Reads one dw beyond the end of T0. */
LUXC1    F0, 0(T0) /* set up by reading 1st src dw */
LI        T3, 0      /* index into src and dst arrays */
ADDIU    T4, T0, 8   /* base for odd dw loads */
ADDIU    T5, T1, -8 /* base for odd dw stores */
LOOP:
LUXC1    F1, T3(T4)
ALNV.PS  F2, F0, F1, T0/* switch F0, F1 for little-endian */
SDC1     F2, T3(T1)
ADDIU    T3, T3, 16
LUXC1    F0, T3(T0)
ALNV.PS  F2, F1, F0, T0/* switch F1, F0 for little-endian */
BNE      T3, T2, LOOP
SDC1     F2, T3(T5)
DONE:
```

ALNV.PS is also useful with SUXC1 to store paired-single results in a vector loop to a possibly misaligned address:

```
/* T1[i] = T0[i] + F8, T0 aligned, T1 unaligned. */
CVT.PS.S F8, F8, F8/* make addend paired-single */

/* Loop header computes 1st pair into F0, stores high half if T1 */
/* misaligned */

LOOP:
LDC1    F2, T3(T4)/* get T0[i+2]/T0[i+3] */
ADD.PS  F1, F2, F8/* compute T1[i+2]/T1[i+3] */
ALNV.PS F3, F0, F1, T1/* align to dst memory */
SUXC1    F3, T3(T1)/* store to T1[i+0]/T1[i+1] */
ADDIU    T3, 16      /* i = i + 4 */
LDC1    F2, T3(T0)/* get T0[i+0]/T0[i+1] */
ADD.PS  F0, F2, F8/* compute T1[i+0]/T1[i+1] */
ALNV.PS F3, F1, F0, T1/* align to dst memory */
BNE      T3, T2, LOOP
SUXC1    F3, T3(T5)/* store to T1[i+2]/T1[i+3] */

/* Loop trailer stores all or half of F0, depending on T1 alignment */
```



31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	AND 1001010000

**Format:** AND rd, rs, rt

microMIPS

**Purpose:** And

To do a bitwise logical AND

**Description:**  $GPR[rd] \leftarrow GPR[rs] \text{ AND } GPR[rt]$

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:**

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

**Exceptions:**

None

31	26 25	21 20	16 15	0
ANDI32 110100	rt	rs	immediate	

6                    5                    5                    16

**Format:** ANDI rt, rs, immediate**microMIPS****Purpose:** And Immediate

To do a bitwise logical AND with a constant

**Description:**  $GPR[rt] \leftarrow GPR[rs] \text{ AND immediate}$ 

The 16-bit immediate is zero-extended to the left and combined with the contents of GPR rs in a bitwise logical AND operation. The result is placed into GPR rt.

**Restrictions:**

None

**Operation:** $GPR[rt] \leftarrow GPR[rs] \text{ and zero\_extend(immediate)}$ **Exceptions:**

None

31	26 25	21 20	16 15	0
BEQ32 100101	0 00000	0 00000		offset

6                    5                    5                    16

**Format:** B offset**Assembly Idiom****Purpose:** Unconditional Branch

To do an unconditional branch

**Description: branch**

B offset is the assembly idiom used to denote an unconditional branch. The actual instruction is interpreted by the hardware as BEQ r0, r0, offset.

An 17-bit signed offset (the 16-bit *offset* field shifted left 1 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.

**Restrictions:**

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

```
I:     target_offset ← sign_extend(offset || 01)
I+1:   PC ← PC + target_offset
```

**Exceptions:**

None

**Programming Notes:**

With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  Kbytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	16 15	0
POOL32I 010000	BLEZ 00100	rs	offset	

6                    5                    5                    16

**Format:** BLEZ rs, offset**microMIPS****Purpose:** Branch on Less Than or Equal to Zero

To test a GPR then do a PC-relative conditional branch

**Description:** if GPR[rs]  $\leq 0$  then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset  $\leftarrow$  sign_extend(offset || 01)
      condition  $\leftarrow$  GPR[rs]  $\leq 0^{\text{GPRLEN}}$ 
I+1:    if condition then
              PC  $\leftarrow$  PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

31	26 25	21 20	16 15	0
POOL32I 010000	BGEZAL 00011	0 00000		offset

6                    5                    5                    16

**Format:** BAL offset**Assembly Idiom****Purpose:** Branch and Link

To do an unconditional PC-relative procedure call

**Description:** procedure\_call

BAL offset is the assembly idiom used to denote an unconditional branch. The actual instruction is interpreted by the hardware as BGEZAL r0, offset.

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

An 17-bit signed offset (the 16-bit *offset* field shifted left 1 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.

**Restrictions:**

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

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 **UNPREDICTABLE**. 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:    target_offset ← sign_extend(offset || 01)
      GPR[31] ← PC + 8
I+1:  PC ← PC + target_offset
```

**Exceptions:**

None

**Programming Notes:**

With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

31	26 25	21 20	18 17 16 15	0
POOL32I 010000	BC1F 11100	cc	00	offset

6                    5                    3                    2                    16

**Format:** BC1F offset (cc = 0 implied)  
 BC1F cc, offset

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#### Purpose:

To test an FP condition code and do a PC-relative conditional branch

**Description:** if FPConditionCode(cc) = 0 then branch

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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), the program branches 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).

#### Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I:   condition ← FPConditionCode(cc) = 0
        target_offset ← (offset15)GPRLEN-(16+1) || offset || 01
I+1: if condition then
          PC ← PC + target_offset
        endif
  
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation

#### Programming Notes:

With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range

#### Historical Information:

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/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 and MIPS32 architectures add 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 and MIPS32.

In the MIPS I, II, and III architectures there must be at least one instruction between the compare instruction that sets the condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.



31	26 25	21 20	18 17 16 15	0
POOL32I 010000	BC1T 11101	cc	00	offset

6                    5                    3                    2                    16

**Format:** BC1T offset (cc = 0 implied)  
 BC1T cc, offset

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#### Purpose:

To test an FP condition code and do a PC-relative conditional branch

**Description:** if FPConditionCode(cc) = 1 then branch

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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), the program branches 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.

#### Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

```

I:    condition ← FPConditionCode(cc) = 1
        target_offset ← (offset15)GPRLEN-(16+1) || offset || 01
I+1:  if condition then
            PC ← PC + target_offset
        endif
  
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation

#### Programming Notes:

With the 17-bit signed instruction offset, the conditional branch range is ± 64 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

#### Historical Information:

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/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 and MIPS32 architectures add 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 and MIPS32.

In the MIPS I, II, and III architectures there must be at least one instruction between the compare instruction that sets the condition code and the branch instruction that tests it. Hardware does not detect a violation of this restriction.



31	26 25	21 20	18 17 16 15	0
POOL32I 010000	BC2F 10100	cc	00	offset

6                    5                    3                    2                    16

**Format:** BC2F offset (cc = 0 implied)  
 BC2F cc, offset

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**Purpose:** Branch on COP2 False

To test a COP2 condition code and do a PC-relative conditional branch

**Description:** if COP2Condition(cc) = 0 then branch

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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 COP2 condition specified by *cc* is false (0), the program branches to the effective target address after the instruction in the delay slot is executed.

#### Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

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 BC2F, BC2FL, BC2T, and BC2TL have specific values for *tf* and *nd*.

```

I:    condition ← COP2Condition(cc) = 0
        target_offset ← (offset15)GPRLEN-(16+1) || offset || 01
I+1:  if condition then
            PC ← PC + target_offset
        endif
  
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Programming Notes:

With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	18 17 16 15	0
POOL32I 010000	BC2T 10101	cc	00	offset

6                    5                    3                    2                    16

**Format:** BC2T offset (cc = 0 implied)  
 BC2T cc, offset

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 microMIPS

**Purpose:** Branch on COP2 True

To test a COP2 condition code and do a PC-relative conditional branch

**Description:** if COP2Condition(cc) = 1 then branch

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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 COP2 condition specified by *cc* is true (1), the program branches to the effective target address after the instruction in the delay slot is executed.

#### Restrictions:

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

#### Operation:

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 BC2F, BC2FL, BC2T, and BC2TL have specific values for *tf* and *nd*.

```

I:   condition ← COP2Condition(cc) = 1
        target_offset ← (offset15)GPRLEN-(16+1) || offset || 01
I+1: if condition then
          PC ← PC + target_offset
        endif
  
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Programming Notes:

With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytesj. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	16 15	0
BEQ32 100101	rt	rs	offset	

6                    5                    5                    16

**Format:** BEQ rs, rt, offset

microMIPS

**Purpose:** Branch on Equal

To compare GPRs then do a PC-relative conditional branch

**Description:** if  $GPR[rs] = GPR[rt]$  then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
            condition ← (GPR[rs] = GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

BEQ r0, r0 offset, expressed as B offset, is the assembly idiom used to denote an unconditional branch.

31	26 25	21 20	16 15	0
POOL32I 010000	BGEZ 00010	rs	offset	

6                    5                    5                    16

**Format:** BGEZ rs, offset**microMIPS****Purpose:** Branch on Greater Than or Equal to Zero

To test a GPR then do a PC-relative conditional branch

**Description:** if  $\text{GPR}[\text{rs}] \geq 0$  then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] ≥ 0GPRLEN
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

31	26 25	21 20	16 15	0
POOL32I 010000	BGEZAL 00011	rs	offset	

6                    5                    5                    16

**Format:** BGEZAL rs, offset

microMIPS

**Purpose:** Branch on Greater Than or Equal to Zero and Link

To test a GPR then do a PC-relative conditional procedure call

**Description:** if  $GPR[rs] \geq 0$  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 continues after a procedure call.

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of BGEZAL.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when reexecuted. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by reexecuting the branch when an exception occurs in the branch delay slot.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] ≥ 0GPRLEN
      GPR[31] ← PC + 8
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

BGEZAL r0, offset, expressed as BAL offset, is the assembly idiom used to denote a PC-relative branch and link. BAL is used in a manner similar to JAL, but provides PC-relative addressing and a more limited target PC range.

31	26 25	21 20	16 15	0
POOL32I 010000	BGTZ 00110	rs	offset	

6                    5                    5                    16

**Format:** BGTZ rs, offset**microMIPS****Purpose:** Branch on Greater Than Zero

To test a GPR then do a PC-relative conditional branch

**Description:** if GPR[rs] > 0 then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] > 0GPRLEN
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.



31	26 25	21 20	16 15	0
POOL32I 010000	BLTZ 00000	rs	offset	

6                    5                    5                    16

**Format:** BLTZ rs, offset

microMIPS

**Purpose:** Branch on Less Than Zero

To test a GPR then do a PC-relative conditional branch

**Description:** if GPR[rs] < 0 then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] < 0GPRLEN
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

31	26 25	21 20	16 15	0
POOL32I 010000	BLTZAL 000001	rs	offset	

6                    5                    5                    16

**Format:** BLTZAL rs, offset

microMIPS

**Purpose:** Branch on Less Than Zero and Link

To test a GPR then do a PC-relative conditional procedure call

**Description:** if GPR[rs] < 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 continues after a procedure call.

A 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of BLTZAL.GPR 31 must not be used for the source register *rs*, because such an instruction does not have the same effect when reexecuted. The result of executing such an instruction is **UNPREDICTABLE**. This restriction permits an exception handler to resume execution by reexecuting the branch when an exception occurs in the branch delay slot.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← GPR[rs] < 0GPRLEN
      GPR[31] ← PC + 8
I+1:    if condition then
              PC ← PC + target_offset
            endif
  
```

**Exceptions:**

None

**Programming Notes:**With the 17-bit signed instruction offset, the conditional branch range is  $\pm 64$  KBytes. Use jump and link (JAL) or jump and link register (JALR) instructions for procedure calls to addresses outside this range.

31	26 25	21 20	16 15	0
BNE32 101101	rt	rs	offset	

6                    5                    5                    16

**Format:** BNE rs, rt, offset**microMIPS****Purpose:** Branch on Not Equal

To compare GPRs then do a PC-relative conditional branch

**Description:** if GPR[rs] ≠ GPR[rt] then branchA 17-bit signed offset (the 16-bit *offset* field shifted left 1 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:**Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I:      target_offset ← sign_extend(offset || 01)
      condition ← (GPR[rs] ≠ GPR[rt])
I+1:    if condition then
            PC ← PC + target_offset
        endif
  
```

**Exceptions:**

None

**Programming Notes:**

With the 17-bit signed instruction offset, the conditional branch range is ± 64 KBytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside this range.

31	26 25		6 5	0
POOL32A 000000		code	BREAK32 000111	

6                    20                    6

**Format:** BREAK

microMIPS

**Purpose:** Breakpoint

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

31	26 25	21 20	16 15	13 12	11 10	9	6 5	0
POOL32F 010101	ft	fs	cc	0	fmt	cond	c.cond(fmt 111100	6

**Format:**

C.cond fmt  
 C.cond.S fs, ft (cc = 0 implied)  
 C.cond.D fs, ft (cc = 0 implied)  
 C.cond.PS fs, ft (cc = 0 implied)  
 C.cond.S cc, fs, ft  
 C.cond.D cc, fs, ft  
 C.cond.PS cc, fs, ft

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**Purpose:** Floating Point Compare

To compare FP values and record the Boolean result in a condition code

**Description:** `FPConditionCode(cc) ← FPR[fs] compare_cond FPR[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*<sub>2..1</sub> is true for the operand values, the result is true; otherwise, the result is false. If no exception is taken, the result is written into condition code *CC*; true is 1 and false is 0.

c.cond.PS compares the upper and lower halves of FPR *fs* and FPR *ft* independently and writes the results into condition codes CC +1 and CC respectively. The CC number must be even. If the number is not even the operation of the instruction is **UNPREDICTABLE**.

If one of the values is an SNaN, or *cond*<sub>3</sub> is set and at least one of the values is a QNaN, an Invalid Operation condition is raised and 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*.

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 among the 16 comparison predicates. The Boolean result of the instruction is obtained by substituting the Boolean value of each ordering relation for the two FP values in the equation. If the *equal* relation is true, for example, then all four example predicates above yield a true result. If the *unordered* relation is true then only the final predicate, *unordered or equal*, yields a true result.

Logical negation of a compare result allows eight distinct comparisons to test for the 16 predicates as shown in [Table 3.25](#). 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, and the second predicate must be false, and vice versa. (Note that the False predicate is never true and False/True do not follow the normal pattern.)

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 can be made with the Branch on FP True (BC1T) instruction and the truth of the second can be made with Branch on FP False (BC1F).

[Table 3.26](#) shows another set of eight compare operations, distinguished by a *cond*<sub>3</sub> value of 1 and testing the same 16 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*, an Invalid Operation

exception occurs.

**Table 5.17 FPU Comparisons Without Special Operand Exceptions**

Instruction Cond Mnemonic	Comparison Predicate Name of Predicate and Logically Negated Predicate (Abbreviation)	Comparison CC Result				Instruction Condition Field 3      2..0	
		Relation Values					
		>	<	=	?		
F	False [this predicate is always False]	F	F	F	F	No	0      0
	True (T)	T	T	T	T		
UN	Unordered	F	F	F	T	T	1
	Ordered (OR)	T	T	T	F		
EQ	Equal	F	F	T	F	T	2
	Not Equal (NEQ)	T	T	F	T		
UEQ	Unordered or Equal	F	F	T	T	T	3
	Ordered or Greater Than or Less Than (OGL)	T	T	F	F		
OLT	Ordered or Less Than	F	T	F	F	T	4
	Unordered or Greater Than or Equal (UGE)	T	F	T	T		
ULT	Unordered or Less Than	F	T	F	T	T	5
	Ordered or Greater Than or Equal (OGE)	T	F	T	F		
OLE	Ordered or Less Than or Equal	F	T	T	F	T	6
	Unordered or Greater Than (UGT)	T	F	F	T		
ULE	Unordered or Less Than or Equal	F	T	T	T	T	7
	Ordered or Greater Than (OGT)	T	F	F	F		

Key: ? = *unordered*, > = *greater than*, < = *less than*, = is *equal*, T = *True*, F = *False*

Table 5.18 FPU Comparisons With Special Operand Exceptions for QNaNs

Instruction	Comparison Predicate					Comparison CC Result		Instruction		
	Cond Mnemonic	Name of Predicate and Logically Negated Predicate (Abbreviation)	Relation Values				If Predicate Is True	Inv Op Excp If QNaN?	Condition Field	
			>	<	=	?			3	2..0
SF		Signaling False [this predicate always False]	F	F	F	F	F	Yes	1	0
		Signaling True (ST)	T	T	T	T			1	
NGLE		Not Greater Than or Less Than or Equal	F	F	F	T	T		2	
		Greater Than or Less Than or Equal (GLE)	T	T	T	F	F		3	
SEQ		Signaling Equal	F	F	T	F	T		4	
		Signaling Not Equal (SNE)	T	T	F	T	F		5	
NGL		Not Greater Than or Less Than	F	F	T	T	T		6	
		Greater Than or Less Than (GL)	T	T	F	F	F		7	
LT		Less Than	F	T	F	F	T			
		Not Less Than (NLT)	T	F	T	T	F			
NGE		Not Greater Than or Equal	F	T	F	T	T			
		Greater Than or Equal (GE)	T	F	T	F	F			
LE		Less Than or Equal	F	T	T	F	T			
		Not Less Than or Equal (NLE)	T	F	F	T	F			
NGT		Not Greater Than	F	T	T	T	T			
		Greater Than (GT)	T	F	F	F	F			

Key: ? = *unordered*, > = *greater than*, < = *less than*, = is *equal*, T = *True*, F = *False*

### Restrictions:

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of C.cond.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode, or if the condition code number is odd.

### Operation:

```

if SNaN(ValueFPR(fs, fmt)) or SNaN(ValueFPR(ft, fmt)) or
   QNaN(ValueFPR(fs, fmt)) or QNaN(ValueFPR(ft, fmt)) then
   less ← false
   equal ← false
   unordered ← true
   if (SNaN(ValueFPR(fs, fmt)) or SNaN(ValueFPR(ft, fmt))) or
      (cond3 and (QNaN(ValueFPR(fs, fmt)) or QNaN(ValueFPR(ft, fmt)))) then
         SignalException(InvalidOperation)
      endif
   else
      less ← ValueFPR(fs, fmt) <fmt ValueFPR(ft, fmt)
      equal ← ValueFPR(fs, fmt) =fmt ValueFPR(ft, fmt)
      unordered ← false
   endif
endif

```

```

condition ← (cond2 and less) or (cond1 and equal)
      or (cond0 and unordered)
SetFPCConditionCode(cc, condition)

```

For c.cond.PS, the pseudo code above is repeated for both halves of the operand registers, treating each half as an independent single-precision values. Exceptions on the two halves are logically ORed and reported together. The results of the lower half comparison are written to condition code CC; the results of the upper half comparison are written to condition code CC+1.

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation, Invalid Operation

#### Programming Notes:

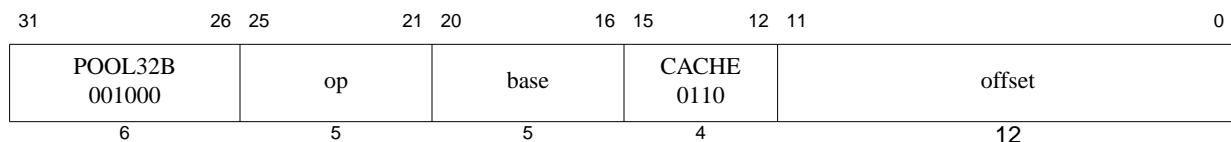
FP computational instructions, including compare, that receive an operand value of Signaling NaN raise the Invalid Operation condition. Comparisons that raise the Invalid Operation condition for Quiet NaNs in addition to SNaNs permit a simpler programming model if NaNs are errors. Using these compares, 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
  c.eq.d $f2,$f4    # check for equal
  nop
  bc1t  L2          # it is equal
  c.un.d $f2,$f4    # it is not equal,
                    # but might be unordered
  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

```



**Format:** CACHE op, offset(base)

microMIPS

**Purpose:** Perform Cache Operation

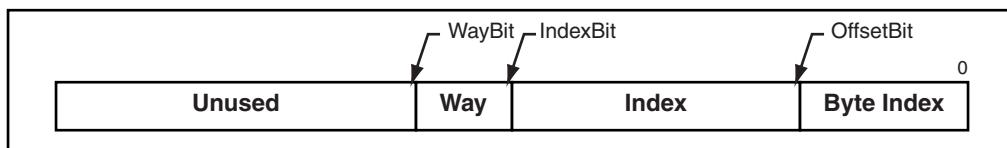
To perform the cache operation specified by op.

**Description:**

The 12-bit offset is sign-extended and added to the contents of the base register to form an effective address. The effective address is used in one of the following ways based on the operation to be performed and the type of cache as described in the following table.

**Table 5.19 Usage of Effective Address**

Operation Requires an	Type of Cache	Usage of Effective Address
Address	Virtual	The effective address is used to address the cache. An address translation may or may not be performed on the effective address (with the possibility that a TLB Refill or TLB Invalid exception might occur)
Address	Physical	The effective address is translated by the MMU to a physical address. The physical address is then used to address the cache
Index	N/A	<p>The effective address is translated by the MMU to a physical address. It is implementation dependent whether the effective address or the translated physical address is used to index the cache. As such, an unmapped address (such as within kseg0) should always be used for cache operations that require an index. See the Programming Notes section below.</p> <p>Assuming that the total cache size in bytes is CS, the associativity is A, and the number of bytes per tag is BPT, the following calculations give the fields of the address which specify the way and the index:</p> <pre> OffsetBit ← Log2(BPT) IndexBit ← Log2(CS / A) WayBit ← IndexBit + Ceiling(Log2(A)) Way ← Addr<sub>WayBit-1..IndexBit</sub> Index ← Addr<sub>IndexBit-1..OffsetBit</sub> </pre> <p>For a direct-mapped cache, the Way calculation is ignored and the Index value fully specifies the cache tag. This is shown symbolically in the figure below.</p>

**Figure 5.2 Usage of Address Fields to Select Index and Way**

A TLB Refill and TLB Invalid (both with cause code equal TLBL) exception can occur on any operation. For index operations (where the address is used to index the cache but need not match the cache tag) software should use unmapped addresses to avoid TLB exceptions. This instruction never causes TLB Modified exceptions nor TLB Refill exceptions with a cause code of TLBS. This instruction never causes Execute-Inhibit nor Read-Inhibit exceptions.

The effective address may be an arbitrarily-aligned by address. The CACHE instruction never causes an Address Error Exception due to an non-aligned address.

A Cache Error exception may occur as a by-product of some operations performed by this instruction. For example, if a Writeback operation detects a cache or bus error during the processing of the operation, that error is reported via a Cache Error exception. Similarly, a Bus Error Exception may occur if a bus operation invoked by this instruction is terminated in an error. However, cache error exceptions must not be triggered by an Index Load Tag or Index Store tag operation, as these operations are used for initialization and diagnostic purposes.

An Address Error Exception (with cause code equal AdEL) may occur if the effective address references a portion of the kernel address space which would normally result in such an exception. It is implementation dependent whether such an exception does occur.

It is implementation dependent whether a data watch is triggered by a cache instruction whose address matches the Watch register address match conditions.

The CACHE instruction and the memory transactions which are sourced by the CACHE instruction, such as cache refill or cache writeback, obey the ordering and completion rules of the SYNC instruction.

Bits [22:21] of the instruction specify the cache on which to perform the operation, as follows:

**Table 5.20 Encoding of Bits[17:16] of CACHE Instruction**

Code	Name	Cache
0b00	I	Primary Instruction
0b01	D	Primary Data or Unified Primary
0b10	T	Tertiary
0b11	S	Secondary

Bits [25:23] of the instruction specify the operation to perform. To provide software with a consistent base of cache operations, certain encodings must be supported on all processors. The remaining encodings are recommended

For implementations which implement multiple level of caches and where the hardware maintains the smaller cache as a proper subset of a larger cache (every address which is resident in the smaller cache is also resident in the larger cache; also known as the inclusion property), it is recommended that the CACHE instructions which operate on the larger, outer-level cache; should first operate on the smaller, inner-level cache. For example, a Hit\_Writeback\_Invalidate operation targeting the Secondary cache, should first operate on the primary data cache first. If the CACHE instruction implementation does not follow this policy then any software which flushes the caches must mimic this behavior. That is, the software sequences must first operate on the inner cache then operate on the outer cache. The software must place a SYNC instruction after the CACHE instruction whenever there are possible writebacks from the inner cache to ensure that the writeback data is resident in the outer cache before operating on the outer cache. If neither the CACHE instruction implementation nor the software cache flush sequence follow this policy, then the inclusion property of the caches can be broken, which might be a condition that the cache management hardware can not properly deal with.

For implementations which implement multiple level of caches without the inclusion property, the use of a SYNC instruction after the CACHE instruction is still needed whenever writeback data has to be resident in the next level of

memory hierarchy.

For multiprocessor implementations that maintain coherent caches, some of the Hit type of CACHE instruction operations may optionally affect all coherent caches within the implementation. If the effective address uses a coherent Cache Coherency Attribute (CCA), then the operation is *globalized*, meaning it is broadcast to all of the coherent caches within the system. If the effective address does not use one of the coherent CCAs, there is no broadcast of the operation. If multiple levels of caches are to be affected by one CACHE instruction, all of the affected cache levels must be processed in the same manner - either all affected cache levels use the globalized behavior or all affected cache levels use the non-globalized behavior.

**Table 5.21 Encoding of Bits [20:18] of the CACHE Instruction**

Code	Caches	Name	Effective Address Operand Type	Operation	Compliance Implemented
0b000	I	Index Invalidate	Index	<p>Set the state of the cache block at the specified index to invalid. This required encoding may be used by software to invalidate the entire instruction cache by stepping through all valid indices.</p>	Required
	D	Index Writeback Invalidate / Index Invalidate	Index	<p>For a write-back cache: If the state of the cache block at the specified index is valid and dirty, write the block back to the memory address specified by the cache tag. After that operation is completed, set the state of the cache block to invalid. If the block is valid but not dirty, set the state of the block to invalid.</p>	Required
	S, T	Index Writeback Invalidate / Index Invalidate	Index	<p>For a write-through cache: Set the state of the cache block at the specified index to invalid. This required encoding may be used by software to invalidate the entire data cache by stepping through all valid indices. Note that Index Store Tag should be used to initialize the cache at power up.</p>	Required if S, T cache is implemented
0b001	All	Index Load Tag	Index	<p>Read the tag for the cache block at the specified index into the <i>TagLo</i> and <i>TagHi</i> Coprocessor 0 registers. If the <i>DataLo</i> and <i>DataHi</i> registers are implemented, also read the data corresponding to the byte index into the <i>DataLo</i> and <i>DataHi</i> registers. This operation must not cause a Cache Error Exception. The granularity and alignment of the data read into the <i>DataLo</i> and <i>DataHi</i> registers is implementation-dependent, but is typically the result of an aligned access to the cache, ignoring the appropriate low-order bits of the byte index.</p>	Recommended

Table 5.21 Encoding of Bits [20:18] of the CACHE Instruction (Continued)

Code	Caches	Name	Effective Address Operand Type	Operation	Compliance Implemented
0b010	All	Index Store Tag	Index	Write the tag for the cache block at the specified index from the <i>TagLo</i> and <i>TagHi</i> Coprocessor 0 registers. This operation must not cause a Cache Error Exception. This required encoding may be used by software to initialize the entire instruction or data caches by stepping through all valid indices. Doing so requires that the <i>TagLo</i> and <i>TagHi</i> registers associated with the cache be initialized first.	Required
0b011	All	Implementation Dependent	Unspecified	Available for implementation-dependent operation.	Optional
0b100	I, D	Hit Invalidate	Address	If the cache block contains the specified address, set the state of the cache block to invalid. This required encoding may be used by software to invalidate a range of addresses from the instruction cache by stepping through the address range by the line size of the cache.	Required (Instruction Cache Encoding Only), Recommended otherwise
	S, T	Hit Invalidate	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Optional, if Hit_Invalidate_D is implemented, the S and T variants are recommended.
0b101	I	Fill	Address	Fill the cache from the specified address.	Recommended
	D	Hit Writeback Invalidate / Hit Invalidate	Address	For a write-back cache: If the cache block contains the specified address and it is valid and dirty, write the contents back to memory. After that operation is completed, set the state of the cache block to invalid. If the block is valid but not dirty, set the state of the block to invalid. For a write-through cache: If the cache block contains the specified address, set the state of the cache block to invalid. This required encoding may be used by software to invalidate a range of addresses from the data cache by stepping through the address range by the line size of the cache.	Required
	S, T	Hit Writeback Invalidate / Hit Invalidate	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Required if S, T cache is implemented

**Table 5.21 Encoding of Bits [20:18] of the CACHE Instruction (Continued)**

<b>Code</b>	<b>Caches</b>	<b>Name</b>	<b>Effective Address Operand Type</b>	<b>Operation</b>	<b>Compliance Implemented</b>
0b110	D	Hit Writeback	Address	If the cache block contains the specified address and it is valid and dirty, write the contents back to memory. After the operation is completed, leave the state of the line valid, but clear the dirty state. For a write-through cache, this operation may be treated as a nop.	Recommended
	S, T	Hit Writeback	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Optional, if Hit_Writeback_D is implemented, the S and T variants are recommended.
0b111	I, D	Fetch and Lock	Address	If the cache does not contain the specified address, fill it from memory, performing a writeback if required, and set the state to valid and locked. If the cache already contains the specified address, set the state to locked. In set-associative or fully-associative caches, the way selected on a fill from memory is implementation dependent.  The lock state may be cleared by executing an Index Invalidate, Index Writeback Invalidate, Hit Invalidate, or Hit Writeback Invalidate operation to the locked line, or via an Index Store Tag operation to the line that clears the lock bit. Note that clearing the lock state via Index Store Tag is dependent on the implementation-dependent cache tag and cache line organization, and that Index and Index Writeback Invalidate operations are dependent on cache line organization. Only Hit and Hit Writeback Invalidate operations are generally portable across implementations.  It is implementation dependent whether a locked line is displaced as the result of an external invalidate or intervention that hits on the locked line. Software must not depend on the locked line remaining in the cache if an external invalidate or intervention would invalidate the line if it were not locked. It is implementation dependent whether a Fetch and Lock operation affects more than one line. For example, more than one line around the referenced address may be fetched and locked. It is recommended that only the single line containing the referenced address be affected.	Recommended

**Restrictions:**

The operation of this instruction is **UNDEFINED** for any operation/cache combination that is not implemented.

The operation of this instruction is **UNDEFINED** if the operation requires an address, and that address is uncachable.

The operation of the instruction is **UNPREDICTABLE** if the cache line that contains the CACHE instruction is the target of an invalidate or a writeback invalidate.

If this instruction is used to lock all ways of a cache at a specific cache index, the behavior of that cache to subsequent cache misses to that cache index is **UNDEFINED**.

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

Any use of this instruction that can cause cacheline writebacks should be followed by a subsequent SYNC instruction to avoid hazards where the writeback data is not yet visible at the next level of the memory hierarchy.

**Operation:**

```
vAddr ← GPR[base] + sign_extend(offset)
(pAddr, uncached) ← AddressTranslation(vAddr, DataReadReference)
CacheOp(op, vAddr, pAddr)
```

**Exceptions:**

TLB Refill Exception.

TLB Invalid Exception

Coprocessor Unusable Exception

Address Error Exception

Cache Error Exception

Bus Error Exception

**Programming Notes:**

For cache operations that require an index, it is implementation dependent whether the effective address or the translated physical address is used as the cache index. Therefore, the index value should always be converted to an unmapped address (such as an kseg0 address - by ORing the index with 0x80000000 before being used by the cache instruction). For example, the following code sequence performs a data cache Index Store Tag operation using the index passed in GPR a0:

```
li      a1, 0x80000000      /* Base of kseg0 segment */
or      a0, a0, a1          /* Convert index to kseg0 address */
cache  DCIndexStTag, 0(a1)  /* Perform the index store tag operation */
```

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	op	base	ST-EVA 1010	CACHEE 011	offset	

6                    5                    5                    4                    3                    9

**Format:** CACHEE op, offset(base)

microMIPS

**Purpose:** Perform Cache Operation EVA

To perform the cache operation specified by op using a user mode virtual address while in kernel mode.

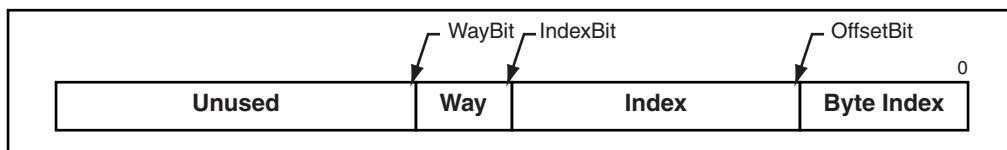
#### Description:

The 9 bit offset is sign-extended and added to the contents of the base register to form an effective address. The effective address is used in one of the following ways based on the operation to be performed and the type of cache as described in the following table.

**Table 5.22 Usage of Effective Address**

Operation Requires an	Type of Cache	Usage of Effective Address
Address	Virtual	The effective address is used to address the cache. An address translation may or may not be performed on the effective address (with the possibility that a TLB Refill or TLB Invalid exception might occur)
Address	Physical	The effective address is translated by the MMU to a physical address. The physical address is then used to address the cache
Index	N/A	<p>The effective address is translated by the MMU to a physical address. It is implementation dependent whether the effective address or the translated physical address is used to index the cache. As such, a kseg0 address should always be used for cache operations that require an index. See the Programming Notes section below.</p> <p>Assuming that the total cache size in bytes is CS, the associativity is A, and the number of bytes per tag is BPT, the following calculations give the fields of the address which specify the way and the index:</p> <pre> OffsetBit ← Log2(BPT) IndexBit ← Log2(CS / A) WayBit ← IndexBit + Ceiling(Log2(A)) Way ← Addr<sub>WayBit-1..IndexBit</sub> Index ← Addr<sub>IndexBit-1..OffsetBit</sub> </pre> <p>For a direct-mapped cache, the Way calculation is ignored and the Index value fully specifies the cache tag. This is shown symbolically in the figure below.</p>

**Figure 5.3 Usage of Address Fields to Select Index and Way**



A TLB Refill and TLB Invalid (both with cause code equal TLBL) exception can occur on any operation. For index operations (where the address is used to index the cache but need not match the cache tag) software should use unmapped addresses to avoid TLB exceptions. This instruction never causes TLB Modified exceptions nor TLB Refill exceptions with a cause code of TLBS. This instruction never causes Execute-Inhibit nor Read-Inhibit exceptions.

The effective address may be an arbitrarily-aligned by address. The CACHEE instruction never causes an Address Error Exception due to an non-aligned address.

A Cache Error exception may occur as a by-product of some operations performed by this instruction. For example, if a Writeback operation detects a cache or bus error during the processing of the operation, that error is reported via a Cache Error exception. Similarly, a Bus Error Exception may occur if a bus operation invoked by this instruction is terminated in an error. However, cache error exceptions must not be triggered by an Index Load Tag or Index Store tag operation, as these operations are used for initialization and diagnostic purposes.

An Address Error Exception (with cause code equal AdEL) may occur if the effective address references a portion of the kernel address space which would normally result in such an exception. It is implementation dependent whether such an exception does occur.

It is implementation dependent whether a data watch is triggered by a cache instruction whose address matches the Watch register address match conditions.

The CACHEE instruction and the memory transactions which are sourced by the CACHEE instruction, such as cache refill or cache writeback, obey the ordering and completion rules of the SYNC instruction.

Bits [22:21] of the instruction specify the cache on which to perform the operation, as follows:

**Table 5.23 Encoding of Bits[22:21] of CACHEE Instruction**

Code	Name	Cache
0b00	I	Primary Instruction
0b01	D	Primary Data or Unified Primary
0b10	T	Tertiary
0b11	S	Secondary

Bits [25:23] of the instruction specify the operation to perform. To provide software with a consistent base of cache operations, certain encodings must be supported on all processors. The remaining encodings are recommended

For implementations which implement multiple level of caches and where the hardware maintains the smaller cache as a proper subset of a larger cache (every address which is resident in the smaller cache is also resident in the larger cache; also known as the inclusion property), it is recommended that the CACHEE instructions which operate on the larger, outer-level cache; should first operate on the smaller, inner-level cache. For example, a Hit\_Writeback\_Invalidate operation targeting the Secondary cache, should first operate on the primary data cache first. If the CACHEE instruction implementation does not follow this policy then any software which flushes the caches must mimic this behavior. That is, the software sequences must first operate on the inner cache then operate on the outer cache. The software must place a SYNC instruction after the CACHEE instruction whenever there are possible writebacks from the inner cache to ensure that the writeback data is resident in the outer cache before operating on the outer cache. If neither the CACHEE instruction implementation nor the software cache flush sequence follow this policy, then the inclusion property of the caches can be broken, which might be a condition that the cache management hardware can not properly deal with.

For implementations which implement multiple level of caches without the inclusion property, the use of a SYNC instruction after the CACHEE instruction is still needed whenever writeback data has to be resident in the next level

of memory hierarchy.

For multiprocessor implementations that maintain coherent caches, some of the Hit type of CACHEE instruction operations may optionally affect all coherent caches within the implementation. If the effective address uses a coherent Cache Coherency Attribute (CCA), then the operation is *globalized*, meaning it is broadcast to all of the coherent caches within the system. If the effective address does not use one of the coherent CCAs, there is no broadcast of the operation. If multiple levels of caches are to be affected by one CACHEE instruction, all of the affected cache levels must be processed in the same manner - either all affected cache levels use the globalized behavior or all affected cache levels use the non-globalized behavior.

The CACHEE instruction functions in exactly the same fashion as the CACHE instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible . Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

**Table 5.24 Encoding of Bits [20:18] of the CACHEE Instruction**

Code	Caches	Name	Effective Address Operand Type	Operation	Compliance Implemented
0b000	I	Index Invalidate	Index	<p>Set the state of the cache block at the specified index to invalid.</p> <p>This required encoding may be used by software to invalidate the entire instruction cache by stepping through all valid indices.</p>	Required
	D	Index Writeback Invalidate / Index Invalidate	Index	<p>For a write-back cache: If the state of the cache block at the specified index is valid and dirty, write the block back to the memory address specified by the cache tag. After that operation is completed, set the state of the cache block to invalid. If the block is valid but not dirty, set the state of the block to invalid.</p>	Required
	S, T	Index Writeback Invalidate / Index Invalidate	Index	<p>For a write-through cache: Set the state of the cache block at the specified index to invalid.</p> <p>This required encoding may be used by software to invalidate the entire data cache by stepping through all valid indices. Note that Index Store Tag should be used to initialize the cache at power up.</p>	Required if S, T cache is implemented

**Table 5.24 Encoding of Bits [20:18] of the CACHEE Instruction (Continued)**

<b>Code</b>	<b>Caches</b>	<b>Name</b>	<b>Effective Address Operand Type</b>	<b>Operation</b>	<b>Compliance Implemented</b>
0b001	All	Index Load Tag	Index	Read the tag for the cache block at the specified index into the <i>TagLo</i> and <i>TagHi</i> Coprocessor 0 registers. If the <i>DataLo</i> and <i>DataHi</i> registers are implemented, also read the data corresponding to the byte index into the <i>DataLo</i> and <i>DataHi</i> registers. This operation must not cause a Cache Error Exception. The granularity and alignment of the data read into the <i>DataLo</i> and <i>DataHi</i> registers is implementation-dependent, but is typically the result of an aligned access to the cache, ignoring the appropriate low-order bits of the byte index.	Recommended
0b010	All	Index Store Tag	Index	Write the tag for the cache block at the specified index from the <i>TagLo</i> and <i>TagHi</i> Coprocessor 0 registers. This operation must not cause a Cache Error Exception. This required encoding may be used by software to initialize the entire instruction or data caches by stepping through all valid indices. Doing so requires that the <i>TagLo</i> and <i>TagHi</i> registers associated with the cache be initialized first.	Required
0b011	All	Implementation Dependent	Unspecified	Available for implementation-dependent operation.	Optional
0b100	I, D	Hit Invalidate	Address	If the cache block contains the specified address, set the state of the cache block to invalid. This required encoding may be used by software to invalidate a range of addresses from the instruction cache by stepping through the address range by the line size of the cache.	Required (Instruction Cache Encoding Only), Recommended otherwise
	S, T	Hit Invalidate	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Optional, if Hit_Invalidate_D is implemented, the S and T variants are recommended.

**Table 5.24 Encoding of Bits [20:18] of the CACHEE Instruction (Continued)**

<b>Code</b>	<b>Caches</b>	<b>Name</b>	<b>Effective Address Operand Type</b>	<b>Operation</b>	<b>Compliance Implemented</b>
0b101	I	Fill	Address	Fill the cache from the specified address.	Recommended
	D	Hit Writeback Invalidate / Hit Invalidate	Address	For a write-back cache: If the cache block contains the specified address and it is valid and dirty, write the contents back to memory. After that operation is completed, set the state of the cache block to invalid. If the block is valid but not dirty, set the state of the block to invalid. For a write-through cache: If the cache block contains the specified address, set the state of the cache block to invalid. This required encoding may be used by software to invalidate a range of addresses from the data cache by stepping through the address range by the line size of the cache.	Required
	S, T	Hit Writeback Invalidate / Hit Invalidate	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Required if S, T cache is implemented
0b110	D	Hit Writeback	Address	If the cache block contains the specified address and it is valid and dirty, write the contents back to memory. After the operation is completed, leave the state of the line valid, but clear the dirty state. For a write-through cache, this operation may be treated as a nop.	Recommended
	S, T	Hit Writeback	Address	In multiprocessor implementations with coherent caches, the operation may optionally be broadcast to all coherent caches within the system.	Optional, if Hit_Writeback_D is implemented, the S and T variants are recommended.

**Table 5.24 Encoding of Bits [20:18] of the CACHEE Instruction (Continued)**

<b>Code</b>	<b>Caches</b>	<b>Name</b>	<b>Effective Address Operand Type</b>	<b>Operation</b>	<b>Compliance Implemented</b>
0b111	I, D	Fetch and Lock	Address	<p>If the cache does not contain the specified address, fill it from memory, performing a writeback if required, and set the state to valid and locked. If the cache already contains the specified address, set the state to locked. In set-associative or fully-associative caches, the way selected on a fill from memory is implementation dependent.</p> <p>The lock state may be cleared by executing an Index Invalidate, Index Writeback Invalidate, Hit Invalidate, or Hit Writeback Invalidate operation to the locked line, or via an Index Store Tag operation to the line that clears the lock bit. Note that clearing the lock state via Index Store Tag is dependent on the implementation-dependent cache tag and cache line organization, and that Index and Index Writeback Invalidate operations are dependent on cache line organization. Only Hit and Hit Writeback Invalidate operations are generally portable across implementations.</p> <p>It is implementation dependent whether a locked line is displaced as the result of an external invalidate or intervention that hits on the locked line. Software must not depend on the locked line remaining in the cache if an external invalidate or intervention would invalidate the line if it were not locked.</p> <p>It is implementation dependent whether a Fetch and Lock operation affects more than one line. For example, more than one line around the referenced address may be fetched and locked. It is recommended that only the single line containing the referenced address be affected.</p>	Recommended

**Restrictions:**

The operation of this instruction is **UNDEFINED** for any operation/cache combination that is not implemented.

The operation of this instruction is **UNDEFINED** if the operation requires an address, and that address is uncachable.

The operation of the instruction is **UNPREDICTABLE** if the cache line that contains the CACHEE instruction is the target of an invalidate or a writeback invalidate.

If this instruction is used to lock all ways of a cache at a specific cache index, the behavior of that cache to subsequent cache misses to that cache index is **UNDEFINED**.

Any use of this instruction that can cause cacheline writebacks should be followed by a subsequent SYNC instruction to avoid hazards where the writeback data is not yet visible at the next level of the memory hierarchy.

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

```
vAddr ← GPR[base] + sign_extend(offset)
(pAddr, uncached) ← AddressTranslation(vAddr, DataReadReference)
CacheOp(op, vAddr, pAddr)
```

**Exceptions:**

TLB Refill Exception.  
TLB Invalid Exception  
Coprocessor Unusable Exception  
Reserved Instruction  
Address Error Exception  
Cache Error Exception  
Bus Error Exception

**Programming Notes:**

For cache operations that require an index, it is implementation dependent whether the effective address or the translated physical address is used as the cache index. Therefore, the index value should always be converted to a kseg0 address by ORing the index with 0x80000000 before being used by the cache instruction. For example, the following code sequence performs a data cache Index Store Tag operation using the index passed in GPR a0:

```
li      a1, 0x80000000      /* Base of kseg0 segment */
or      a0, a0, a1          /* Convert index to kseg0 address */
cache  DCIndexStTag, 0(a1)  /* Perform the index store tag operation */
```

31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	CEIL.L 01001100	POOL32FXf 111011

6            5            5            1    1            8            6

**Format:** CEIL.L fmtCEIL.L.S ft, fs  
CEIL.L.D ft, fsmicroMIPS  
microMIPS**Purpose:** Fixed Point Ceiling Convert to Long Fixed Point

To convert an FP value to 64-bit fixed point, rounding up

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`The value in FPR *fs*, in format *fmt*, is converted to a value in 64-bit long fixed point format and rounding toward  $+\infty$  (rounding mode 2). The result is placed in FPR *ft*.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, an IEEE Invalid Operation condition exists, and 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,  $2^{63}-1$ , is written to *fd*.**Restrictions:**The fields *fs* and *ft* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed point; if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**`StoreFPR(ft, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))`**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Invalid Operation, Unimplemented Operation, Inexact



31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fm t	CEIL.W 01101100	POOL32FXf 111011

6                    5                    5                    1    1                    8                    6

**Format:** CEIL.W(fmt)CEIL.W.S   ft, fs  
CEIL.W.D   ft, fsmicroMIPS  
microMIPS**Purpose:** Floating Point Ceiling Convert to Word Fixed Point

To convert an FP value to 32-bit fixed point, rounding up

**Description:** FPR[ft]  $\leftarrow$  convert\_and\_round(FPR[fs])The value in FPR fs, in format fmt, is converted to a value in 32-bit word fixed point format and rounding toward  $+\infty$  (rounding mode 2). The result is placed in FPR ft.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, an IEEE Invalid Operation condition exists, and 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,  $2^{31}-1$ , is written to fd.**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 **UNPREDICTABLE**.The operand must be a value in format fmt; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.**Operation:**

StoreFPR(ft, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Invalid Operation, Unimplemented Operation, Inexact



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	CFC1 01000000	POOL32FXf 111011

**Format:** CFC1 rt, fs

microMIPS

**Purpose:** Move Control Word From Floating Point

To copy a word from an FPU control register to a GPR

**Description:** GPR[rt]  $\leftarrow$  FP\_Control[fs]Copy the 32-bit word from FP (coprocessor 1) control register *fs* into GPR *rt*.**Restrictions:**

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

**Operation:**

```

if fs = 0 then
    temp  $\leftarrow$  FIR
elseif fs = 25 then
    temp  $\leftarrow$  024 || FCSR31..25 || FCSR23
elseif fs = 26 then
    temp  $\leftarrow$  014 || FCSR17..12 || 05 || FCSR6..2 || 02
elseif fs = 28 then
    temp  $\leftarrow$  020 || FCSR11..7 || 04 || FCSR24 || FCSR1..0
elseif fs = 31 then
    temp  $\leftarrow$  FCSR
else
    temp  $\leftarrow$  UNPREDICTABLE
endif
GPR[rt]  $\leftarrow$  temp

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Historical Information:**

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

MIPS V and MIPS32 introduced the three control registers that access portions of FCSR. These registers were not available in MIPS I, II, III, or IV.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	CFC2 1100110100	POOL32AXf 111100	6

**Format:** CFC2 rt, Impl

microMIPS

The syntax shown above is an example using CFC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Control Word From Coprocessor 2

To copy a word from a Coprocessor 2 control register to a GPR

**Description:** GPR[rt]  $\leftarrow$  CP2CCR[Impl]

Copy the 32-bit word from the Coprocessor 2 control register denoted by the *Impl* field. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

#### Restrictions:

The result is **UNPREDICTABLE** if *Impl* specifies a register that does not exist.

#### Operation:

```
temp  $\leftarrow$  CP2CCR[Impl]
GPR[rt]  $\leftarrow$  temp
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	CLO 0100101100	POOL32AXf 111100	6

**Format:** CLO rt, rs**microMIPS****Purpose:** Count Leading Ones in Word

To count the number of leading ones in a word

**Description:** GPR[rt]  $\leftarrow$  count\_leading\_ones GPR[rs]Bits 31..0 of GPR rs are scanned from most significant to least significant bit. The number of leading ones is counted and the result is written to GPR rt. If all of bits **31..0** were set in GPR rs, the result written to GPR rt is 32.**Restrictions:****Operation:**

```

temp  $\leftarrow$  32
for i in 31 .. 0
    if GPR[rs]i = 0 then
        temp  $\leftarrow$  31 - i
        break
    endif
endfor
GPR[rt]  $\leftarrow$  temp

```

**Exceptions:**

None



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	CLZ 0101101100	POOL32AXf 111100	6

**Format:** CLZ rt, rs**microMIPS****Purpose:** Count Leading Zeros in Word

Count the number of leading zeros in a word

**Description:** GPR[rt]  $\leftarrow$  count\_leading\_zeros GPR[rs]

Bits 31..0 of GPR rs are scanned from most significant to least significant bit. The number of leading zeros is counted and the result is written to GPR rt. If no bits were set in GPR rs, the result written to GPR rt is 32.

**Restrictions:****Operation:**

```

temp  $\leftarrow$  32
for i in 31 .. 0
    if GPR[rs]i = 1 then
        temp  $\leftarrow$  31 - i
        break
    endif
endfor
GPR[rt]  $\leftarrow$  temp

```

**Exceptions:**

None

31	26 25		3 2 0
POOL32A 000000	cofun	COP2 010	3

**Format:** COP2 func**microMIPS****Purpose:** Coprocessor Operation to Coprocessor 2

To perform an operation to Coprocessor 2

**Description:** CoprocessorOperation(2, cofun)

An implementation-dependent operation is performed to Coprocessor 2, with the *cofun* value passed as an argument. The operation may specify and reference internal coprocessor registers, and may change the state of the coprocessor conditions, but does not modify state within the processor. Details of coprocessor operation and internal state are described in the documentation for each Coprocessor 2 implementation.

**Restrictions:****Operation:**

CoprocessorOperation(2, cofun)

**Exceptions:**

Coprocessor Unusable

Reserved Instruction



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	CTC1 01100000	POOL32FXf 111011

**Format:** CTC1 rt, fs**microMIPS****Purpose:** Move Control Word to Floating Point

To copy a word from a GPR to an FPU control register

**Description:** FP\_Control[fs]  $\leftarrow$  GPR[rt]Copy the low word from GPR *rt* into the FP (coprocessor 1) control register indicated by *fs*.

Writing to the floating point *Control/Status* register, the *FCSR*, causes the appropriate exception if any *Cause* bit and its corresponding *Enable* bit are both set. The register is written before the exception occurs. Writing to *FEXR* to set a cause bit whose enable bit is already set, or writing to *FENR* to set an enable bit whose cause bit is already set causes the appropriate exception. The register is written before the exception occurs and the *EPC* register contains the address of the CTC1 instruction.

**Restrictions:**

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

**Operation:**

```

temp  $\leftarrow$  GPR[rt]31..0
if fs = 25 then /* FCCR */
    if temp31..8  $\neq$  024 then
        UNPREDICTABLE
    else
        FCSR  $\leftarrow$  temp7..1 || FCSR24 || temp0 || FCSR22..0
    endif
elseif fs = 26 then /* FEXR */
    if temp31..18  $\neq$  0 or temp11..7  $\neq$  0 or temp2..0  $\neq$  0 then
        UNPREDICTABLE
    else
        FCSR  $\leftarrow$  FCSR31..18 || temp17..12 || FCSR11..7 ||
            temp6..2 || FCSR1..0
    endif
elseif fs = 28 then /* FENR */
    if temp31..12  $\neq$  0 or temp6..3  $\neq$  0 then
        UNPREDICTABLE
    else
        FCSR  $\leftarrow$  FCSR31..25 || temp2 || FCSR23..12 || temp11..7
            || FCSR6..2 || temp1..0
    endif
elseif fs = 31 then /* FCSR */
    if (FCSRImpl field is not implemented) and (temp22..18  $\neq$  0) then
        UNPREDICTABLE
    elseif (FCSRImpl field is implemented) and temp20..18  $\neq$  0 then
        UNPREDICTABLE
    else
        FCSR  $\leftarrow$  temp
    endif
else

```

```
UNPREDICTABLE
endif
CheckFPEexception()
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Unimplemented Operation, Invalid Operation, Division-by-zero, Inexact, Overflow, Underflow

**Historical Information:**

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

MIPS V and MIPS32 introduced the three control registers that access portions of FCSR. These registers were not available in MIPS I, II, III, or IV.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	CTC2 1101110100	POOL32AXf 111100	6

**Format:** CTC2 rt, Impl

microMIPS

The syntax shown above is an example using CTC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Control Word to Coprocessor 2

To copy a word from a GPR to a Coprocessor 2 control register

**Description:** CP2CCR[Impl]  $\leftarrow$  GPR[rt]

Copy the low word from GPR *rt* into the Coprocessor 2 control register denoted by the *Impl* field. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

**Restrictions:**

The result is **UNPREDICTABLE** if *rd* specifies a register that does not exist.

**Operation:**

```
temp  $\leftarrow$  GPR[rt]
CP2CCR[Impl]  $\leftarrow$  temp
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

31	26 25	21 20	16 15 14 13 12	6 5	0
POOL32F 010101	ft	fs	0 fmt	CVT.D 1001101	POOL32FXf 111011

6                    5                    5                    1                    2                    7                    6

**Format:** CVT.D fmt  
 CVT.D.S ft, fs  
 CVT.D.W ft, fs  
 CVT.D.L ft, fs

microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Convert to Double Floating Point

To convert an FP or fixed point value to double FP

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`

The value in FPR *fs*, in format *fmt*, is converted to a value in double floating point format and rounded according to the current rounding mode in *FCSR*. The result is placed in FPR *ft*. If *fmt* is S or W, then the operation is always exact.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *ft* for double floating point—if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

For CVT.D.L, the result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
StoreFPR (ft, D, ConvertFmt(ValueFPR(fs, fmt), fmt, D))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Invalid Operation, Unimplemented Operation, Inexact



31	26 25	21 20	16 15 14 13		6 5	0
POOL32F 010101	ft	fs	0   fmt	CVT.L 00000100	POOL32FXf 111011	6

**Format:** CVT.L fmt  
 CVT.L.S ft, fs  
 CVT.L.D ft, fs

microMIPS  
 microMIPS

**Purpose:** Floating Point Convert to Long Fixed Point

To convert an FP value to a 64-bit fixed point

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`

Convert the value in format *fmt* in FPR *fs* to long fixed point format and round according to the current rounding mode in *FCSR*. The result is placed in FPR *ft*.

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, an IEEE Invalid Operation condition exists, and 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,  $2^{63}-1$ , is written to *fd*.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *fd* for long fixed point—if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

`StoreFPR (ft, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))`

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Invalid Operation, Unimplemented Operation, Inexact,



31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	ft	fs	fd	00	CVT.PS.S 110000000

6                    5                    5                    5                    2                    9

**Format:** CVT.PS.S fd, fs, ft

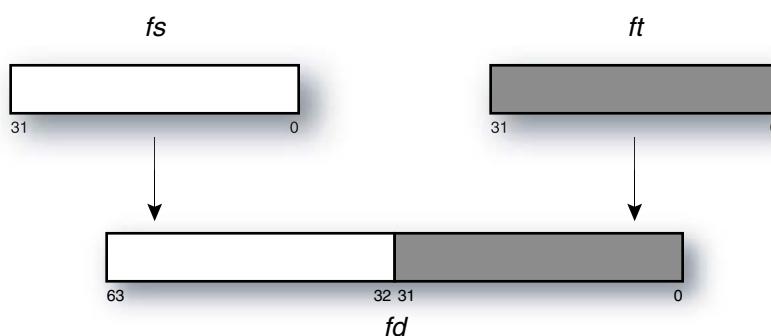
microMIPS

**Purpose:** Floating Point Convert Pair to Paired Single

To convert two FP values to a paired single value

**Description:** FPR[fd]  $\leftarrow$  FPR[fs]<sub>31..0</sub> || FPR[ft]<sub>31..0</sub>

The single-precision values in FPR fs and ft are written into FPR fd as a paired-single value. The value in FPR fs is written into the upper half, and the value in FPR ft is written into the lower half.



CVT.PS.S is similar to PLL.PS, except that it expects operands of format S instead of PS.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields fs and ft must specify FPRs valid for operands of type S; if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format S; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

StoreFPR(fd, S, ValueFPR(fs, S) || ValueFPR(ft, S))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Invalid Operation, Unimplemented Operation



31	26 25	21 20	16 15 14 13 12	6 5	0
POOL32F 010101	ft	fs	0 fmt	CVT.S 1101101	POOL32FXf 111011

6                    5                    5                    1                    2                    7                    6

**Format:**

- CVT.S fmt
- CVT.S.D ft, fs
- CVT.S.W ft, fs
- CVT.S.L ft, fs

microMIPS  
microMIPS  
microMIPS

**Purpose:** Floating Point Convert to Single Floating Point

To convert an FP or fixed point value to single FP

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`

The value in FPR *fs*, in format *fmt*, is converted to a value in single floating point format and rounded according to the current rounding mode in *FCSR*. The result is placed in FPR *ft*.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *fd* for single floating point. If they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

For CVT.S.L, the result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

`StoreFPR(ft, S, ConvertFmt(ValueFPR(fs, fmt), fmt, S))`

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Invalid Operation, Unimplemented Operation, Inexact, Overflow, Underflow



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	CVT.S.PL 10000100	POOL32FXf 111011

**Format:** CVT.S.PL ft, fs

microMIPS

#### Purpose:

Floating Point Convert Pair Lower to Single Floating Point

To convert one half of a paired single FP value to single FP

**Description:** FPR[ft]  $\leftarrow$  FPR[fs]<sub>31..0</sub>

The lower paired single value in FPR fs, in format PS, is converted to a value in single floating point format. The result is placed in FPR ft. This instruction can be used to isolate the lower half of a paired single value.

The operation is non-arithmetic; it causes no IEEE 754 exceptions.

#### Restrictions:

The fields fs and ft must specify valid FPRs—fs for type PS and ft for single floating point. If they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format PS; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of CVT.S.PL is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
StoreFPR (ft, S, ConvertFmt(ValueFPR(fs, PS), PL, S))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0   fmt	CVT.S.PU 10100100	POOL32FXf 111011

**Format:** CVT.S.PU ft, fs**microMIPS****Purpose:** Floating Point Convert Pair Upper to Single Floating Point

To convert one half of a paired single FP value to single FP

**Description:** FPR[ft]  $\leftarrow$  FPR[fs]<sub>63..32</sub>

The upper paired single value in FPR fs, in format PS, is converted to a value in single floating point format. The result is placed in FPR ft. This instruction can be used to isolate the upper half of a paired single value.

The operation is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields fs and ft must specify valid FPRs—fs for type PS and ft for single floating point. If they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format PS; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of CVT.S.PU is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

StoreFPR (ft, S, ConvertFmt(ValueFPR(fs, PS), PU, S))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0   fmt	CVT.W 00100100	POOL32FXf 111011

**Format:** CVT.W(fmt)  
 CVT.W.S ft, fs  
 CVT.W.D ft, fs

microMIPS  
 microMIPS

**Purpose:** Floating Point Convert to Word Fixed Point

To convert an FP value to 32-bit fixed point

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`

The value in FPR *fs*, in format *fmt*, is converted to a value in 32-bit word fixed point format and rounded according to the current rounding mode in *FCSR*. The result is placed in FPR *ft*.

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, an IEEE Invalid Operation condition exists, and 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,  $2^{31}-1$ , is written to *ft*.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *ft* for word fixed point—if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

#### Operation:

`StoreFPR(ft, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))`

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Invalid Operation, Unimplemented Operation, Inexact



31	26 25	16 15	6 5	0
POOL32A 000000	0 0000000000	DERET 1110001101	POOL32AXf 111100	6

**Format:** DERET**EJTAG microMIPS****Purpose:** Debug Exception Return

To Return from a debug exception.

**Description:**

DERET clears execution and instruction hazards, returns from Debug Mode and resumes non-debug execution at the instruction whose address is contained in the *DEPC* register. DERET does not execute the next instruction (i.e. it has no delay slot).

**Restrictions:**

A DERET placed between an LL and SC instruction does not cause the SC to fail.

If the *DEPC* register with the return address for the DERET was modified by an MTC0 or a DMTC0 instruction, a CP0 hazard exists that must be removed via software insertion of the appropriate number of SSNOP instructions (for implementations of Release 1 of the Architecture) or by an EHB, or other execution hazard clearing instruction (for implementations of Release 2 of the Architecture).

DERET implements a software barrier that resolves all execution and instruction hazards created by Coprocessor 0 state changes (for Release 2 implementations, refer to the SYNC1 instruction for additional information on resolving instruction hazards created by writing the instruction stream). The effects of this barrier are seen starting with the instruction fetch and decode of the instruction at the PC to which the DERET returns.

This instruction is legal only if the processor is executing in Debug Mode. The operation of the processor is **UNDEFINED** if a DERET is executed in the delay slot of a branch or jump instruction.

**Operation:**

```

DebugDM ← 0
DebugIEXI ← 0
if IsMIPS16Implemented() || (Config3ISA > 0) then
    PC ← DEPC31..1 || 0
    ISAMode ← DEPC0
else
    PC ← DEPC
endif
ClearHazards()

```

**Exceptions:**

Coprocessor Unusable Exception  
 Reserved Instruction Exception



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	DI 0100011101	POOL32AXf 111100	6

**Format:** DI  
DI rs

microMIPS  
microMIPS

#### Purpose:

Disable Interrupts

To return the previous value of the *Status* register and disable interrupts. If DI is specified without an argument, GPR r0 is implied, which discards the previous value of the Status register.

**Description:**  $\text{GPR}[rs] \leftarrow \text{Status}; \text{Status}_{IE} \leftarrow 0$

The current value of the *Status* register is loaded into general register *rs*. The Interrupt Enable (IE) bit in the *Status* register is then cleared.

#### Restrictions:

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

#### Operation:

```
data ← Status
GPR[rs] ← data
StatusIE ← 0
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction (Release 1 implementations)

#### Programming Notes:

The effects of this instruction are identical to those accomplished by the sequence of reading *Status* into a GPR, clearing the IE bit, and writing the result back to *Status*. Unlike the multiple instruction sequence, however, the DI instruction can not be aborted in the middle by an interrupt or exception.

This instruction creates an execution hazard between the change to the Status register and the point where the change to the interrupt enable takes effect. This hazard is cleared by the EHB, JALR.HB, JR.HB, or ERET instructions. Software must not assume that a fixed latency will clear the execution hazard.

31	26 25	21 20	16 15	5	0
POOL32A 000000	rt	rs	DIV 1010101100	POOL32Ax <sub>f</sub> 111100	6

**Format:** DIV rs, rt

microMIPS

**Purpose:** Divide Word

To divide a 32-bit signed integers

**Description:** (HI, LO)  $\leftarrow$  GPR[rs] / GPR[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:**

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

**Operation:**

```

q  ← GPR[rs]31..0 div GPR[rt]31..0
LO ← q
r  ← GPR[rs]31..0 mod GPR[rt]31..0
HI ← r

```

**Exceptions:**

None

**Programming Notes:**

No arithmetic exception occurs under any circumstances. If divide-by-zero or overflow conditions are 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 within 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 a zero is detected.

By default, most compilers for the MIPS architecture will emit additional instructions to check for the divide-by-zero and overflow cases when this instruction is used. In many compilers, the assembler mnemonic “DIV r0, rs, rt” can be used to prevent these additional test instructions to be emitted.

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 interlocks 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.

**Historical Perspective:**

In MIPS 1 through MIPS III, if either of the two instructions preceding the divide is an MFHI or MFLO, the result of the MFHI or MFLO is **UNPREDICTABLE**. Reads of the *HI* or *LO* special register must be separated from subse-

quent instructions that write to them by two or more instructions. This restriction was removed in MIPS IV and MIPS32 and all subsequent levels of the architecture.

31	26 25	21 20	16 15	11 10 9 8 7	5	0
POOL32F 010101	ft	fs	fd	0 fmt	DIV 11110000	8

**Format:** DIV(fmt  
DIV.S fd, fs, ft  
DIV.D fd, fs, ft)

microMIPS  
microMIPS

**Purpose:** Floating Point Divide

To divide FP values

**Description:**  $FPR[fd] \leftarrow FPR[fs] / FPR[ft]$

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 **UNPREDICABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

#### Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt) / ValueFPR(ft, fmt))

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Inexact, Invalid Operation, Unimplemented Operation, Division-by-zero, Overflow, Underflow

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	DIVU 1011101100	POOL32AXf 111100	6

**Format:** DIVU rs, rt

microMIPS

**Purpose:** Divide Unsigned Word

To divide a 32-bit unsigned integers

**Description:**  $(HI, LO) \leftarrow GPR[rs] / GPR[rt]$ 

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:**

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

**Operation:**

```

q  ← (0 || GPR[rs]31..0) div (0 || GPR[rt]31..0)
r  ← (0 || GPR[rs]31..0) mod (0 || GPR[rt]31..0)
LO ← sign_extend(q31..0)
HI ← sign_extend(r31..0)

```

**Exceptions:**

None

**Programming Notes:**

See “Programming Notes” for the [DIV](#) instruction.

**Historical Perspective:**

In MIPS 1 through MIPS III, if either of the two instructions preceding the divide is an MFHI or MFLO, the result of the MFHI or MFLO is UNPREDICTABLE. Reads of the *HI* or *LO* special register must be separated from subsequent instructions that write to them by two or more instructions. This restriction was removed in MIPS IV and MIPS32 and all subsequent levels of the architecture.

31	26 25	21 20	16 15	11 10	6 5	0
POOL32A 000000	0 00000	0 00000	3 00011	0 00000	SLL32 000000	6

6                    5                    5                    5                    5                    6

**Format:** EHB

microMIPS

**Purpose:** Execution Hazard Barrier

To stop instruction execution until all execution hazards have been cleared.

**Description:**

EHB is the assembly idiom used to denote execution hazard barrier. The actual instruction is interpreted by the hardware as SLL r0, r0, 3.

This instruction alters the instruction issue behavior on a pipelined processor by stopping execution until all execution hazards have been cleared. Other than those that might be created as a consequence of setting Status<sub>CU0</sub>, there are no execution hazards visible to an unprivileged program running in User Mode. All execution hazards created by previous instructions are cleared for instructions executed immediately following the EHB, even if the EHB is executed in the delay slot of a branch or jump. The EHB instruction does not clear instruction hazards—such hazards are cleared by the JALR.HB, JR.HB, and ERET instructions.

**Restrictions:**

None

**Operation:**

ClearExecutionHazards()

**Exceptions:**

None

**Programming Notes:**

In MIPS32 Release 2 implementations, this instruction resolves all execution hazards. On a superscalar processor, EHB alters the instruction issue behavior in a manner identical to SSNOP. For backward compatibility with Release 1 implementations, the last of a sequence of SSNOPs can be replaced by an EHB. In Release 1 implementations, the EHB will be treated as an SSNOP, thereby preserving the semantics of the sequence. In Release 2 implementations, replacing the final SSNOP with an EHB should have no performance effect because a properly sized sequence of SSNOPs will have already cleared the hazard. As EHB becomes the standard in MIPS implementations, the previous SSNOPs can be removed, leaving only the EHB.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	EI 0101011101	POOL32AXf 111100	6

**Format:** EI  
EI rs

microMIPS  
microMIPS

#### Purpose:

To return the previous value of the *Status* register and enable interrupts. If EI is specified without an argument, GPR r0 is implied, which discards the previous value of the Status register.

**Description:**  $\text{GPR}[rt] \leftarrow \text{Status}; \text{Status}_{IE} \leftarrow 1$

The current value of the *Status* register is loaded into general register *rt*. The Interrupt Enable (IE) bit in the *Status* register is then set.

#### Restrictions:

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

#### Operation:

```
data ← Status
GPR[rs] ← data
StatusIE ← 1
```

#### Exceptions:

Coprocessor Unusable  
Reserved Instruction (Release 1 implementations)

#### Programming Notes:

The effects of this instruction are identical to those accomplished by the sequence of reading *Status* into a GPR, setting the IE bit, and writing the result back to *Status*. Unlike the multiple instruction sequence, however, the EI instruction can not be aborted in the middle by an interrupt or exception.

This instruction creates an execution hazard between the change to the Status register and the point where the change to the interrupt enable takes effect. This hazard is cleared by the EHB, JALR.HB, JR.HB, or ERET instructions. Software must not assume that a fixed latency will clear the execution hazard.



31	26 25	16 15	6 5	0
POOL32A 000000	0 0000000000	ERET 1111001101	POOL32AXf 111100	6

**Format:** ERET**microMIPS****Purpose:** Exception Return

To return from interrupt, exception, or error trap.

**Description:**

ERET clears execution and instruction hazards, conditionally restores SRSCtl<sub>CSS</sub> from SRSCtl<sub>ΠΣΣ</sub> in a Release 2 implementation, and returns to the interrupted instruction at the completion of interrupt, exception, or error processing. ERET does not execute the next instruction (i.e., it has no delay slot).

**Restrictions:**

The operation of the processor is **UNDEFINED** if an ERET is executed in the delay slot of a branch or jump instruction.

An ERET placed between an LL and SC instruction will always cause the SC to fail.

ERET implements a software barrier that resolves all execution and instruction hazards created by Coprocessor 0 state changes (for Release 2 implementations, refer to the SYNCI instruction for additional information on resolving instruction hazards created by writing the instruction stream). The effects of this barrier are seen starting with the instruction fetch and decode of the instruction at the PC to which the ERET returns.

In a Release 2 implementation, ERET does not restore SRSCtl<sub>CSS</sub> from SRSCtl<sub>PSS</sub> if Status<sub>BEV</sub> = 1, or if Status<sub>ERL</sub> = 1 because any exception that sets Status<sub>ERL</sub> to 1 (Reset, Soft Reset, NMI, or cache error) does not save SRSCtl<sub>CSS</sub> in SRSCtl<sub>PSS</sub>. If software sets Status<sub>ERL</sub> to 1, it must be aware of the operation of an ERET that may be subsequently executed.

**Operation:**

```

if StatusERL = 1 then
    temp ← ErrorEPC
    StatusERL ← 0
else
    temp ← EPC
    StatusEXL ← 0
    if (ArchitectureRevision ≥ 2) and (SRSCtlHSS > 0) and (StatusBEV = 0) then
        SRSCtlCSS ← SRSCtlPSS
    endif
endif
if IsMIPS16Implemented() | (Config3ISA > 0) then
    PC ← temp31..1 || 0
    ISAMode ← temp0
else
    PC ← temp
endif
LLbit ← 0
ClearHazards()

```

**Exceptions:**

Coprocessor Unusable Exception



31	26 25	21 20	16 15	11 10	6 5	0
POOL32A 000000	rt	rs	msbd (size-1)	lsb (pos)	EXT 101100	

6                    5                    5                    5                    5                    6

**Format:** EXT rt, rs, pos, size

microMIPS

**Purpose:** Extract Bit Field

To extract a bit field from GPR rs and store it right-justified into GPR rt.

**Description:**  $\text{GPR}[rt] \leftarrow \text{ExtractField}(\text{GPR}[rs], \text{msbd}, \text{lsb})$

The bit field starting at bit *pos* and extending for *size* bits is extracted from GPR rs and stored zero-extended and right-justified in GPR rt. The assembly language arguments *pos* and *size* are converted by the assembler to the instruction fields *msbd* (the most significant bit of the destination field in GPR rt), in instruction bits **15..11**, and *lsb* (least significant bit of the source field in GPR rs), in instruction bits **10..6**, as follows:

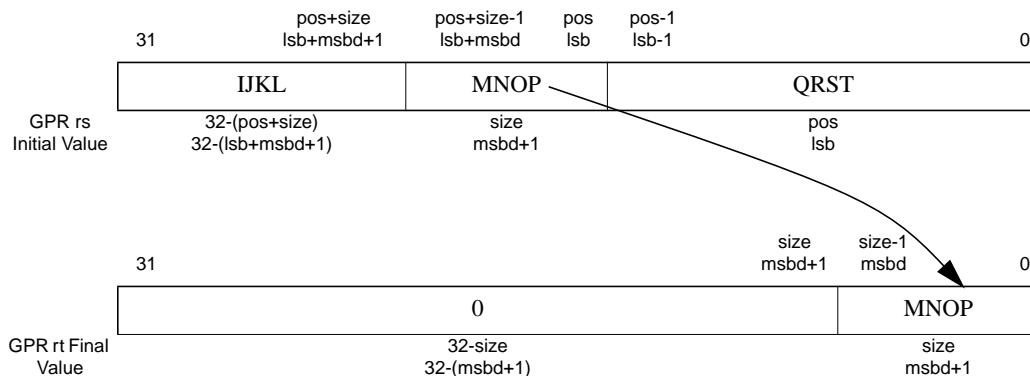
```
msbd ← size-1
lsb ← pos
```

The values of *pos* and *size* must satisfy all of the following relations:

```
0 ≤ pos < 32
0 < size ≤ 32
0 < pos+size ≤ 32
```

Figure 3-9 shows the symbolic operation of the instruction.

**Figure 5.4 Operation of the EXT Instruction**



### Restrictions:

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

The operation is **UNPREDICTABLE** if  $lsb+msbd > 31$ .

### Operation:

```
if (lsb + msbd) > 31) then
    UNPREDICTABLE
endif
temp ← 032-(msbd+1) || GPR[rs]msbd+lsb..lsb
```

GPR[rt] ← temp

**Exceptions:**

Reserved Instruction

31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	FLOOR.L 00001100	POOL32FXf 111011

**Format:** FLOOR.L fmt

FLOOR.L.S ft, fs

FLOOR.L.D ft, fs

microMIPS

microMIPS

**Purpose:** Floating Point Floor Convert to Long Fixed Point

To convert an FP value to 64-bit fixed point, rounding down

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`The value in FPR *fs*, in format *fmt*, is converted to a value in 64-bit long fixed point format and rounded toward  $-\infty$  (rounding mode 3). The result is placed in FPR *ft*.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, an IEEE Invalid Operation condition exists, and 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,  $2^{63}-1$ , is written to *fd*.**Restrictions:**The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *ft* for long fixed point—if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**`StoreFPR(ft, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))`**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Invalid Operation, Unimplemented Operation, Inexact



31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	FLOOR.W 00101100	POOL32FXf 111011

6            5            5            1    1            8            6

**Format:** FLOOR.W(fmt)FLOOR.W.S    ft, fs  
FLOOR.W.D    ft, fsmicroMIPS  
microMIPS**Purpose:** Floating Point Floor Convert to Word Fixed Point

To convert an FP value to 32-bit fixed point, rounding down

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`The value in FPR *fs*, in format *fmt*, is converted to a value in 32-bit word fixed point format and rounded toward  $-\infty$  (rounding mode 3). The result is placed in FPR *ft*.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, an IEEE Invalid Operation condition exists, and 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,  $2^{31}-1$ , is written to *ft*.**Restrictions:**The fields *fs* and *ft* must specify valid FPRs—*fs* for type *fmt* and *ft* for word fixed point—if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.**Operation:**`StoreFPR(ft, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))`**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Invalid Operation, Unimplemented Operation, Inexact



31	26..25	21..20	16..15	11..10	6..5	0
POOL32A 000000	rt	rs	msbd (pos+size-1)	lsb (pos)	INS 001100	6

**Format:** INS rt, rs, pos, size

microMIPS

**Purpose:** Insert Bit Field

To merge a right-justified bit field from GPR rs into a specified field in GPR rt.

**Description:**  $\text{GPR}[rt] \leftarrow \text{InsertField}(\text{GPR}[rt], \text{GPR}[rs], \text{msb}, \text{lsb})$

The right-most  $size$  bits from GPR  $rs$  are merged into the value from GPR  $rt$  starting at bit position  $pos$ . The result is placed back in GPR  $rt$ . The assembly language arguments  $pos$  and  $size$  are converted by the assembler to the instruction fields  $msb$  (the most significant bit of the field), in instruction bits 15..11, and  $lsb$  (least significant bit of the field), in instruction bits 10..6, as follows:

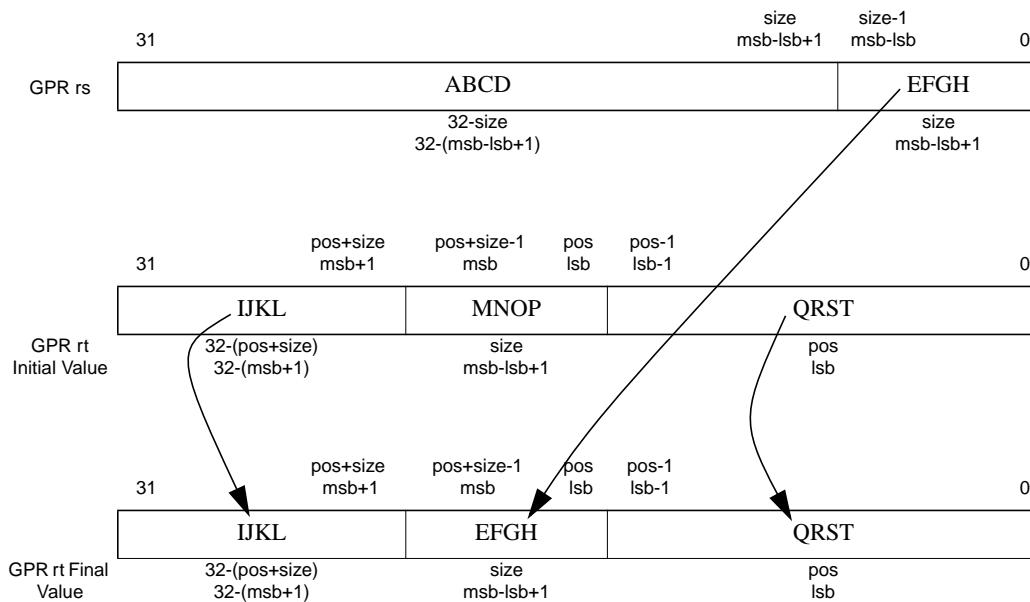
```
msb ← pos+size-1
lsb ← pos
```

The values of  $pos$  and  $size$  must satisfy all of the following relations:

```
0 ≤ pos < 32
0 < size ≤ 32
0 < pos+size ≤ 32
```

Figure 3-10 shows the symbolic operation of the instruction.

**Figure 5.5 Operation of the INS Instruction**



#### Restrictions:

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

The operation is **UNPREDICTABLE** if  $lsb > msb$ .

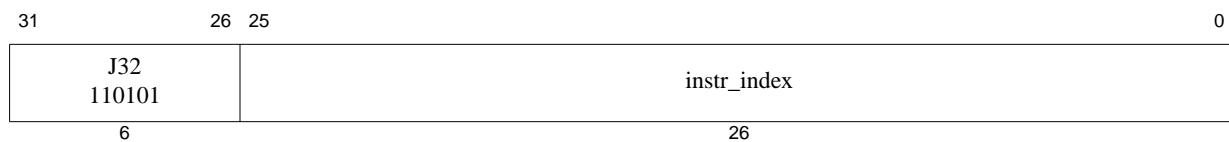
**Operation:**

```
if lsb > msb) then
    UNPREDICTABLE
endif
GPR[rt] ← GPR[rt]31..msb+1 || GPR[rs]msb-lsb..0 || GPR[rt]lsb-1..0
```

**Exceptions:**

Reserved Instruction





**Format:** `J target`

microMIPS

**Purpose:** Jump

To branch within the current 128 MB-aligned region

**Description:**

This is a PC-region branch (not PC-relative); the effective target address is in the “current” 128 MB-aligned region. The low 27 bits of the target address is the *instr\_index* field shifted left 1 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 that follows the jump, in the branch delay slot, before executing the jump itself.

**Restrictions:**

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

**I:**  
**I+1:**  $PC \leftarrow PC_{GPRLEN-1..27} || instr\_index || 0^1$

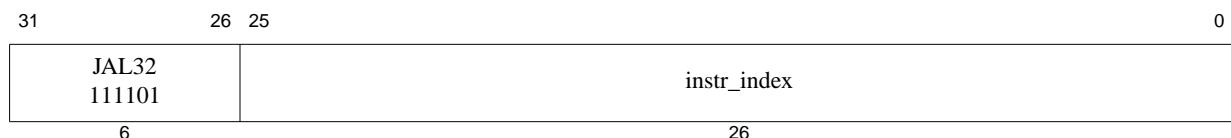
**Exceptions:**

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 128 MB region aligned on a 128 MB boundary. It allows a branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative offset.

This definition creates the following boundary case: When the jump instruction is in the last word of a 128 MB region, it can branch only to the following 128 MB region containing the branch delay slot.

**Format:** JAL target**microMIPS****Purpose:** Jump and Link

To execute a procedure call within the current 128 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, at which location execution continues after a procedure call.

This is a PC-region branch (not PC-relative); the effective target address is in the “current” 128 MB-aligned region. The low 27 bits of the target address is the *instr\_index* field shifted left 1 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 that follows the jump, in the branch delay slot, before executing the jump itself.

**Restrictions:**

The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JAL.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

```
I:      GPR[31] ← PC + 8
I+1:    PC ← PCGPRLEN-1..27 || instr_index || 01
```

**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 128 MB region aligned on a 128 MB boundary. It allows a branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative offset.

This definition creates the following boundary case: When the branch instruction is in the last word of a 128 MB region, it can branch only to the following 128 MB region containing the branch delay slot.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	JALR 0000111100	POOL32AXf 111100	6

**Format:** JALR rs (rt = 31 implied)  
JALR rt, rs

microMIPS  
microMIPS

### Purpose:

Jump and Link Register

To execute a procedure call to an instruction address in a register

**Description:** GPR[rt]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs]

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

*For processors that do not implement the MIPS32/64ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32/64ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR rs bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

### Restrictions:

The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JALR.

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

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR rs.

For processors which implement MIPS32/64 and if the ISAMode bit of the target is MIPS32/64 (bit 0 of GPR rs is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32/64 ISA, if the intended target ISAMode is MIPS32/64 (bit 0 of GPR rs is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

### Operation:

```

I: temp  $\leftarrow$  GPR[rs]
      GPR[rt]  $\leftarrow$  PC + 8
I+1: if Config1CA = 0 then
          PC  $\leftarrow$  temp
        else

```

```
PC ← tempGPRLEN-1..1 || 0
ISAMode ← temp0
endif
```

**Exceptions:**

None

**Programming Notes:**

This branch-and-link instruction that can select a register for the return link; 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	16 15	6 5	0
POOL32A 000000	rd	rs	JALR.HB 0001111100	POOL32AXf 111100	6

**Format:** JALR.HB rs (rt = 31 implied)  
JALR.HB rt, rs

microMIPS  
microMIPS

#### Purpose: Jump and Link Register with Hazard Barrier

To execute a procedure call to an instruction address in a register and clear all execution and instruction hazards

**Description:** GPR[rt]  $\leftarrow$  return\_addr, PC  $\leftarrow$  GPR[rs], clear execution and instruction hazards

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

*For processors that do not implement the MIPS32/64 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

*For processors that do implement the MIPS32/64 ISA:*

- Jump to the effective target address in GPR rs. Execute the instruction that follows the jump, in the branch delay slot, before executing the jump itself. Set the *ISA Mode* bit to the value in GPR rs bit 0. Bit 0 of the target get address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

JALR.HB implements a software barrier that resolves all execution and instruction hazards created by Coprocessor 0 state changes (for Release 2 implementations, refer to the SYNCI instruction for additional information on resolving instruction hazards created by writing the instruction stream). The effects of this barrier are seen starting with the instruction fetch and decode of the instruction at the PC to which the JALR.HB instruction jumps. An equivalent barrier is also implemented by the ERET instruction, but that instruction is only available if access to Coprocessor 0 is enabled, whereas JALR.HB is legal in all operating modes.

This instruction clears both execution and instruction hazards. Refer to the [EHB](#) instruction description for the method of clearing execution hazards alone.

#### Restrictions:

The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JAL.HB.

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

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR rs.

For processors which implement MIPS32/64 and if the ISAMode bit of the target address is MIPS32/64 (bit 0 of GPR rs is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32/64 ISA, if the intended target ISAMode is MIPS32/64 (bit 0 of GPR *rs* is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

After modifying an instruction stream mapping or writing to the instruction stream, execution of those instructions has **UNPREDICTABLE** behavior until the instruction hazard has been cleared with JALR.HB, JALRS.HB, JR.HB, ERET, or DERET. Further, the operation is **UNPREDICTABLE** if the mapping of the current instruction stream is modified.

JALR.HB does not clear hazards created by any instruction that is executed in the delay slot of the JALR.HB. Only hazards created by instructions executed before the JALR.HB are cleared by the JALR.HB.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

### Operation:

```

I: temp ← GPR[rs]
      GPR[rt] ← PC + 8
I+1:if Config1CA = 0 then
      PC ← temp
    else
      PC ← tempGPRLEN-1..1 || 0
      ISAMode ← temp0
    endif
    ClearHazards()
  
```

### Exceptions:

None

### Programming Notes:

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

This instruction implements the final step in clearing execution and instruction hazards before execution continues. A hazard is created when a Coprocessor 0 or TLB write affects execution or the mapping of the instruction stream, or after a write to the instruction stream. When such a situation exists, software must explicitly indicate to hardware that the hazard should be cleared. Execution hazards alone can be cleared with the EHB instruction. Instruction hazards can only be cleared with a JR.HB, JALR.HB, or ERET instruction. These instructions cause hardware to clear the hazard before the instruction at the target of the jump is fetched. Note that because these instructions are encoded as jumps, the process of clearing an instruction hazard can often be included as part of a call (JALR) or return (JR) sequence, by simply replacing the original instructions with the HB equivalent.

Example: Clearing hazards due to an ASID change

```

/*
 * Code used to modify ASID and call a routine with the new
 * mapping established.
 *
 * a0 = New ASID to establish
 * a1 = Address of the routine to call
 */
mfc0  v0, C0_EntryHi      /* Read current ASID */
li    v1, ~M_EntryHiASID  /* Get negative mask for field */
and   v0, v0, v1            /* Clear out current ASID value */
or    v0, v0, a0             /* OR in new ASID value */
mtc0  v0, C0_EntryHi      /* Rewrite EntryHi with new ASID */
jalr.hb a1                 /* Call routine, clearing the hazard */
  
```

nop

31	26 25	21 20	16 15 14 13	6 5	0
POOL32A 000000	00000	rs	00	JALR 00111100	POOL32AXf 111100

6                    5                    5                    2                    8                    6

**Format:** JR rs

microMIPS

**Purpose:** Jump Register

To execute a branch to an instruction address in a register

**Description:**  $PC \leftarrow GPR[rs]$ Jump to the effective target address in GPR  $rs$ . Execute the instruction following the jump, in the branch delay slot, before jumping.For processors that implement the MIPS32/64 ISA, set the *ISA Mode* bit to the value in GPR  $rs$  bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one**Restrictions:**The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JALR.If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR  $rs$ .For processors which implement MIPS32/64 and the ISAMode bit of the target address is MIPS32/64 (bit 0 of GPR  $rs$  is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.For processors that do not implement MIPS32/64 ISA, if the intended target ISAMode is MIPS32/64(bit 0 of GPR  $rs$  is zero), an Address Error exception occurs when the jump target is fetched as an instruction.Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.**Operation:**

```

I: temp  $\leftarrow$  GPR[rs]
I+1: if Config1CA = 0 then
        PC  $\leftarrow$  temp
    else
        PC  $\leftarrow$  tempGPRLEN-1..1 || 0
        ISAMode  $\leftarrow$  temp0
    endif

```

**Exceptions:**

None

**Programming Notes:**Software should use the value 31 for the  $rs$  field of the instruction word on return from a JAL, JALR, or BGEZAL, and should use a value other than 31 for remaining uses of JR.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	JALR.HB 01111100	POOL32AXf 111100	6

**Format:** JR.HB rs**microMIPS****Purpose:** Jump Register with Hazard Barrier

To execute a branch to an instruction address in a register and clear all execution and instruction hazards.

**Description:**  $PC \leftarrow GPR[rs]$ , clear execution and instruction hazards

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

JR.HB implements a software barrier that resolves all execution and instruction hazards created by Coprocessor 0 state changes (for Release 2 implementations, refer to the SYNCI instruction for additional information on resolving instruction hazards created by writing the instruction stream). The effects of this barrier are seen starting with the instruction fetch and decode of the instruction at the PC to which the JR.HB instruction jumps. An equivalent barrier is also implemented by the ERET instruction, but that instruction is only available if access to Coprocessor 0 is enabled, whereas JR.HB is legal in all operating modes.

This instruction clears both execution and instruction hazards. Refer to the [EHB](#) instruction description for the method of clearing execution hazards alone.

For processors that implement the MIPS32/64 ISA, set the *ISA Mode* bit to the value in GPR *rs* bit 0. Bit 0 of the target address is always zero so that no Address Exceptions occur when bit 0 of the source register is one.

**Restrictions:**

The delay-slot instruction must be 32-bits in size. Processor operation is **UNPREDICTABLE** if a 16-bit instruction is placed in the delay slot of JALR.

If only one instruction set is implemented, then the effective target address must obey the alignment rules of the instruction set. If multiple instruction sets are implemented, the effective target address must obey the alignment rules of the intended instruction set of the target address as specified by the bit 0 or GPR *rs*.

For processors which implement MIPS32/64 and the ISAMode bit of the target address is MIPS32/64 (bit 0 of GPR *rs* is 0) and address bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

For processors that do not implement MIPS32/64 ISA, if the intended target ISAMode is MIPS32/64 (bit 0 of GPR *rs* is zero), an Address Error exception occurs when the jump target is fetched as an instruction.

After modifying an instruction stream mapping or writing to the instruction stream, execution of those instructions has **UNPREDICTABLE** behavior until the hazard has been cleared with JALR.HB, JALRS.HB, JR.HB, ERET, or DERET. Further, the operation is **UNPREDICTABLE** if the mapping of the current instruction stream is modified.

JR.HB does not clear hazards created by any instruction that is executed in the delay slot of the JR.HB. Only hazards created by instructions executed before the JR.HB are cleared by the JR.HB.

Processor operation is **UNPREDICTABLE** if a branch, jump, ERET, DERET, or WAIT instruction is placed in the delay slot of a branch or jump.

**Operation:**

```

I: temp ← GPR[rs]
I+1:if Config1CA = 0 then
        PC ← temp
    
```

```

else
    PC ← tempGPRLEN-1..1 || 0
    ISAMode ← temp0
endif
ClearHazards()

```

**Exceptions:**

None

**Programming Notes:**

This instruction implements the final step in clearing execution and instruction hazards before execution continues. A hazard is created when a Coprocessor 0 or TLB write affects execution or the mapping of the instruction stream, or after a write to the instruction stream. When such a situation exists, software must explicitly indicate to hardware that the hazard should be cleared. Execution hazards alone can be cleared with the EHB instruction. Instruction hazards can only be cleared with a JR.HB, JALR.HB, or ERET instruction. These instructions cause hardware to clear the hazard before the instruction at the target of the jump is fetched. Note that because these instructions are encoded as jumps, the process of clearing an instruction hazard can often be included as part of a call (JALR) or return (JR) sequence, by simply replacing the original instructions with the HB equivalent.

Example: Clearing hazards due to an ASID change

```

/*
 * Routine called to modify ASID and return with the new
 * mapping established.
 *
 * a0 = New ASID to establish
 */
    mfc0    v0, C0_EntryHi      /* Read current ASID */
    li      v1, ~M_EntryHiASID /* Get negative mask for field */
    and    v0, v0, v1          /* Clear out current ASID value */
    or     v0, v0, a0          /* OR in new ASID value */
    mtc0    v0, C0_EntryHi      /* Rewrite EntryHi with new ASID */
    jr.hb   ra                /* Return, clearing the hazard */
    nop

```

Example: Making a write to the instruction stream visible

```

/*
 * Routine called after new instructions are written to
 * make them visible and return with the hazards cleared.
 */
    {Synchronize the caches - see the SYNCI and CACHE instructions}
    sync           /* Force memory synchronization */
    jr.hb   ra      /* Return, clearing the hazard */
    nop

```

Example: Clearing instruction hazards in-line

```

la      AT, 10f
jr.hb   AT           /* Jump to next instruction, clearing */
nop                 /* hazards */
10:

```



31	26 25	21 20	16 15	0
LB32 000111	rt	base	offset	

6                    5                    5                    16

**Format:** LB rt, offset(base)**microMIPS****Purpose:** Load Byte

To load a byte from memory as a signed value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
memword  $\leftarrow$  LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte  $\leftarrow$  vAddr1..0 xor BigEndianCPU2
GPR[rt]  $\leftarrow$  sign_extend(memword7+8*byte..8*byte)

```

**Exceptions:**

TLB Refill, TLB Invalid, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LBE 100	offset	

6                    5                    5                    4                    3                    9

**Format:** LBE rt, offset(base)

microMIPS

**Purpose:** Load Byte EVA

To load a byte as a signed value from user mode virtual address space when executing in kernel mode.

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$ 

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 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The LBE instruction functions in exactly the same fashion as the LB instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode and executing in kernel mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $Config_{EVA}$  field being set to one.

#### Restrictions:

Only usable when access to Coprocessor0 is enabled and accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
memword ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor BigEndianCPU2
GPR[rt] ← sign_extend(memword7+8*byte..8*byte)
```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	0
LBU32 000101	rt	base	offset	

6                    5                    5                    16

**Format:** LBU rt, offset(base)**microMIPS****Purpose:** Load Byte Unsigned

To load a byte from memory as an unsigned value

**Description:**  $\text{GPR}[rt] \leftarrow \text{memory}[\text{GPR}[base] + \text{offset}]$ The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR *rt*. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.**Restrictions:**

None

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
memword ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor BigEndianCPU2
GPR[rt] ← zero_extend(memword7+8*byte..8*byte)

```

**Exceptions:**

TLB Refill, TLB Invalid, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LBUE 000	offset	

6                    5                    5                    4                    3                    9

**Format:** LBUE rt, offset(base)

microMIPS

**Purpose:** Load Byte Unsigned EVA

To load a byte as an unsigned value from user mode virtual address space when executing in kernel mode.

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$ 

The contents of the 8-bit byte at the memory location specified by the effective address are fetched, zero-extended, and placed in GPR *rt*. The 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The LBUE instruction functions in exactly the same fashion as the LBU instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $\text{Config}_{EVA}$  field being set to one.

**Restrictions:**

Only usable when access to Coprocessor0 is enabled and accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
memword ← LoadMemory (CCA, BYTE, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor BigEndianCPU2
GPR[rt] ← zero_extend(memword7+8*byte..8*byte)

```

**Exceptions:**

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable



31	26 25	21 20	16 15	0
LDC132 101111	ft	base	offset	

6                    5                    5                    16

**Format:** LDC1 ft, offset(base)

microMIPS

**Purpose:** Load Doubleword to Floating Point

To load a doubleword from memory to an FPR

**Description:**  $FPR[ft] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$

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.

#### Restrictions:

An Address Error exception occurs if EffectiveAddress<sub>2..0</sub> ≠ 0 (not doubleword-aligned).

#### Operation:

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr2..0 ≠ 03 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
memlsw ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
memmsw ← LoadMemory(CCA, WORD, pAddr, vAddr+4, DATA)
memdoubleword ← memmsw || memlsw
StoreFPR(ft, UNINTERPRETED_DOUBLEWORD, memdoubleword)

```

#### Exceptions:

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

31	26 25	21 20	16 15	12 11	0
POOL32B 001000	rt	base	LDC2 0010	offset	

6                    5                    5                    4                    12

**Format:** LDC2 rt, offset(base)

microMIPS

**Purpose:** Load Doubleword to Coprocessor 2

To load a doubleword from memory to a Coprocessor 2 register

**Description:**  $CPR[2, rt, 0] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$

The contents of the 64-bit doubleword at the memory location specified by the aligned effective address are fetched and placed in Coprocessor 2 register *rt*. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

An Address Error exception occurs if EffectiveAddress<sub>2..0</sub> ≠ 0 (not doubleword-aligned).

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
if vAddr2..0 ≠ 03 then SignalException(AddressError) endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
memlsw ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
memmsw ← LoadMemory(CCA, WORD, pAddr, vAddr+4, DATA)
←memlsw
←memmsw
```

#### Exceptions:

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



31	26 25	21 20	16 15	0
LH32 001111	rt	base	offset	

6                    5                    5                    16

**Format:** LH rt, offset(base)**microMIPS****Purpose:** Load Halfword

To load a halfword from memory as a signed value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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.

**Operation:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr0  $\neq$  0 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation(vAddr, DATA, LOAD)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword  $\leftarrow$  LoadMemory(CCA, HALFWORD, pAddr, vAddr, DATA)
byte  $\leftarrow$  vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt]  $\leftarrow$  sign_extend(memword15+8*byte..8*byte)

```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LHE 101	offset	

6                    5                    5                    4                    3                    9

**Format:** LHE rt, offset(base)**microMIPS****Purpose:** Load Halfword EVA

To load a halfword as a signed value from user mode virtual address space when executing in kernel mode.

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The LHE instruction functions in exactly the same fashion as the LH instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

### Restrictions:

Only usable when access to Coprocessor0 is enabled and accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

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

### Operation:

```
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword  $\leftarrow$  LoadMemory (CCA, HALFWORD, pAddr, vAddr, DATA)
byte  $\leftarrow$  vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt]  $\leftarrow$  sign_extend(memword15+8*byte..8*byte)
```

### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	0
LHU32 001101	rt	base	offset	

6                    5                    5                    16

**Format:** LHU rt, offset(base)**microMIPS****Purpose:** Load Halfword Unsigned

To load a halfword from memory as an unsigned value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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.

**Operation:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr0  $\neq$  0 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation(vAddr, DATA, LOAD)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword  $\leftarrow$  LoadMemory(CCA, HALFWORD, pAddr, vAddr, DATA)
byte  $\leftarrow$  vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt]  $\leftarrow$  zero_extend(memword15+8*byte..8*byte)

```

**Exceptions:**

TLB Refill, TLB Invalid, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LHUE 001	offset	

**Format:** LHUE rt, offset(base)

microMIPS

**Purpose:** Load Halfword Unsigned EVA

To load a halfword as an unsigned value from user mode virtual address space when executing in kernel mode.

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$

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 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The LHUE instruction functions in exactly the same fashion as the LHU instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

#### Restrictions:

Only usable when access to Coprocessor0 is enabled and accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

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

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
memword ← LoadMemory (CCA, HALFWORD, pAddr, vAddr, DATA)
byte ← vAddr1..0 xor (BigEndianCPU || 0)
GPR[rt] ← zero_extend(memword15+8*byte..8*byte)
```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	LL32 0011	offset	

6                    5                    5                    5                    12

**Format:** LL rt, offset(base)

microMIPS

**Purpose:** Load Linked Word

To load a word from memory for an atomic read-modify-write

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

The LL and SC instructions provide the primitives to implement atomic read-modify-write (RMW) operations for synchronizable memory locations.

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched and written into GPR *rt*. The 12-bit signed *offset* is added to the contents of GPR *base* to form an effective address.

This begins a RMW sequence on the current processor. There can be only one active RMW sequence per processor. When an LL is executed it starts an 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.

Executing LL on one processor does not cause an action that, by itself, causes 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 synchronizable by all processors and I/O devices sharing the location; if it is not, the result is **UNPREDICTABLE**. Which storage is synchronizable is a function of both CPU and system implementations. See the documentation of the **SC** instruction for the formal definition.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the effective address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt]  $\leftarrow$  memword
LLbit  $\leftarrow$  1
```

#### Exceptions:

TLB Refill, TLB Invalid, Address Error, Watch

#### Programming Notes:



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LLE 110	offset	

6                    5                    5                    4                    3                    9

**Format:** LLE rt, offset(base)

microMIPS

**Purpose:** Load Linked Word EVA

To load a word from a user mode virtual address when executing in kernel mode for an atomic read-modify-write

**Description:**  $GPR[rt] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$ 

The LLE and SCE instructions provide the primitives to implement atomic read-modify-write (RMW) operations for synchronizable memory locations using user mode virtual addresses while executing in kernel mode.

The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched and written into GPR *rt*. The 12-bit signed *offset* is added to the contents of GPR *base* to form an effective address.

This begins a RMW sequence on the current processor. There can be only one active RMW sequence per processor. When an LLE is executed it starts an active RMW sequence replacing any other sequence that was active. The RMW sequence is completed by a subsequent SCE instruction that either completes the RMW sequence atomically and succeeds, or does not and fails.

Executing LLE on one processor does not cause an action that, by itself, causes an SCE for the same block to fail on another processor.

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

The LLE instruction functions in exactly the same fashion as the LL instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Segmentation Control for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

### Restrictions:

The addressed location must be synchronizable by all processors and I/O devices sharing the location; if it is not, the result is **UNPREDICTABLE**. Which storage is synchronizable is a function of both CPU and system implementations. See the documentation of the **SCE** instruction for the formal definition.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the effective address is non-zero, an Address Error exception occurs.

### Operation:

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)
memword ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)
GPR[rt] ← memword
LLbit ← 1

```

**Exceptions:**

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

**Programming Notes:**

31	26 25	21 20	16 15	0
6	5	5	16	
POOL32I 010000	LUI 01101	rs	immediate	

**Format:** LUI rs, immediate**microMIPS****Purpose:** Load Upper Immediate

To load a constant into the upper half of a word

**Description:** GPR[rs]  $\leftarrow$  immediate || 0<sup>16</sup>The 16-bit *immediate* is shifted left 16 bits and concatenated with 16 bits of low-order zeros. The 32-bit result is placed into GPR *rt*.**Restrictions:**

None

**Operation:**GPR[rs]  $\leftarrow$  immediate || 0<sup>16</sup>**Exceptions:**

None

31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	index	base	fd	00	LUXC1 101001000

6                    5                    5                    5                    2                    9

**Format:** LUXC1 fd, index(base)microMIPS  
microMIPS**Purpose:** Load Doubleword Indexed Unaligned to Floating Point

To load a doubleword from memory to an FPR (GPR+GPR addressing), ignoring alignment

**Description:**  $FPR[fd] \leftarrow \text{memory}[(GPR[\text{base}] + GPR[\text{index}])_{\text{PSIZE}-1..3}]$ 

The contents of the 64-bit doubleword at the memory location specified by the effective address are fetched and placed into the low word of FPR *fd*. The contents of GPR *index* and GPR *base* are added to form the effective address. The effective address is doubleword-aligned; EffectiveAddress<sub>2..0</sub> are ignored.

**Restrictions:**The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

```

vAddr ← (GPR[base]+GPR[index])63..3 || 03
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
memlsw ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
memmsw ← LoadMemory(CCA, WORD, pAddr, vAddr+4, DATA)
memdoubleword ← memmsw || memlsw
StoreFPR(ft, UNINTERPRETED_DOUBLEWORD, memdoubleword)

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, Watch

31	26 25	21 20	16 15	0
LW32 111111	rt	base	offset	

6                    5                    5                    16

**Format:** LW rt, offset(base)**microMIPS****Purpose:** Load Word

To load a word from memory as a signed value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

**Operation:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt]  $\leftarrow$  memword

```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch

**Load Word**

**LW**

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LWE 111	offset	

6                    5                    5                    4                    3                    9

**Format:** LWE rt, offset(base)

microMIPS

**Purpose:** Load Word EVA

To load a word from user mode virtual address space when executing in kernel mode.

**Description:**  $\text{GPR}[rt] \leftarrow \text{memory}[\text{GPR}[base] + \text{offset}]$

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 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The LWE instruction functions in exactly the same fashion as the LW instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $\text{Config5}_{EVA}$  field being set to one.

#### Restrictions:

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt] ← memword
```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	0
LWC132 100111	ft	base	offset	

6                    5                    5                    16

**Format:** LWC1 ft, offset(base)

microMIPS

**Purpose:** Load Word to Floating Point

To load a word from memory to an FPR

**Description:**  $FPR[ft] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$

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 FPR *ft*. If FPRs are 64 bits wide, bits 63..32 of FPR *ft* become **UNPREDICTABLE**. The 16-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

An Address Error exception occurs if EffectiveAddress<sub>1..0</sub> ≠ 0 (not word-aligned).

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)

memword ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)

StoreFPR(ft, UNINTERPRETED_WORD,
          memword)
```

#### Exceptions:

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

31	26 25	21 20	16 15	12 11	0
POOL32B 001000	rt	base	LWC2 0000	offset	

6                    5                    5                    4                    12

**Format:** LWC2 rt, offset(base)**microMIPS****Purpose:** Load Word to Coprocessor 2

To load a word from memory to a COP2 register

**Description:**  $COP2[2, rt, 0] \leftarrow \text{memory}[GPR[\text{base}] + \text{offset}]$ 

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 **COP2** (Coprocessor 2) general register *rt*. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

**Restrictions:**

An Address Error exception occurs if EffectiveAddress<sub>1..0</sub> ≠ 0 (not word-aligned).

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr12..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)

memword ← LoadMemory(CCA, DOUBLEWORD, pAddr, vAddr, DATA)

COP2[2, rt, 0] ← memword

```

**Exceptions:**

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

31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	LWL32 0000	offset	

6                    5                    5                    5                    12

**Format:** LWL rt, offset(base)

microMIPS

**Purpose:** Load Word Left

To load the most-significant part of a word as a signed value from an unaligned memory address

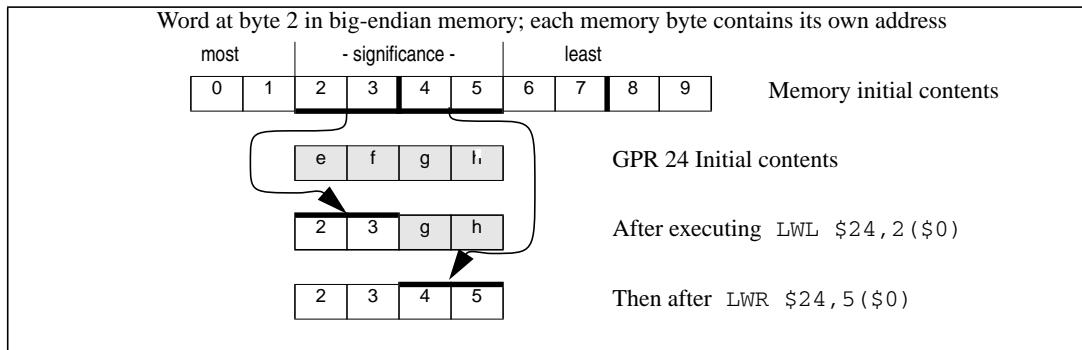
**Description:** GPR[rt]  $\leftarrow$  GPR[rt] MERGE memory[GPR[base] + offset]

The 12-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

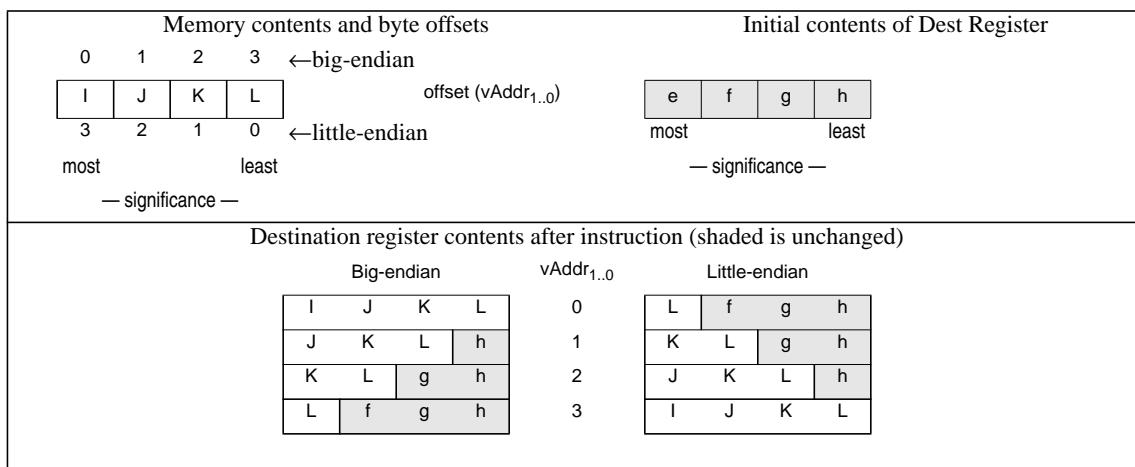
The most-significant 1 to 4 bytes of *W* is in the aligned word containing the *EffAddr*. This part of *W* is loaded into the most-significant (left) part of the word in GPR *rt*. The remaining least-significant part of the word in GPR *rt* is unchanged.

The figure below illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the most-significant byte at 2. First, LWL loads these 2 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

**Figure 5.6 Unaligned Word Load Using LWL and LWR**



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ( $v\text{Addr}_{1..0}$ ), and the current byte-ordering mode of the processor (big- or little-endian). The figure below shows the bytes loaded for every combination of offset and byte ordering.

**Figure 5.7 Bytes Loaded by LWL Instruction****Restrictions:**

None

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
if BigEndianMem = 0 then
    pAddr ← pAddrPSIZE-1..2 || 02
endif
byte ← vAddr1..0 xor BigEndianCPU2
memword ← LoadMemory (CCA, byte, pAddr, vAddr, DATA)
temp ← memword7+8*byte..0 || GPR[rt]23-8*byte..0
GPR[rt] ← temp

```

**Exceptions:**

None

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch

**Programming Notes:**

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

**Historical Information:**

In the MIPS I architecture, the LWL and LWR instructions were exceptions to the load-delay scheduling restriction. A LWL or LWR instruction which was immediately followed by another LWL or LWR instruction, and used the same destination register would correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction. All such restrictions were removed from the architecture in MIPS II.

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LWLE 010	offset	

6                    5                    5                    4                    3                    9

**Format:** LWLE rt, offset(base)

microMIPS

**Purpose:** Load Word Left EVA

To load the most-significant part of a word as a signed value from an unaligned user mode virtual address while executing in kernel mode.

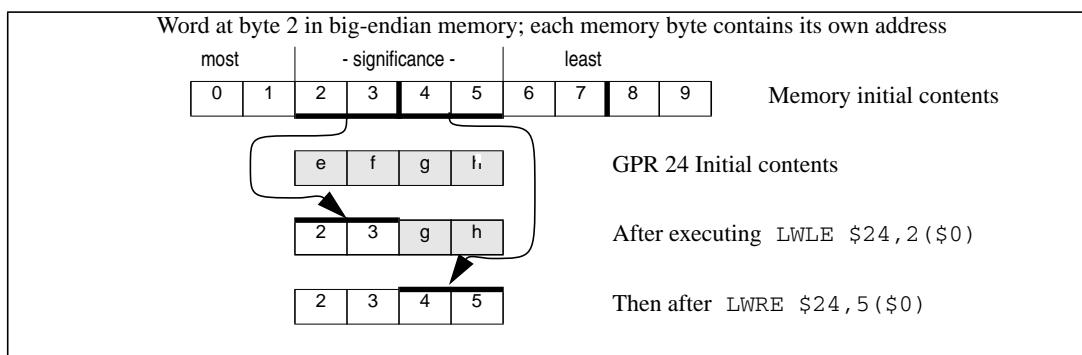
**Description:**  $GPR[rt] \leftarrow GPR[rt] \text{ MERGE memory}[GPR[\text{base}] + \text{offset}]$

The 9-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

The most-significant 1 to 4 bytes of *W* is in the aligned word containing the *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.

The figure below illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2.5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the most-significant byte at 2. First, LWLE loads these 2 bytes into the left part of the destination register word and leaves the right part of the destination word unchanged. Next, the complementary LWRE loads the remainder of the unaligned word

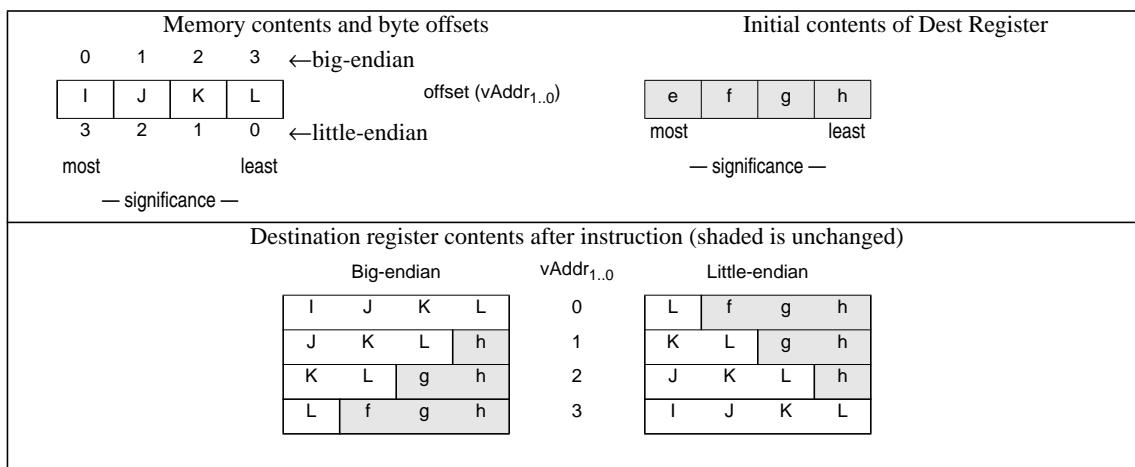
**Figure 5.8 Unaligned Word Load Using LWLE and LWRE**



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ( $v\text{Addr}_{1..0}$ ), and the current byte-ordering mode of the processor (big- or little-endian). The figure below shows the bytes loaded for every combination of offset and byte ordering.

The LWLE instruction functions in exactly the same fashion as the LWL instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $\text{Config5}_{EVA}$  field being set to one.

**Figure 5.9 Bytes Loaded by LWLE Instruction****Restrictions:**

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

```

 $vAddr \leftarrow sign\_extend(offset) + GPR[base]$ 
 $(pAddr, CCA) \leftarrow AddressTranslation(vAddr, DATA, LOAD)$ 
 $pAddr \leftarrow pAddr_{PSIZE-1..2} || (pAddr_{1..0} \text{ xor } ReverseEndian^2)$ 
if BigEndianMem = 0 then
     $pAddr \leftarrow pAddr_{PSIZE-1..2} || 0^2$ 
endif
byte  $\leftarrow vAddr_{1..0} \text{ xor } BigEndianCPU^2$ 
memword  $\leftarrow LoadMemory(CCA, byte, pAddr, vAddr, DATA)$ 
temp  $\leftarrow memword_{7+8*byte..0} || GPR[rt]_{23-8*byte..0}$ 
GPR[rt]  $\leftarrow temp$ 

```

**Exceptions:**

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

**Programming Notes:**

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

**Historical Information:**

In the MIPS I architecture, the LWL and LWR instructions were exceptions to the load-delay scheduling restriction. A LWL or LWR instruction which was immediately followed by another LWL or LWR instruction, and used the same destination register would correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction. All such restrictions were removed from the architecture in MIPS II.



31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	LWR32 0001	offset	

6                    5                    5                    5                    12

**Format:** LWR rt, offset(base)

microMIPS

**Purpose:** Load Word Right

To load the least-significant part of a word from an unaligned memory address as a signed value

**Description:**  $GPR[rt] \leftarrow GPR[rt] \text{ MERGE memory}[GPR[\text{base}] + \text{offset}]$

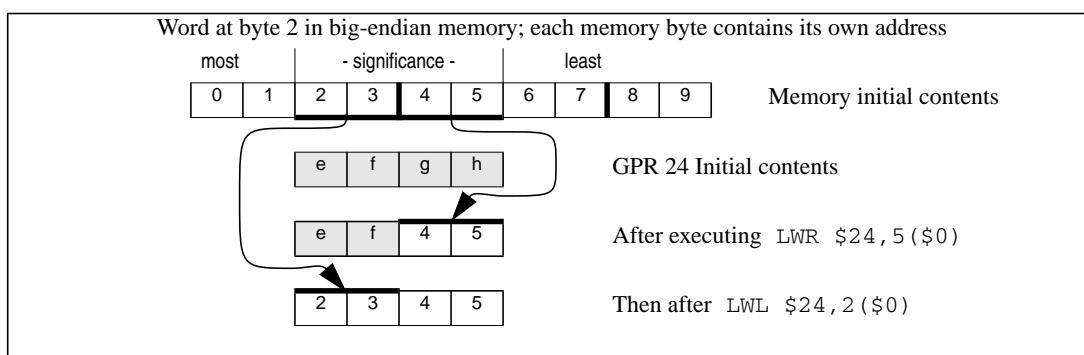
The 12-bit signed *offset* is added to the contents of GPR *base* to form an effective address (*EffAddr*). *EffAddr* is the address of the least-significant of 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

A part of *W*, the least-significant 1 to 4 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.

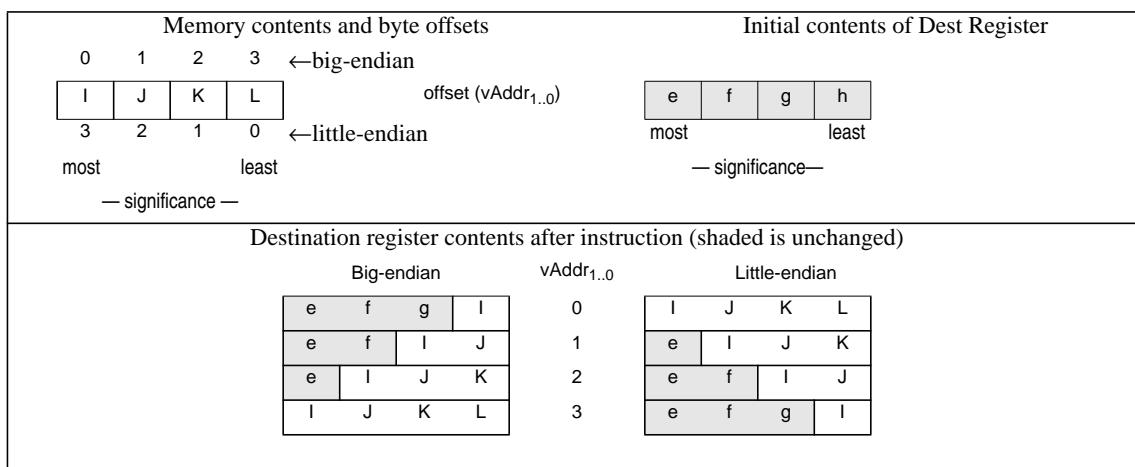
Executing both LWR and LWL, in either order, delivers a sign-extended word value in the destination register.

The figure below illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the least-significant byte at 5. First, LWR loads these 2 bytes into the right part of the destination register. Next, the complementary LWL loads the remainder of the unaligned word.

**Figure 5.10 Unaligned Word Load Using LWL and LWR**



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ( $v\text{Addr}_{1..0}$ ), and the current byte-ordering mode of the processor (big- or little-endian). The figure below shows the bytes loaded for every combination of offset and byte ordering.

**Figure 5.11 Bytes Loaded by LWR Instruction****Restrictions:**

None

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
if BigEndianMem = 0 then
    pAddr ← pAddrPSIZE-1..2 || 02
endif
byte ← vAddr1..0 xor BigEndianCPU2
memword ← LoadMemory (CCA, byte, pAddr, vAddr, DATA)
temp ← memword31..32-8*byte || GPR[rt]31-8*byte..0
GPR[rt] ← temp

```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error, Watch

**Programming Notes:**

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

**Historical Information:**

In the MIPS I architecture, the LWL and LWR instructions were exceptions to the load-delay scheduling restriction. A LWL or LWR instruction which was immediately followed by another LWL or LWR instruction, and used the same destination register would correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction. All such restrictions were removed from the architecture in MIPS II.

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	LD-EVA 0110	LWRE 011	offset	

**Format:** LWRE rt, offset(base)

microMIPS

**Purpose:** Load Word Right EVA

To load the least-significant part of a word from an unaligned user mode virtual memory address as a signed value while executing in kernel mode.

**Description:**  $GPR[rt] \leftarrow GPR[rt] \text{ MERGE } \text{memory}[GPR[\text{base}] + \text{offset}]$

The 9-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

A part of *W*, the least-significant 1 to 4 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.

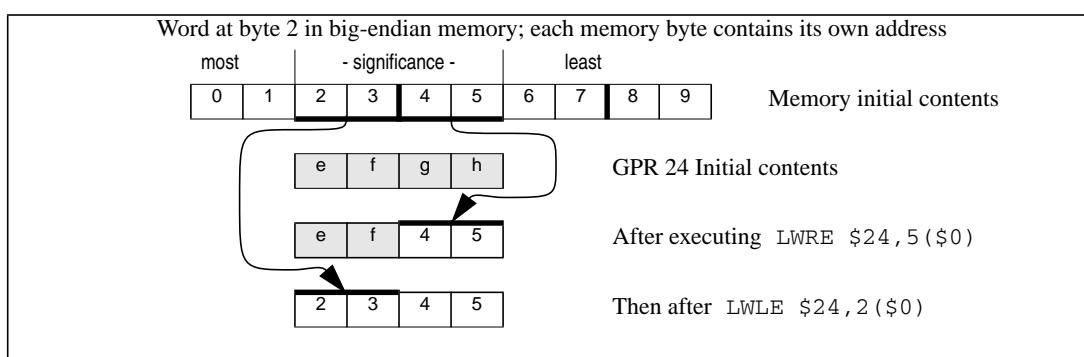
Executing both LWRE and LWLE, in either order, delivers a sign-extended word value in the destination register.

The figure below illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is in the aligned word containing the least-significant byte at 5. First, LWRE loads these 2 bytes into the right part of the destination register. Next, the complementary LWLE loads the remainder of the unaligned word.

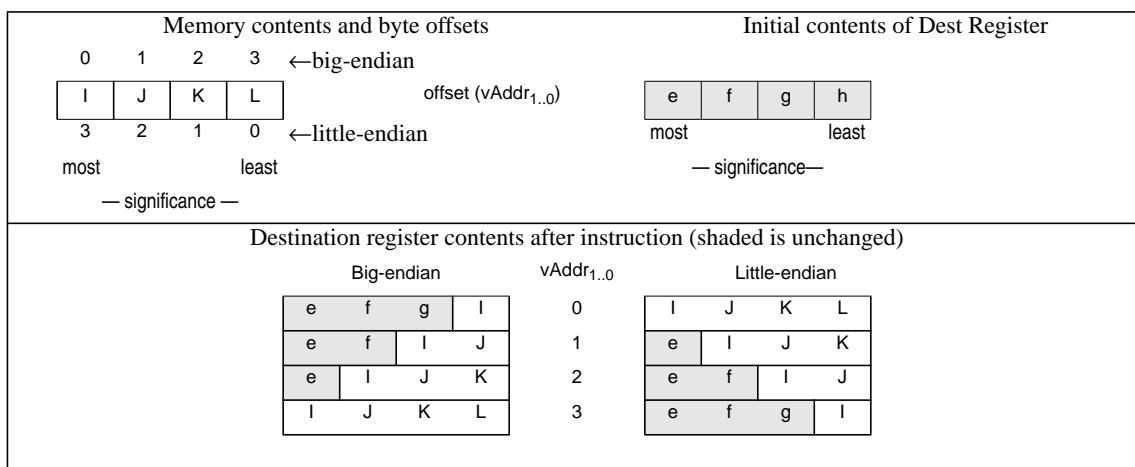
The LWRE instruction functions in exactly the same fashion as the LWR instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5EVA* field being set to one.

**Figure 5.12 Unaligned Word Load Using LWLE and LWRE**



The bytes loaded from memory to the destination register depend on both the offset of the effective address within an aligned word, that is, the low 2 bits of the address ( $v\text{Addr}_{1..0}$ ), and the current byte-ordering mode of the processor (big- or little-endian). The figure below shows the bytes loaded for every combination of offset and byte ordering.

**Figure 5.13 Bytes Loaded by LWRE Instruction****Restrictions:****Operation:**

```

 $vAddr \leftarrow \text{sign\_extend}(\text{offset}) + \text{GPR}[\text{base}]$ 
( $\text{pAddr}$ , CCA)  $\leftarrow \text{AddressTranslation } (vAddr, \text{DATA}, \text{LOAD})$ 
 $\text{pAddr} \leftarrow \text{pAddr}_{\text{PSIZE}-1..2} \parallel (\text{pAddr}_{1..0} \text{xor ReverseEndian}^2)$ 
if BigEndianMem = 0 then
     $\text{pAddr} \leftarrow \text{pAddr}_{\text{PSIZE}-1..2} \parallel 0^2$ 
endif
byte  $\leftarrow vAddr_{1..0} \text{xor BigEndianCPU}^2$ 
memword  $\leftarrow \text{LoadMemory } (\text{CCA}, \text{byte}, \text{pAddr}, \text{vAddr}, \text{DATA})$ 
temp  $\leftarrow \text{memword}_{31..32-8*\text{byte}} \parallel \text{GPR}[\text{rt}]_{31-8*\text{byte}..0}$ 
 $\text{GPR}[\text{rt}] \leftarrow \text{temp}$ 

```

**Exceptions:**

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

**Programming Notes:**

The architecture provides no direct support for treating unaligned words as unsigned values, that is, zeroing bits 63..32 of the destination register when bit 31 is loaded.

**Historical Information:**

In the MIPS I architecture, the LWL and LWR instructions were exceptions to the load-delay scheduling restriction. A LWL or LWR instruction which was immediately followed by another LWL or LWR instruction, and used the same destination register would correctly merge the 1 to 4 loaded bytes with the data loaded by the previous instruction. All such restrictions were removed from the architecture in MIPS II.



31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	LWU 1110	offset	

6                    5                    5                    4                    12

**Format:** LWU rt, offset(base)**microMIPS64****Purpose:** Load Word Unsigned

To load a word from memory as an unsigned value

**Description:** GPR[rt]  $\leftarrow$  memory[GPR[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 12-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 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

**Operation:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, LOAD)
memword  $\leftarrow$  LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[rt]  $\leftarrow$  032 || memword

```

**Exceptions:**

TLB Refill, TLB Invalid, Bus Error, Address Error, Reserved Instruction, Watch



31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	index	base	fd	00	LWXC1 001001000

6                    5                    5                    5                    2                    9

**Format:** LWXC1 fd, index(base)

microMIPS  
microMIPS

**Purpose:** Load Word Indexed to Floating Point

To load a word from memory to an FPR (GPR+GPR addressing)

**Description:**  $FPR[fd] \leftarrow \text{memory}[\text{GPR}[base] + \text{GPR}[index]]$

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 FPR *fd*. If FPRs are 64 bits wide, bits 63..32 of FPR *fd* become **UNPREDICTABLE**. The contents of GPR *index* and GPR *base* are added to form the effective address.

#### Restrictions:

An Address Error exception occurs if EffectiveAddress<sub>1..0</sub> ≠ 0 (not word-aligned).

#### Operation:

```

vAddr ← GPR[base] + GPR[index]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)

memword ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)

StoreFPR(fd, UNINTERPRETED_WORD,
          memword)

```

#### Exceptions:

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

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MADD 1100101100	POOL32AXf 111100	6

**Format:** MADD rs, rt**microMIPS****Purpose:** Multiply and Add Word to Hi,Lo

To multiply two words and add the result to Hi, Lo

**Description:**  $(HI, LO) \leftarrow (HI, LO) + (GPR[rs] \times GPR[rt])$ 

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The product is added to the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

**Restrictions:**

None

This instruction does not provide the capability of writing directly to a target GPR.

**Operation:**

```
temp ← (HI || LO) + (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

**Exceptions:**

None

**Programming Notes:**

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

	31	26 25	21 20	16 15	11 10	6 5	0
POOL32F 010101	ft	fs	fd	fr	MADD.S 000001		
POOL32F 010101	ft	fs	fd	fr	MADD.D 001001		
POOL32F 010101	ft	fs	fd	fr	MADD.PS 010001		

**Format:** MADD.fmt

MADD.S fd, fr, fs, ft

microMIPS

MADD.D fd, fr, fs, ft

microMIPS

MADD.PS fd, fr, fs, ft

microMIPS

**Purpose:** Floating Point Multiply Add

To perform a combined multiply-then-add of FP values

**Description:**  $FPR[fd] \leftarrow (FPR[fs] \times FPR[ft]) + FPR[fr]$ 

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. If *FIR<sub>Has2008</sub>*=0 or *FCSR<sub>MAC2008</sub>*=0 then the intermediate product is rounded according to the current rounding mode in *FCSR*. If *FCSR<sub>MAC2008</sub>*=1 then the intermediate product is calculated to infinite precision. 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*.

If *FIR<sub>Has2008</sub>*=0 or *FCSR<sub>MAC2008</sub>*=0 then the results and flags are as if separate floating-point multiply and add instructions were executed. If *FCSR<sub>MAC2008</sub>*=1, the multiply operation can only signal invalid operation among the IEEE exceptions.

MADD.PS multiplies then adds the upper and lower halves of FPR *fr*, FPR *fs*, and FPR *ft* independently, and ORs together any generated exceptional conditions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

**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 **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of MADD.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```

vfr ← ValueFPR(fr, fmt)
vfs ← ValueFPR(fs, fmt)
vft ← ValueFPR(ft, fmt)
StoreFPR(fd, fmt, (vfs ×fmt vft) +fmt vfr)

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Unimplemented Operation, Invalid Operation, Overflow, Underflow

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MADDU 1101101100	POOL32AXf 111100	6

**Format:** MADDU rs, rt**microMIPS****Purpose:** Multiply and Add Unsigned Word to Hi,LoTo multiply two unsigned words and add the result to *HI, LO*.**Description:**  $(HI, LO) \leftarrow (HI, LO) + (GPR[rs] \times GPR[rt])$ 

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as unsigned values, to produce a 64-bit result. The product is added to the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

**Restrictions:**

None

This instruction does not provide the capability of writing directly to a target GPR.

**Operation:**

```
temp ← (HI || LO) + (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

**Exceptions:**

None

**Programming Notes:**

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

31	26 25	21 20	16 15 14 13	11 10	6 5	0
POOL32A 000000	rt	rs	00	sel	MFC0 00011	POOL32AXf 111100

6                    5                    5                    3                    5                    6                    0

**Format:** MFC0 rt, rs  
MFC0 rt, rs, sel

microMIPS  
microMIPS

**Purpose:** Move from Coprocessor 0

To move the contents of a coprocessor 0 register to a general register.

**Description:** GPR[rt]  $\leftarrow$  CPR[0,rs,sel]

The contents of the coprocessor 0 register specified by the combination of *rs* and *sel* are loaded into general register *rt*. Note that not all coprocessor 0 registers support the *sel* field. In those instances, the *sel* field must be zero.

#### Restrictions:

The results are **UNDEFINED** if coprocessor 0 does not contain a register as specified by *rs* and *sel*.

#### Operation:

```
reg = rs
data  $\leftarrow$  CPR[0,reg,sel]
GPR[rt]  $\leftarrow$  data
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	MFC1 10000000	POOL32FXf 111011

**Format:** MFC1 rt, fs**microMIPS****Purpose:** Move Word From Floating Point

To copy a word from an FPU (CP1) general register to a GPR

**Description:** GPR[rt]  $\leftarrow$  FPR[fs]

The contents of FPR fs are loaded into general register rt.

**Restrictions:****Operation:**

```
data  $\leftarrow$  ValueFPR(fs, UNINTERPRETED_WORD)
GPR[rt]  $\leftarrow$  data
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Historical Information:**For MIPS I, MIPS II, and MIPS III the contents of GPR rt are **UNPREDICTABLE** for the instruction immediately following MFC1.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	MFC2 0100110100	POOL32AXf 111100	6

**Format:** MFC2 rt, Impl

microMIPS

The syntax shown above is an example using MFC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Word From Coprocessor 2

To copy a word from a COP2 general register to a GPR

**Description:** GPR[rt]  $\leftarrow$  CP2CPR[Impl]

The contents of the coprocessor 2 register denoted by the *Impl* field are and placed into general register *rt*. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

**Restrictions:**

The results are **UNPREDICTABLE** if *Impl* specifies a coprocessor 2 register that does not exist.

**Operation:**

```
data  $\leftarrow$  CP2CPR[Impl]
GPR[rt]  $\leftarrow$  data
```

**Exceptions:**

Coprocessor Unusable

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	MFHC1 1100000	POOL32FXf 111011

**Format:** MFHC1 rt, fs

microMIPS

**Purpose:** Move Word From High Half of Floating Point Register

To copy a word from the high half of an FPU (CP1) general register to a GPR

**Description:**  $GPR[rt] \leftarrow FPR[fs]_{63..32}$

The contents of the high word of FPR *fs* are loaded into general register *rt*. This instruction is primarily intended to support 64-bit floating point units on a 32-bit CPU, but the semantics of the instruction are defined for all cases.

#### Restrictions:

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

The results are **UNPREDICTABLE** if  $Status_{FR} = 0$  and *fs* is odd.

#### Operation:

```
data ← ValueFPR(fs, UNINTERPRETED_DOUBLEWORD)63..32
GPR[rt] ← data
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	MFHC2 1000110100	POOL32AXf 111100	6

**Format:** MFHC2 rt, Impl**microMIPS**

The syntax shown above is an example using MFHC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Word From High Half of Coprocessor 2 Register

To copy a word from the high half of a COP2 general register to a GPR

**Description:**  $\text{GPR}[rt] \leftarrow \text{CP2CPR}[\text{Impl}]_{63..32}$

The contents of the high word of the coprocessor 2 register denoted by the *Impl* field are placed into GPR *rt*. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

#### Restrictions:

The results are **UNPREDICTABLE** if *Impl* specifies a coprocessor 2 register that does not exist, or if that register is not 64 bits wide.

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

#### Operation:

```
data ← CP2CPR[Impl]63..32
GPR[rt] ← data
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	MFHI32 0000110101	POOL32AXf 111100	6

**Format:** MFHI rs**microMIPS****Purpose:** Move From HI RegisterTo copy the special purpose *HI* register to a GPR**Description:** GPR[rs]  $\leftarrow$  HIThe contents of special register *HI* are loaded into GPR *rs*.**Restrictions:**

None

**Operation:**GPR[rs]  $\leftarrow$  HI**Exceptions:**

None

**Historical Information:**

In the MIPS I, II, and III architectures, the two instructions which follow the MFHI must not modify the *HI* register. If this restriction is violated, the result of the MFHI is **UNPREDICTABLE**. This restriction was removed in MIPS IV and MIPS32, and all subsequent levels of the architecture.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	MFLO32 0001110101	POOL32AXf 111100	6

**Format:** MFLO rs

microMIPS

**Purpose:** Move From LO RegisterTo copy the special purpose *LO* register to a GPR**Description:** GPR[rs] ← LOThe contents of special register *LO* are loaded into GPR *rs*.**Restrictions:**

None

**Operation:**

GPR[rs] ← LO

**Exceptions:**

None

**Historical Information:**

In the MIPS I, II, and III architectures, the two instructions which follow the MFLO must not modify the *HI* register. If this restriction is violated, the result of the MFLO is **UNPREDICTABLE**. This restriction was removed in MIPS IV and MIPS32, and all subsequent levels of the architecture.

31	26 25	21 20	16 15 14 13 12	6 5	0
POOL32F 010101	ft	fs	0 fmt	MOV 0000001	POOL32FXf 111011

6                    5                    5                    1                    2                    7                    6

**Format:** MOV.fmt

MOV.S ft, fs

microMIPS

MOV.D ft, fs

microMIPS

MOV.PS ft, fs

microMIPS

**Purpose:** Floating Point Move

To move an FP value between FPRs

**Description:** FPR[ft]  $\leftarrow$  FPR[fs]The value in FPR *fs* is placed into FPR *ft*. The source and destination are values in format *fmt*. In paired-single format, both the halves of the pair are copied to *ft*.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of MOV.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

StoreFPR(ft, fmt, ValueFPR(fs, fmt))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Unimplemented Operation



31	26 25	22 21 20	16 15 14 13 12	6 5	0
POOL32F 010101	rt	rs	cc	MOVF 0000101	POOL32FXf 111011

6                    5                    5                    3                    7                    6

**Format:** MOVF rt, rs, cc**microMIPS****Purpose:** Move Conditional on Floating Point False

To test an FP condition code then conditionally move a GPR

**Description:** if FPConditionCode(cc) = 0 then GPR[rt] ← GPR[rs]

If the floating point condition code specified by CC is zero, then the contents of GPR rs are placed into GPR rt.

**Restrictions:****Operation:**

```

if FPConditionCode(cc) = 0 then
    GPR[rt] ← GPR[rs]
endif

```

**Exceptions:**

Reserved Instruction, Coprocessor Unusable

31	26 25	21 20	16 15	13 12 11	10 9	8	5	0
POOL32F 010101	ft	fs	cc	0 00	fmt	MOVF 000100000	9	

**Format:** MOVF.fmt  
 MOVF.S ft, fs, cc  
 MOVF.D ft, fs, cc  
 MOVF.PS ft, fs, cc

microMIPS  
 microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Move Conditional on Floating Point False

To test an FP condition code then conditionally move an FP value

**Description:** if  $\text{FPConditionCode}(cc) = 0$  then  $\text{FPR}[ft] \leftarrow \text{FPR}[fs]$

If the floating point condition code specified by  $CC$  is zero, then the value in  $\text{FPR}[fs]$  is placed into  $\text{FPR}[ft]$ . The source and destination are values in format  $fmt$ .

If the condition code is not zero, then  $\text{FPR}[fs]$  is not copied and  $\text{FPR}[ft]$  retains its previous value in format  $fmt$ . If  $ft$  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  $ft$  becomes **UNPREDICTABLE**.

MOVF.PS conditionally merges the lower half of  $\text{FPR}[fs]$  into the lower half of  $\text{FPR}[ft]$  if condition code  $CC$  is zero, and independently merges the upper half of  $\text{FPR}[fs]$  into the upper half of  $\text{FPR}[ft]$  if condition code  $CC+1$  is zero. The  $CC$  field must be even; if it is odd, the result of this operation is **UNPREDICTABLE**.

The move is non-arithmetic; it causes no IEEE 754 exceptions.

#### Restrictions:

The fields  $fs$  and  $ft$  must specify FPRs valid for operands of type  $fmt$ ; if they are not valid, the result is **UNPREDICTABLE**. The operand must be a value in format  $fmt$ ; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of MOVF.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
if  $\text{FPConditionCode}(cc) = 0$  then
  StoreFPR(ft, fmt, ValueFPR(fs, fmt))
else
  StoreFPR(ft, fmt, ValueFPR(ft, fmt))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation



31	26 25	21 20	16 15	11 10 9	5	0
POOL32A 000000	rt	rs	rd	0	MOVN 0000011000	10

**Format:** MOVN rd, rs, rt

microMIPS

**Purpose:** Move Conditional on Not Zero

To conditionally move a GPR after testing a GPR value

**Description:** if GPR[rt] ≠ 0 then GPR[rd] ← GPR[rs]

If the value in GPR *rt* is not equal to zero, then the contents of GPR *rs* are placed into GPR *rd*.

**Restrictions:**

None

**Operation:**

```
if GPR[rt] ≠ 0 then
    GPR[rd] ← GPR[rs]
endif
```

**Exceptions:**

None

**Programming Notes:**

The non-zero value tested might be the *condition true* result from the SLT, SLTI, SLTU, and SLTIU comparison instructions or a boolean value read from memory.

31	26 25	21 20	16 15	11 10 9 8 7	0
POOL32F 010101	ft	fs	fd	0 fmt	MOVN 00111000

6                    5                    5                    5                    1    2                    8

**Format:** MOVN.fmt  
 MOVN.S fd, fs, rt  
 MOVN.D fd, fs, rt  
 MOVN.PS fd, fs, rt

microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Move Conditional on Not Zero

To test a GPR then conditionally move an FP value

**Description:** if GPR[rt] ≠ 0 then FPR[fd] ← FPR[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 **UNPREDICTABLE**.

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 **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of MOVN.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
if GPR[rt] ≠ 0 then
  StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
  StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation



31	26 25	22 21 20	16 15	13 12	6 5	0
POOL32F 010101	rt	rs	cc	MOVT 0100101	POOL32FXf 111011	

6                    5                    5                    3                    7                    6

**Format:** MOVT rt, rs, cc**microMIPS****Purpose:** Move Conditional on Floating Point True

To test an FP condition code then conditionally move a GPR

**Description:** if FPConditionCode(cc) = 1 then GPR[rt] ← GPR[rs]

If the floating point condition code specified by CC is one, then the contents of GPR rs are placed into GPR rt.

**Restrictions:****Operation:**

```

if FPConditionCode(cc) = 1 then
    GPR[rt] ← GPR[rs]
endif

```

**Exceptions:**

Reserved Instruction, Coprocessor Unusable

31	26 25	21 20	16 15	13 12 11	10 9 8	0
POOL32F 010101	ft	fs	cc	0 00	fmt	MOVT 001100000

6                    5                    5                    3                    2                    2                    9

**Format:** MOVT.fmt

MOVT.S ft, fs, cc

microMIPS

MOVT.D ft, fs, cc

microMIPS

MOVT.PS ft, fs, cc

microMIPS

**Purpose:** Floating Point Move Conditional on Floating Point True

To test an FP condition code then conditionally move an FP value

**Description:** if FPConditionCode(cc) = 1 then FPR[ft] ← FPR[fs]If the floating point condition code specified by CC is one, then the value in FPR *fs* is placed into FPR *ft*. The source and destination are values in format *fmt*.If the condition code is not one, then FPR *fs* is not copied and FPR *ft* contains its previous value in format *fmt*. If *ft* 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 *ft* becomes **UNPREDICTABLE**.MOVT.PS conditionally merges the lower half of FPR *fs* into the lower half of FPR *ft* if condition code CC is one, and independently merges the upper half of FPR *fs* into the upper half of FPR *ft* if condition code CC+1 is one. The CC field should be even; if it is odd, the result of this operation is **UNPREDICTABLE**.

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 **UNPREDICTABLE**. The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of MOVT.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

```

if FPConditionCode(cc) = 0 then
    StoreFPR(ft, fmt, ValueFPR(fs, fmt))
else
    StoreFPR(ft, fmt, ValueFPR(ft, fmt))
endif

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Unimplemented Operation



31	26 25	21 20	16 15	11 10 9	5	0
POOL32A 000000	rt	rs	rd	0	MOVZ 0001011000	10

**Format:** MOVZ rd, rs, rt

microMIPS

**Purpose:** Move Conditional on Zero

To conditionally move a GPR after testing a GPR value

**Description:** if GPR[rt] = 0 then GPR[rd] ← GPR[rs]

If the value in GPR *rt* is equal to zero, then the contents of GPR *rs* are placed into GPR *rd*.

**Restrictions:**

None

**Operation:**

```
if GPR[rt] = 0 then
    GPR[rd] ← GPR[rs]
endif
```

**Exceptions:**

None

**Programming Notes:**

The zero value tested might be the *condition false* result from the SLT, SLTI, SLTU, and SLTIU comparison instructions or a boolean value read from memory.

31	26 25	21 20	16 15	11 10 9 8 7	0
POOL32F 010101	ft	fs	fd	0 fmt	MOVZ 01111000

6                    5                    5                    5                    1    2                    8

**Format:** MOVZ .fmt

MOVZ.S fd, fs, rt

microMIPS

MOVZ.D fd, fs, rt

microMIPS

MOVZ.PS fd, fs, rt

microMIPS

**Purpose:** Floating Point Move Conditional on Zero

To test a GPR then conditionally move an FP value

**Description:** if GPR[rt] = 0 then FPR[fd] ← FPR[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 **UNPREDICTABLE**.

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 **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.The result of MOVZ.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**

```

if GPR[rt] = 0 then
    StoreFPR(fd, fmt, ValueFPR(fs, fmt))
else
    StoreFPR(fd, fmt, ValueFPR(fd, fmt))
endif

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Unimplemented Operation



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MSUB 1110101100	POOL32AXf 111100	6

**Format:** MSUB rs, rt

microMIPS

**Purpose:** Multiply and Subtract Word to Hi,LoTo multiply two words and subtract the result from *HI*, *LO***Description:**  $(HI, LO) \leftarrow (HI, LO) - (GPR[rs] \times GPR[rt])$ 

The 32-bit word value in GPR *rs* is multiplied by the 32-bit value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

**Restrictions:**

None

This instruction does not provide the capability of writing directly to a target GPR.

**Operation:**

```
temp ← (HI || LO) - (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

**Exceptions:**

None

**Programming Notes:**

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

	31	26 25	21 20	16 15	11 10	6 5	0
POOL32F 010101	ft	fs	fd	fr	MSUB.S 100001		
	6	5	5	5	5	6	0
POOL32F 010101	ft	fs	fd	fr	MSUB.D 101001		
	6	5	5	5	5	6	0
POOL32F 010101	ft	fs	fd	fr	MSUB.PS 110001		
	6	5	5	5	5	6	0

**Format:** MSUB . fmt

MSUB.S fd, fr, fs, ft

microMIPS

MSUB.D fd, fr, fs, ft

microMIPS

MSUB.PS fd, fr, fs, ft

microMIPS

**Purpose:** Floating Point Multiply Subtract

To perform a combined multiply-then-subtract of FP values

**Description:** FPR[fd]  $\leftarrow$  (FPR[fs]  $\times$  FPR[ft]) - FPR[fr]

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. If *FIR<sub>Has2008</sub>*=0 or *FCSR<sub>MAC2008</sub>*=0 then the intermediate product is rounded according to the current rounding mode in *FCSR*. If *FCSR<sub>MAC2008</sub>*=1 then the intermediate product is calculated to infinite precision. 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*.

If *FIR<sub>Has2008</sub>*=0 or *FCSR<sub>MAC2008</sub>*=0 then the results and flags are as if separate floating-point multiply and subtract instructions were executed. If *FCSR<sub>MAC2008</sub>*=1, the multiply operation can only signal invalid operation among the IEEE exceptions.

MSUB.PS multiplies then subtracts the upper and lower halves of FPR *fr*, FPR *fs*, and FPR *ft* independently, and ORs together any generated exceptional conditions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

**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 **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of MSUB.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```
vfr  $\leftarrow$  ValueFPR(fr, fmt)
vfs  $\leftarrow$  ValueFPR(fs, fmt)
vft  $\leftarrow$  ValueFPR(ft, fmt)
StoreFPR(fd, fmt, (vfs  $\times_{\text{fmt}}$  vft) -fmt vfr))
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Unimplemented Operation, Invalid Operation, Overflow, Underflow

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MSUBU 1111101100	POOL32AXf 111100	6

**Format:** MSUBU rs, rt

microMIPS

**Purpose:** Multiply and Subtract Word to Hi,LoTo multiply two words and subtract the result from *HI, LO***Description:**  $(HI, LO) \leftarrow (HI, LO) - (GPR[rs] \times GPR[rt])$ 

The 32-bit word value in GPR *rs* is multiplied by the 32-bit word value in GPR *rt*, treating both operands as unsigned values, to produce a 64-bit result. The product is subtracted from the 64-bit concatenated values of *HI* and *LO*. The most significant 32 bits of the result are written into *HI* and the least significant 32 bits are written into *LO*. No arithmetic exception occurs under any circumstances.

**Restrictions:**

None

This instruction does not provide the capability of writing directly to a target GPR.

**Operation:**

```
temp ← (HI || LO) - (GPR[rs] × GPR[rt])
HI ← temp63..32
LO ← temp31..0
```

**Exceptions:**

None

**Programming Notes:**

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

31	26 25	21 20	16 15 14	13	11 10	6 5	0
POOL32A 000000	rt	rs	00	sel	MTC0 01011	POOL32AXf 111100	6

**Format:** MTC0 rt, rs  
MTC0 rt, rs, sel

microMIPS  
microMIPS

**Purpose:** Move to Coprocessor 0

To move the contents of a general register to a coprocessor 0 register.

**Description:** CPR[0, rs, sel]  $\leftarrow$  GPR[rt]

The contents of general register rt are loaded into the coprocessor 0 register specified by the combination of rs and sel. Not all coprocessor 0 registers support the the sel field. In those instances, the sel field must be set to zero.

**Restrictions:**

The results are **UNDEFINED** if coprocessor 0 does not contain a register as specified by rs and sel.

**Operation:**

```
data  $\leftarrow$  GPR[rt]
reg  $\leftarrow$  rs
CPR[0, reg, sel]  $\leftarrow$  data
```

**Exceptions:**

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	MTC1 10100000	POOL32FXf 111011

**Format:** MTC1 rt, fs**microMIPS****Purpose:** Move Word to Floating Point

To copy a word from a GPR to an FPU (CP1) general register

**Description:**  $FPR[fs] \leftarrow GPR[rt]$ The low word in GPR *rt* is placed into the low word of FPR *fs*.**Restrictions:****Operation:**

```
data ← GPR[rt]31..0
StoreFPR(fs, UNINTERPRETED_WORD, data)
```

**Exceptions:**

Coprocessor Unusable

**Historical Information:**For MIPS I, MIPS II, and MIPS III the value of FPR *fs* is **UNPREDICTABLE** for the instruction immediately following MTC1.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	MTC2 0101110100	POOL32AXf 111100	6

**Format:** MTC2 rt, Impl**microMIPS**

The syntax shown above is an example using MTC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Word to Coprocessor 2

To copy a word from a GPR to a COP2 general register

**Description:** CP2CPR[*Impl*] ← GPR[*rt*]

The low word in GPR *rt* is placed into the low word of coprocessor 2 general register denoted by the *Impl* field. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

#### Restrictions:

The results are **UNPREDICTABLE** if *Impl* specifies a coprocessor 2 register that does not exist.

#### Operation:

```
data ← GPR[rt]
CP2CPR[Impl] ← data
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	rt	fs	00	MTHC1 11100000	POOL32FXf 111011

6                    5                    5                    2                    8                    6

**Format:** MTHC1 rt, fs**microMIPS****Purpose:** Move Word to High Half of Floating Point Register

To copy a word from a GPR to the high half of an FPU (CP1) general register

**Description:**  $FPR[fs]_{63..32} \leftarrow GPR[rt]$ The word in GPR *rt* is placed into the high word of FPR *fs*. This instruction is primarily intended to support 64-bit floating point units on a 32-bit CPU, but the semantics of the instruction are defined for all cases.**Restrictions:**

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

The results are **UNPREDICTABLE** if  $Status_{FR} = 0$  and *fs* is odd.**Operation:**

```
newdata ← GPR[rt]
olddata ← ValueFPR(fs, UNINTERPRETED_DOUBLEWORD)_{31..0}
StoreFPR(fs, UNINTERPRETED_DOUBLEWORD, newdata || olddata)
```

**Exceptions:**

Coprocessor Unusable

Reserved Instruction

**Programming Notes**When paired with MTC1 to write a value to a 64-bit FPR, the MTC1 must be executed first, followed by the MTHC1. This is because of the semantic definition of MTC1, which is not aware that software will be using an MTHC1 instruction to complete the operation, and sets the upper half of the 64-bit FPR to an **UNPREDICTABLE** value.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	Impl	MTHC2 1001110100	POOL32AXf 111100	6

**Format:** MTHC2 rt, Impl**microMIPS**

The syntax shown above is an example using MTHC1 as a model. The specific syntax is implementation dependent.

**Purpose:** Move Word to High Half of Coprocessor 2 Register

To copy a word from a GPR to the high half of a COP2 general register

**Description:**  $CP2CPR[Impl]_{63..32} \leftarrow GPR[rt]$

The word in GPR *rt* is placed into the high word of coprocessor 2 general register denoted by the *Impl* field. The interpretation of the *Impl* field is left entirely to the Coprocessor 2 implementation and is not specified by the architecture.

#### Restrictions:

The results are **UNPREDICTABLE** if *Impl* specifies a coprocessor 2 register that does not exist, or if that register is not 64 bits wide.

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

#### Operation:

```
data ← GPR[rt]
CP2CPR[Impl] ← data || CPR[2,rd,sel]_{31..0}
```

#### Exceptions:

Coprocessor Unusable

Reserved Instruction

#### Programming Notes

When paired with MTC2 to write a value to a 64-bit CPR, the MTC2 must be executed first, followed by the MTHC2. This is because of the semantic definition of MTC2, which is not aware that software will be using an MTHC2 instruction to complete the operation, and sets the upper half of the 64-bit CPR to an **UNPREDICTABLE** value.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	MTHI 0010110101	POOL32AXf 111100	6

**Format:** MTHI rs

microMIPS

**Purpose:** Move to HI RegisterTo copy a GPR to the special purpose *HI* register**Description:** HI ← GPR[rs]The contents of GPR *rs* are loaded into special register *HI*.**Restrictions:**

A computed result written to the *HI/LO* pair by DIV, DIVU,MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either *HI* or *LO*.

If an MTHI instruction is executed following one of these arithmetic instructions, but before an MFLO or MFHI instruction, the contents of *LO* are **UNPREDICTABLE**. The following example shows this illegal situation:

```
MULT    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 UNPREDICTABLE value
```

**Operation:**

HI ← GPR[rs]

**Exceptions:**

None

**Historical Information:**

In MIPS I-III, if either of the two preceding instructions is MFHI, the result of that MFHI is **UNPREDICTABLE**. Reads of the *HI* or *LO* special register must be separated from any subsequent instructions that write to them by two or more instructions. In MIPS IV and later, including MIPS32 and MIPS64, this restriction does not exist.

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	0 00000	rs	MTLO 0011110101	POOL32AXf 111100	6

**Format:** MTLO rs**microMIPS****Purpose:** Move to LO RegisterTo copy a GPR to the special purpose *LO* register**Description:** LO  $\leftarrow$  GPR[rs]The contents of GPR *rs* are loaded into special register *LO*.**Restrictions:**

A computed result written to the *HI/LO* pair by DIV, DIVU, MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either *HI* or *LO*.

If an MTLO instruction is executed following one of these arithmetic instructions, but before an MFLO or MFHI instruction, the contents of *HI* are **UNPREDICTABLE**. The following example shows this illegal situation:

```
MULT    r2,r4  # start operation that will eventually write to HI,LO
...
        # code not containing mfhi or mflo
MTLO    r6
...
        # code not containing mfhi
MFHI    r3      # this mfhi would get an UNPREDICTABLE value
```

**Operation:**LO  $\leftarrow$  GPR[rs]**Exceptions:**

None

**Historical Information:**

In MIPS I-III, if either of the two preceding instructions is MFHI, the result of that MFHI is **UNPREDICTABLE**. Reads of the *HI* or *LO* special register must be separated from any subsequent instructions that write to them by two or more instructions. In MIPS IV and later, including MIPS32 and MIPS64, this restriction does not exist.

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	MUL 1000010000

**Format:** MUL rd, rs, rt

microMIPS

**Purpose:** Multiply Word to GPR

To multiply two words and write the result to a GPR.

**Description:**  $\text{GPR}[\text{rd}] \leftarrow \text{GPR}[\text{rs}] \times \text{GPR}[\text{rt}]$

The 32-bit word value in GPR *rs* is multiplied by the 32-bit value in GPR *rt*, treating both operands as signed values, to produce a 64-bit result. The least significant 32 bits of the product are written to GPR *rd*. The contents of *HI* and *LO* are **UNPREDICTABLE** after the operation. No arithmetic exception occurs under any circumstances.

#### Restrictions:

Note that this instruction does not provide the capability of writing the result to the *HI* and *LO* registers.

#### Operation:

```
temp ← GPR[rs] × GPR[rt]
GPR[rd] ← temp31..0
HI ← UNPREDICTABLE
LO ← UNPREDICTABLE
```

#### 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 GPR *rd* before the results are written interlocks 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.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



31	26 25	21 20	16 15	11 10 9 8 7	0
POOL32F 010101	ft	fs	fd	0 fmt	MUL 10110000

6                    5                    5                    5                    1    2                    8

**Format:** MUL(fmt)  
 MUL.S fd, fs, ft  
 MUL.D fd, fs, ft  
 MUL.PS fd, fs, ft

microMIPS  
 microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Multiply

To multiply FP values

**Description:**  $FPR[fd] \leftarrow FPR[fs] \times FPR[ft]$

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*. MUL.PS multiplies the upper and lower halves of FPR *fs* and FPR *ft* independently, and ORs together any generated exceptional conditions.

#### Restrictions:

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of MUL.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

StoreFPR (fd, fmt, ValueFPR(fs, fmt)  $\times_{fmt}$  ValueFPR(ft, fmt))

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Inexact, Unimplemented Operation, Invalid Operation, Overflow, Underflow



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MULT 1000101100	POOL32AXf 111100	6

**Format:** MULT rs, rt

microMIPS

**Purpose:** Multiply Word

To multiply 32-bit signed integers

**Description:**  $(HI, LO) \leftarrow GPR[rs] \times GPR[rt]$ 

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:****None****Operation:**

```
prod ← GPR[rs]31..0 × GPR[rt]31..0
LO ← prod31..0
HI ← prod63..32
```

**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 interlocks 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.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	MULTU 1001101100	POOL32AXf 111100	6

**Format:** MULTU rs, rt

microMIPS

**Purpose:** Multiply Unsigned Word

To multiply 32-bit unsigned integers

**Description:**  $(HI, LO) \leftarrow GPR[rs] \times GPR[rt]$ 

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:****None****Operation:**

```
prod ← (0 || GPR[rs]31..0) × (0 || GPR[rt]31..0)
LO ← prod31..0
HI ← prod63..32
```

**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 interlocks 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.

Where the size of the operands are known, software should place the shorter operand in GPR *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



31	26 25	21 20	16 15 14 13 12	6 5	0
POOL32F 010101	ft	fs	0 fmt	NEG 0101101	POOL32FXf 111011

6                    5                    5                    1                    2                    7                    6

**Format:** NEG fmt  
 NEG.S ft, fs  
 NEG.D ft, fs  
 NEG.PS ft, fs

microMIPS  
 microMIPS  
 microMIPS

**Purpose:** Floating Point Negate

To negate an FP value

**Description:**  $FPR[ft] \leftarrow -FPR[fs]$

The value in FPR *fs* is negated and placed into FPR *ft*. The value is negated by changing the sign bit value. The operand and result are values in format *fmt*. NEG.PS negates the upper and lower halves of FPR *fs* independently, and ORs together any generated exceptional conditions.

If  $FIR_{Has2008}=0$  or  $FCSR_{ABS2008}=0$  then this operation is arithmetic. For this case , any NaN operand signals invalid operation.

If  $FCSR_{ABS2008}=1$  then this operation is non-arithmetic. For this case, both regular floating point numbers and NAN values are treated alike, only the sign bit is affected by this instruction. No IEEE exception can be generated for this case.

#### Restrictions:

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**. The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of NEG.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

```
StoreFPR(ft, fmt, Negate(ValueFPR(fs, fmt)))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation, Invalid Operation



31	26 25	21 20	16 15	11 10	6 5	0
POOL32F 010101	ft	fs	fd	fr	NMADD.S 000010	
6	5	5	5	5	5	6
31	26 25	21 20	16 15	11 10	6 5	0
POOL32F 010101	ft	fs	fd	fr	NMADD.D 001010	
6	5	5	5	5	5	6
31	26 25	21 20	16 15	11 10	6 5	0
POOL32F 010101	ft	fs	fd	fr	NMADD.PS 010010	
6	5	5	5	5	5	6

**Format:** NMADD.fmt

NMADD.S fd, fr, fs, ft

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NMADD.D fd, fr, fs, ft

microMIPS

NMADD.PS fd, fr, fs, ft

microMIPS

**Purpose:** Floating Point Negative Multiply Add

To negate a combined multiply-then-add of FP values

**Description:**  $FPR[fd] \leftarrow -((FPR[fs] \times FPR[ft]) + FPR[fr])$ 

The value in FPR *fs* is multiplied by the value in FPR *ft* to produce an intermediate product. If *FIR*<sub>Has2008</sub>=0 or *FCSR*<sub>MAC2008</sub>=0 then the intermediate product is rounded according to the current rounding mode in *FCSR*. If *FCSR*<sub>MAC2008</sub>=1 then the intermediate product is calculated to infinite precision. 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*.

If *FIR*<sub>Has2008</sub>=0 or *FCSR*<sub>MAC2008</sub>=0 then the results and flags are as if separate floating-point multiply and add and negate instructions were executed. If *FCSR*<sub>MAC2008</sub>=1, the multiply operation can only signal invalid operation among the IEEE exceptions. If *FCSR*<sub>MAC2008</sub>=1, the negate portion of the instruction is arithmetic (regardless of the setting of *FCSR*<sub>ABS2008</sub>) and will not invert the sign bit of QNAN result coming from the sum portion of the instruction.

NMADD.PS applies the operation to the upper and lower halves of FPR *fr*, FPR *fs*, and FPR *ft* independently, and ORs together any generated exceptional conditions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

#### 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 **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of NMADD.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```
vfr ← ValueFPR(fr, fmt)
vfs ← ValueFPR(fs, fmt)
vft ← ValueFPR(ft, fmt)
StoreFPR(fd, fmt, -(vfr +fmt (vfs ×fmt vft)))
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Unimplemented Operation, Invalid Operation, Overflow, Underflow

31	26	25	21	20	16	15	11	10	6	5	0
POOL32F 010101	ft	fs		fd		fr		NMSUB.S 100010			
6	5	5	5	5	5	5	5	6	5	6	0
31	26	25	21	20	16	15	11	10	6	5	0
POOL32F 010101	ft	fs		fd		fr		NMSUB.D 101010			
6	5	5	5	5	5	5	5	6	5	6	0
31	26	25	21	20	16	15	11	10	6	5	0
POOL32F 010101	ft	fs		fd		fr		NMSUB.PS 110010			
6	5	5	5	5	5	5	5	6	5	6	0

**Format:** NMSUB.fmt

NMSUB.S fd, fr, fs, ft

NMSUB.D fd, fr, fs, ft

NMSUB.PS fd, fr, fs, ft

microMIPS

microMIPS

microMIPS

**Purpose:** Floating Point Negative Multiply Subtract

To negate a combined multiply-then-subtract of FP values

**Description:**  $FPR[fd] \leftarrow -((FPR[fs] \times FPR[ft]) - FPR[fr])$

The value in FPR  $fs$  is multiplied by the value in FPR  $ft$  to produce an intermediate product. If  $FIR_{Has2008}=0$  or  $FCSR_{MAC2008}=0$  then the intermediate product is rounded according to the current rounding mode in  $FCSR$ . If  $FCSR_{MAC2008}=1$  then the intermediate product is calculated to infinite precision. 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*.

If  $FIR_{Has2008}=0$  or  $FCSR_{MAC2008}=0$  then the results and flags are as if separate floating-point multiply and subtract and negate instructions were executed. If  $FCSR_{MAC2008}=1$ , the multiply operation can only signal invalid operation among the IEEE exceptions. If  $FCSR_{MAC2008}=1$ , the negate portion of the instruction is arithmetic (regardless of the setting of  $FCSR_{ABS2008}$ ) and will not invert the sign bit of QNAN result coming from the sum portion of the instruction.

NMSUB.PS applies the operation to the upper and lower halves of FPR *fr*, FPR *fs*, and FPR *ft* independently, and ORs together any generated exceptional conditions.

*Cause* bits are ORed into the *Flag* bits if no exception is taken.

### **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 **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of NMSUB.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```
vfr ← ValueFPR(fr, fmt)
vfs ← ValueFPR(fs, fmt)
vft ← ValueFPR(ft, fmt)
StoreFPR(fd, fmt, -((vfs ×fmt vft) −fmt vfr))
```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Unimplemented Operation, Invalid Operation, Overflow, Underflow

## No Operation

NOP

31	26 25	21 20	16 15	11 10	5	0
	POOL32A 000000	0 00000	0 00000	0 00000	0 00000	SLL 000000

**Format:** NOP

**Assembly Idiom microMIPS**

**Purpose:** No Operation

To perform no operation.

**Description:**

NOP is the assembly idiom used to denote no operation. The actual instruction is interpreted by the hardware as SLL r0, r0, 0.

**Restrictions:**

None

**Operation:**

None

**Exceptions:**

None

**Programming Notes:**

The zero instruction word, which represents SLL, r0, r0, 0, is the preferred NOP for software to use to fill branch and jump delay slots and to pad out alignment sequences.

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	NOR 1011010000

**Format:** NOR rd, rs, rt

microMIPS

**Purpose:** Not Or

To do a bitwise logical NOT OR

**Description:**  $GPR[rd] \leftarrow GPR[rs] \text{ NOR } GPR[rt]$

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

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	OR 1010010000

**Format:** OR rd, rs, rt

microMIPS

**Purpose:** Or

To do a bitwise logical OR

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

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:**

None

31	26 25	21 20	16 15	0
ORI32 010100	rt	rs	immediate	

6                    5                    5                    16

**Format:** ORI rt, rs, immediate**microMIPS****Purpose:** Or Immediate

To do a bitwise logical OR with a constant

**Description:** GPR[rt]  $\leftarrow$  GPR[rs] or immediateThe 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]  $\leftarrow$  GPR[rs] or zero\_extend(immediate)**Exceptions:**

None

31	26 25			6 5	0
POOL32A 000000	0 00000	0 00000	5 00101	0 00000	SLL 000000

6      5      6

**Format:** PAUSE**microMIPS****Purpose:** Wait for the LLBit to clear**Description:**

Locks implemented using the LL/SC instructions are a common method of synchronization between threads of control. A typical lock implementation does a load-linked instruction and checks the value returned to determine whether the software lock is set. If it is, the code branches back to retry the load-linked instruction, thereby implementing an active busy-wait sequence. The PAUSE instruction is intended to be placed into the busy-wait sequence to block the instruction stream until such time as the load-linked instruction has a chance to succeed in obtaining the software lock.

The precise behavior of the PAUSE instruction is implementation-dependent, but it usually involves descheduling the instruction stream until the LLBit is zero. In a single-threaded processor, this may be implemented as a short-term WAIT operation which resumes at the next instruction when the LLBit is zero or on some other external event such as an interrupt. On a multi-threaded processor, this may be implemented as a short term YIELD operation which resumes at the next instruction when the LLBit is zero. In either case, it is assumed that the instruction stream which gives up the software lock does so via a write to the lock variable, which causes the processor to clear the LLBit as seen by this thread of execution.

The encoding of the instruction is such that it is backward compatible with all previous implementations of the architecture. The PAUSE instruction can therefore be placed into existing lock sequences and treated as a NOP by the processor, even if the processor does not implement the PAUSE instruction.

**Restrictions:**

The operation of the processor is **UNPREDICTABLE** if a PAUSE instruction is placed in the delay slot of a branch or a jump.

**Operation:**

```
if LLBit ≠ 0 then
    EPC ← PC + 4
    DescheduleInstructionStream()
endif
```

**Exceptions:**

None

**Programming Notes:**

The PAUSE instruction is intended to be inserted into the instruction stream after an LL instruction has set the LLBit and found the software lock set. The program may wait forever if a PAUSE instruction is executed and there is no possibility that the LLBit will ever be cleared.

An example use of the PAUSE instruction is included in the following example:

```
acquire_lock:
```

```
    ll      t0, 0(a0)          /* Read software lock, set hardware lock */
    bnez   t0, acquire_lock_retry: /* Branch if software lock is taken */
    addiu  t0, t0, 1           /* Set the software lock */
    sc     t0, 0(a0)          /* Try to store the software lock */
    bnez   t0, 10f            /* Branch if lock acquired successfully */
    sync
acquire_lock_retry:
    pause                /* Wait for LLBIT to clear before retry */
    b      acquire_lock       /* and retry the operation */
    nop
10:
    Critical region code

release_lock:
    sync
    sw     zero, 0(a0)        /* Release software lock, clearing LLBIT */
                               /* for any PAUSED waiters */
```

31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	ft	fs	fd	00	PLL.PS 010000000

6                    5                    5                    5                    2                    9

**Format:** PLL.PS fd, fs, ft**microMIPS****Purpose:** Pair Lower Lower

To merge a pair of paired single values with realignment

**Description:**  $FPR[fd] \leftarrow \text{lower}(FPR[fs]) \mid\mid \text{lower}(FPR[ft])$ A new paired-single value is formed by catenating the lower single of FPR *fs* (bits 31..0) and the lower single of FPR *ft* (bits 31..0).

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *PS*. If they are not valid, the result is **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**`StoreFPR(fd, PS, ValueFPR(fs, PS)31..0 || ValueFPR(ft, PS)31..0)`**Exceptions:**

Coprocessor Unusable, Reserved Instruction



31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	ft	fs	fd	00	PLU.PS 011000000

**Format:** PLU.PS fd, fs, ft**microMIPS****Purpose:** Pair Lower Upper

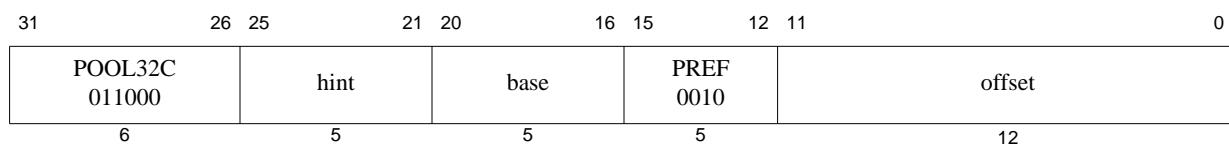
To merge a pair of paired single values with realignment

**Description:**  $FPR[fd] \leftarrow \text{lower}(FPR[fs]) \mid\mid \text{upper}(FPR[ft])$ A new paired-single value is formed by catenating the lower single of FPR *fs* (bits 31..0) and the upper single of FPR *ft* (bits 63..32).

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *PS*. If they are not valid, the result is **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:**`StoreFPR(fd, PS, ValueFPR(fs, PS)31..0 || ValueFPR(ft, PS)63..32)`**Exceptions:**

Coprocessor Unusable, Reserved Instruction



**Format:** PREF hint,offset(base)

microMIPS

**Purpose:** Prefetch

To move data between memory and cache.

**Description:** prefetch\_memory(GPR[base] + offset)

PREF adds the 12-bit signed *offset* to the contents of GPR *base* to form an effective byte address. The *hint* field supplies information about the way that the data is expected to be used.

PREF enables the processor to take some action, typically causing data to be moved to or from the 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 as long as it does not change architecturally visible state or alter the meaning of a program. Implementations are expected either to do nothing, or to take an action that increases the performance of the program. The PrepareForStore function is unique in that it may modify the architecturally visible state.

PREF does not cause addressing-related exceptions, including TLB exceptions. If the address specified would cause an addressing exception, the exception condition is ignored and no data movement occurs. However even if no data is moved, some action that is not architecturally visible, such as writeback of a dirty cache line, can take place.

It is implementation dependent whether a Bus Error or Cache Error exception is reported if such an error is detected as a byproduct of the action taken by the PREF instruction.

PREF neither generates a memory operation nor modifies the state of a cache line for a location with an *uncached* memory access type, whether this type is specified by the address segment (e.g., kseg1), the programmed cacheability and coherency attribute of a segment (e.g., the use of the K0, KU, or K23 fields in the *Config* register), or the per-page cacheability and coherency attribute provided by the TLB.

If PREF results in a memory operation, the memory access type and cacheability&coherency attribute used for the operation are determined by the memory access type and cacheability&coherency attribute 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.

For a cached location, the expected and useful action for the processor is 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.

In coherent multiprocessor implementations, if the effective address uses a coherent Cacheability and Coherency Attribute (CCA), then the instruction causes a coherent memory transaction to occur. This means a prefetch issued on one processor can cause data to be evicted from the cache in another processor.

The PREF instruction and the memory transactions which are sourced by the PREF instruction, such as cache refill or cache writeback, obey the ordering and completion rules of the SYNC instruction.

**Table 5.25 Values of *hint* Field for PREF Instruction**

Value	Name	Data Use and Desired Prefetch Action
0	load	Use: Prefetched data is expected to be read (not modified). Action: Fetch data as if for a load.

**Table 5.25 Values of *hint* Field for PREF Instruction**

1	store	Use: Prefetched data is expected to be stored or modified. Action: Fetch data as if for a store.
2-3	Reserved	Reserved for future use - not available to implementations.
4	load_streamed	Use: Prefetched data is expected to be read (not modified) but not reused extensively; it “streams” through cache. Action: Fetch data as if for a load and place it in the cache so that it does not displace data prefetched as “retained.”
5	store_streamed	Use: Prefetched data is expected to be stored or modified but not reused extensively; it “streams” through cache. Action: Fetch data as if for a store and place it in the cache so that it does not displace data prefetched as “retained.”
6	load_retained	Use: Prefetched data is expected to be read (not modified) and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a load and place it in the cache so that it is not displaced by data prefetched as “streamed.”
7	store_retained	Use: Prefetched data is expected to be stored or modified and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a store and place it in the cache so that it is not displaced by data prefetched as “streamed.”
8-20	Reserved	Reserved for future use - not available to implementations.
21-24	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.
25	writeback_invalidate (also known as “nudge”)	Use: Data is no longer expected to be used. Action: For a writeback cache, schedule a writeback of any dirty data. At the completion of the writeback, mark the state of any cache lines written back as invalid. If the cache line is not dirty, it is implementation dependent whether the state of the cache line is marked invalid or left unchanged. If the cache line is locked, no action is taken.
26-29	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.

**Table 5.25 Values of *hint* Field for PREF Instruction**

30	PrepareForStore	Use: Prepare the cache for writing an entire line, without the overhead involved in filling the line from memory. Action: If the reference hits in the cache, no action is taken. If the reference misses in the cache, a line is selected for replacement, any valid and dirty victim is written back to memory, the entire line is filled with zero data, and the state of the line is marked as valid and dirty. Programming Note: Because the cache line is filled with zero data on a cache miss, software must not assume that this action, in and of itself, can be used as a fast bzero-type function.
31	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.

**Restrictions:**

None

**Operation:**

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

**Exceptions:**

Bus Error, Cache Error

Prefetch does not take any TLB-related or address-related exceptions under any circumstances.

**Programming Notes:**

Prefetch cannot move data to or 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. A prefetch may be used using an address pointer before the validity of the pointer is determined without worrying about an addressing exception.

It is implementation dependent whether a Bus Error or Cache Error exception is reported if such an error is detected as a byproduct of the action taken by the PREF instruction. Typically, this only occurs in systems which have high-reliability requirements.

Prefetch operations have no effect on cache lines that were previously locked with the CACHE instruction.

*Hint* field encodings whose function is described as “streamed” or “retained” convey usage intent from software to hardware. Software should not assume that hardware will always prefetch data in an optimal way. If data is to be truly retained, software should use the Cache instruction to lock data into the cache.



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	hint	base	ST-EVA 1010	PREFE 010	offset	

6                    5                    5                    4                    3                    9

**Format:** PREFE hint,offset(base)

microMIPS

**Purpose:** Prefetch EVA

To move data between user mode virtual address space memory and cache while operating in kernel mode.

**Description:** prefetch\_memory(GPR[base] + offset)

PREFE adds the 9-bit signed *offset* to the contents of GPR *base* to form an effective byte address. The *hint* field supplies information about the way that the data is expected to be used.

PREFE enables the processor to take some action, typically causing data to be moved to or from the cache, to improve program performance. The action taken for a specific PREFE instruction is both system and context dependent. Any action, including doing nothing, is permitted as long as it does not change architecturally visible state or alter the meaning of a program. Implementations are expected either to do nothing, or to take an action that increases the performance of the program. The PrepareForStore function is unique in that it may modify the architecturally visible state.

PREFE does not cause addressing-related exceptions, including TLB exceptions. If the address specified would cause an addressing exception, the exception condition is ignored and no data movement occurs. However even if no data is moved, some action that is not architecturally visible, such as writeback of a dirty cache line, can take place.

It is implementation dependent whether a Bus Error or Cache Error exception is reported if such an error is detected as a byproduct of the action taken by the PREFE instruction.

PREFE neither generates a memory operation nor modifies the state of a cache line for a location with an *uncached* memory access type, whether this type is specified by the address segment (e.g., kseg1), the programmed cacheability and coherency attribute of a segment (e.g., the use of the K0, KU, or K23 fields in the *Config* register), or the per-page cacheability and coherency attribute provided by the TLB.

If PREFE results in a memory operation, the memory access type and cacheability&coherency attribute used for the operation are determined by the memory access type and cacheability&coherency attribute 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.

For a cached location, the expected and useful action for the processor is 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.

In coherent multiprocessor implementations, if the effective address uses a coherent Cacheability and Coherency Attribute (CCA), then the instruction causes a coherent memory transaction to occur. This means a prefetch issued on one processor can cause data to be evicted from the cache in another processor.

The PREFE instruction and the memory transactions which are sourced by the PREFE instruction, such as cache refill or cache writeback, obey the ordering and completion rules of the SYNC instruction.

The PREFE instruction functions in exactly the same fashion as the PREF instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5\_EVA* field being set to one.

**Table 5.26 Values of *hint* Field for PREFE Instruction**

<b>Value</b>	<b>Name</b>	<b>Data Use and Desired Prefetch Action</b>
0	load	Use: Prefetched data is expected to be read (not modified). Action: Fetch data as if for a load.
1	store	Use: Prefetched data is expected to be stored or modified. Action: Fetch data as if for a store.
2-3	Reserved	Reserved for future use - not available to implementations.
4	load_streamed	Use: Prefetched data is expected to be read (not modified) but not reused extensively; it “streams” through cache. Action: Fetch data as if for a load and place it in the cache so that it does not displace data prefetched as “retained.”
5	store_streamed	Use: Prefetched data is expected to be stored or modified but not reused extensively; it “streams” through cache. Action: Fetch data as if for a store and place it in the cache so that it does not displace data prefetched as “retained.”
6	load_retained	Use: Prefetched data is expected to be read (not modified) and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a load and place it in the cache so that it is not displaced by data prefetched as “streamed.”
7	store_retained	Use: Prefetched data is expected to be stored or modified and reused extensively; it should be “retained” in the cache. Action: Fetch data as if for a store and place it in the cache so that it is not displaced by data prefetched as “streamed.”
8-20	Reserved	Reserved for future use - not available to implementations.
21-24	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.
25	writeback_invalidate (also known as “nudge”)	Use: Data is no longer expected to be used. Action: For a writeback cache, schedule a writeback of any dirty data. At the completion of the writeback, mark the state of any cache lines written back as invalid. If the cache line is not dirty, it is implementation dependent whether the state of the cache line is marked invalid or left unchanged. If the cache line is locked, no action is taken.
26-29	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.

**Table 5.26 Values of *hint* Field for PREFE Instruction**

30	PrepareForStore	Use: Prepare the cache for writing an entire line, without the overhead involved in filling the line from memory. Action: If the reference hits in the cache, no action is taken. If the reference misses in the cache, a line is selected for replacement, any valid and dirty victim is written back to memory, the entire line is filled with zero data, and the state of the line is marked as valid and dirty. Programming Note: Because the cache line is filled with zero data on a cache miss, software must not assume that this action, in and of itself, can be used as a fast bzero-type function.
31	Implementation Dependent	Unassigned by the Architecture - available for implementation-dependent use.

**Restrictions:**

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

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

**Exceptions:**

Bus Error, Cache Error, Address Error, Reserved Instruction, Coprocessor Usable

Prefetch does not take any TLB-related or address-related exceptions under any circumstances.

**Programming Notes:**

Prefetch cannot move data to or 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. A prefetch may be used using an address pointer before the validity of the pointer is determined without worrying about an addressing exception.

It is implementation dependent whether a Bus Error or Cache Error exception is reported if such an error is detected as a byproduct of the action taken by the PREFE instruction. Typically, this only occurs in systems which have high-reliability requirements.

Prefetch operations have no effect on cache lines that were previously locked with the CACHE instruction.

*Hint* field encodings whose function is described as “streamed” or “retained” convey usage intent from software to hardware. Software should not assume that hardware will always prefetch data in an optimal way. If data is to be truly retained, software should use the Cache instruction to lock data into the cache.



31	26 25	21 20	16 15	11 10 9 8	5	0
POOL32F 010101	index	base	hint	00	PREFIX 110100000	

6                    5                    5                    5                    2                    9

**Format:** PREFIX hint, index(base)

microMIPS  
microMIPS

#### Purpose: Prefetch Indexed

To move data between memory and cache.

**Description:** `prefetch_memory[GPR[base] + GPR[index]]`

PREFIX adds the contents of GPR *index* to the contents of GPR *base* to form an effective byte address. The *hint* field supplies information about the way the data is expected to be used.

The only functional difference between the PREF and PREFIX instructions is the addressing mode implemented by the two. Refer to the [PREF](#) instruction for all other details, including the encoding of the *hint* field.

#### Restrictions:

#### Operation:

```
vAddr ← GPR[base] + GPR[index]
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)
Prefetch(CCA, pAddr, vAddr, DATA, hint)
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction, Bus Error, Cache Error

#### Programming Notes:

The PREFIX instruction is only available on processors that implement floating point and should never be generated by compilers in situations other than those in which the corresponding load and store indexed floating point instructions are generated.

Also refer to the corresponding section in the [PREF](#) instruction description.



31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	ft	fs	fd	00	PUL.PS 100000000

6                    5                    5                    5                    2                    9

**Format:** PUL.PS fd, fs, ft**microMIPS****Purpose:** Pair Upper Lower

To merge a pair of paired single values with realignment

**Description:**  $FPR[fd] \leftarrow \text{upper}(FPR[fs]) \mid\mid \text{lower}(FPR[ft])$ A new paired-single value is formed by catenating the upper single of FPR *fs* (bits 63..32) and the lower single of FPR *ft* (bits 31..0).

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *PS*. If they are not valid, the result is **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:** $\text{StoreFPR}(fd, PS, \text{ValueFPR}(fs, PS)_{63..32} \mid\mid \text{ValueFPR}(ft, PS)_{31..0})$ **Exceptions:**

Coprocessor Unusable, Reserved Instruction

31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	ft	fs	fd	00	PUU.PS 101000000

6                    5                    5                    5                    2                    9

**Format:** PUU.PS fd, fs, ft**microMIPS****Purpose:** Pair Upper Upper

To merge a pair of paired single values with realignment

**Description:**  $FPR[fd] \leftarrow \text{upper}(FPR[fs]) \mid\mid \text{upper}(FPR[ft])$ A new paired-single value is formed by catenating the upper single of FPR *fs* (bits 63..32) and the upper single of FPR *ft* (bits 63..32).

The move is non-arithmetic; it causes no IEEE 754 exceptions.

**Restrictions:**The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *PS*. If they are not valid, the result is **UNPREDICTABLE**.The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.**Operation:** $\text{StoreFPR}(fd, PS, \text{ValueFPR}(fs, PS)_{63..32} \mid\mid \text{ValueFPR}(ft, PS)_{63..32})$ **Exceptions:**

Coprocessor Unusable, Reserved Instruction

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	RDHWR 0110101100	POOL32AXf 111100	6

**Format:** RDHWR rt, rs

microMIPS

**Purpose:** Read Hardware Register

To move the contents of a hardware register to a general purpose register (GPR) if that operation is enabled by privileged software.

The purpose of this instruction is to give user mode access to specific information that is otherwise only visible in kernel mode.

**Description:** GPR[rt]  $\leftarrow$  HWR[rs]

If access is allowed to the specified hardware register, the contents of the register specified by *rs* is loaded into general register *rt*. Access control for each register is selected by the bits in the coprocessor 0 *HWREna* register.

The available hardware registers, and the encoding of the *rs* field for each, are shown in [Table 5.27](#).

**Table 5.27 RDHWR Register Numbers**

Register Number (rd Value)	Mnemonic	Description										
0	CPUNum	Number of the CPU on which the program is currently running. This register provides read access to the coprocessor 0 <i>EBase<sub>CPUNum</sub></i> field.										
1	SYNCI_Step	Address step size to be used with the SYNCI instruction, or zero if no caches need be synchronized. See that instruction's description for the use of this value.										
2	CC	High-resolution cycle counter. This register provides read access to the coprocessor 0 <i>Count</i> Register.										
3	CCRes	Resolution of the CC register. This value denotes the number of cycles between update of the register. For example: <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>CCRes Value</th> <th>Meaning</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>CC register increments every CPU cycle</td> </tr> <tr> <td>2</td> <td>CC register increments every second CPU cycle</td> </tr> <tr> <td>3</td> <td>CC register increments every third CPU cycle</td> </tr> <tr> <td></td> <td>etc.</td> </tr> </tbody> </table>	CCRes Value	Meaning	1	CC register increments every CPU cycle	2	CC register increments every second CPU cycle	3	CC register increments every third CPU cycle		etc.
CCRes Value	Meaning											
1	CC register increments every CPU cycle											
2	CC register increments every second CPU cycle											
3	CC register increments every third CPU cycle											
	etc.											
4-28		These registers numbers are reserved for future architecture use. Access results in a Reserved Instruction Exception.										
29	ULR	User Local Register. This register provides read access to the coprocessor 0 <i>UserLocal</i> register, if it is implemented. In some operating environments, the <i>UserLocal</i> register is a pointer to a thread-specific storage block.										

**Table 5.27 RDHWR Register Numbers**

Register Number ( <i>rd</i> Value)	Mnemonic	Description
30-31		These register numbers are reserved for implementation-dependent use. If they are not implemented, access results in a Reserved Instruction Exception.

**Restrictions:**

In implementations of Release 1 of the Architecture, this instruction resulted in a Reserved Instruction Exception.

Access to the specified hardware register is enabled if Coprocessor 0 is enabled, or if the corresponding bit is set in the *HWEEna* register. If access is not allowed or the register is not implemented, a Reserved Instruction Exception is signaled.

**Operation:**

```
case rs
    0: temp ← EBaseCPUNum
    1: temp ← SYNCI_StepSize()
    2: temp ← Count
    3: temp ← CountResolution()
    29: temp ← UserLocal
    30: temp ← Implementation-Dependent-Value
    31: temp ← Implementation-Dependent-Value
    otherwise: SignalException(ReservedInstruction)
endcase
GPR[rt] ← temp
```

**Exceptions:**

Reserved Instruction



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	RDPGPR 1110000101	POOL32AXf 111100	6

**Format:** RDPGPR rt, rs**microMIPS****Purpose:** Read GPR from Previous Shadow Set

To move the contents of a GPR from the previous shadow set to a current GPR.

**Description:**  $GPR[rt] \leftarrow SGPR[SRSCTL_{PSS}, rs]$ The contents of the shadow GPR register specified by  $SRSCTL_{PSS}$  (signifying the previous shadow set number) and  $rs$  (specifying the register number within that set) is moved to the current GPR  $rt$ .**Restrictions:**

In implementations prior to Release 2 of the Architecture, this instruction resulted in a Reserved Instruction Exception.

**Operation:** $GPR[rt] \leftarrow SGPR[SRSCTL_{PSS}, rs]$ **Exceptions:**

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	RECIP 01001000	POOL32FXf 111011

6                5                5                1    1                8                6

**Format:** RECIP.fmtRECIP.S    ft, fs  
RECIP.D    ft, fsmicroMIPS  
microMIPS**Purpose:** Reciprocal Approximation

To approximate the reciprocal of an FP value (quickly)

**Description:**  $FPR[ft] \leftarrow 1.0 / FPR[fs]$ The reciprocal of the value in  $FPR[fs]$  is approximated and placed into  $FPR[ft]$ . 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 *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.**Operation:**

StoreFPR(ft, fmt, 1.0 / valueFPR(fs, fmt))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Division-by-zero, Unimplemented Op, Invalid Op, Overflow, Underflow



31	26 25	21 20	16 15	11 10	6 5	0
POOL32A 000000	rt	rs	sa	0	ROTR 0011000000	10

**Format:** ROTR rt, rs, sa**SmartMIPS Crypto, microMIPS****Purpose:** Rotate Word Right

To execute a logical right-rotate of a word by a fixed number of bits

**Description:**  $GPR[rt] \leftarrow GPR[rs] \leftrightarrow_{(right)} sa$ The contents of the low-order 32-bit word of GPR *rs* are rotated right; the word result is placed in GPR *rt*. The bit-rotate amount is specified by *sa*.**Restrictions:****Operation:**

```

if ((ArchitectureRevision() < 2) and (Config3SM = 0)) then
    UNPREDICTABLE
endif
s ← sa
temp ← GPR[rs]s-1..0 || GPR[rs]31..s
GPR[rt] ← temp

```

**Exceptions:**

Reserved Instruction

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	ROTRV 0011010000

6                    5                    5                    5                    1                    10

**Format:** ROTRV rd, rt, rs**SmartMIPS Crypto, microMIPS****Purpose:** Rotate Word Right Variable

To execute a logical right-rotate of a word by a variable number of bits

**Description:** GPR[rd]  $\leftarrow$  GPR[rt]  $\leftrightarrow_{\text{(right)}}$  GPR[rs]

The contents of the low-order 32-bit word of GPR rt are rotated right; the word result is placed in GPR rd. The bit-rotate amount is specified by the low-order 5 bits of GPR rs.

**Restrictions:****Operation:**

```

if ((ArchitectureRevision() < 2) and (Config3SM = 0)) then
    UNPREDICTABLE
endif
s  $\leftarrow$  GPR[rs]4..0
temp  $\leftarrow$  GPR[rt]s-1..0 || GPR[rt]31..s
GPR[rd]  $\leftarrow$  temp

```

**Exceptions:**

Reserved Instruction

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0   fmt	ROUND.L 11001100	POOL32FXf 111011

**Format:** ROUND.L fmt

ROUND.L.S ft, fs  
ROUND.L.D ft, fs

microMIPS  
microMIPS

**Purpose:** Floating Point Round to Long Fixed Point

To convert an FP value to 64-bit fixed point, rounding to nearest

**Description:** `FPR[ft] ← convert_and_round(FPR[fs])`

The value in FPR *fs*, in format *fmt*, is converted to a value in 64-bit long fixed point format and rounded to nearest/even (rounding mode 0). The result is placed in FPR *ft*.

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. In this case 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 *ft* and an Invalid Operation exception is taken immediately. Otherwise, the default result,  $2^{63}-1$ , is written to *ft*.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs; *fs* for type *fmt* and *fd* for long fixed point; if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

`StoreFPR(ft, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))`

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Inexact, Unimplemented Operation, Invalid Operation



31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	ROUND.W 11101100	POOL32FXf 111011

**Format:** ROUND.W(fmt)ROUND.W.S ft, fs  
ROUND.W.D ft, fsmicroMIPS  
microMIPS**Purpose:** Floating Point Round to Word Fixed Point

To convert an FP value to 32-bit fixed point, rounding to nearest

**Description:** FPR[ft]  $\leftarrow$  convert\_and\_round(FPR[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 ft.

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. In this case 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 ft and an Invalid Operation exception is taken immediately. Otherwise, the default result,  $2^{31}-1$ , is written to ft.**Restrictions:**The fields fs and ft must specify valid FPRs; fs for type fmt and fd for word fixed point; if they are not valid, the result is **UNPREDICTABLE**.The operand must be a value in format fmt; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.**Operation:**

StoreFPR(ft, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))

**Exceptions:**

Coprocessor Unusable, Reserved Instruction

**Floating Point Exceptions:**

Inexact, Unimplemented Operation, Invalid Operation



31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	RSQRT(fmt 00001000)	POOL32FXf 111011

6            5            5            1    1            8            6

**Format:** RSQRT(fmt  
RSQRT.S ft, fs  
RSQRT.D ft, fs)

microMIPS  
microMIPS

#### Purpose:

Reciprocal Square Root Approximation

To approximate the reciprocal of the square root of an FP value (quickly)

**Description:**  $FPR[ft] \leftarrow 1.0 / \sqrt{FPR[fs]}$

The reciprocal of the positive square root of the value in  $FPR[fs]$  is approximated and placed into  $FPR[ft]$ . 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 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).

The effect of the current FCSR rounding mode on the result is implementation dependent.

#### Restrictions:

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

#### Operation:

```
StoreFPR(ft, fmt, 1.0 / SquareRoot(valueFPR(fs, fmt)))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Inexact, Division-by-zero, Unimplemented Operation, Invalid Operation, Overflow, Underflow



31	26 25	21 20	16 15	0
SB32 000110	rt	base	offset	

6                    5                    5                    16

**Format:** SB rt, offset(base)**microMIPS****Purpose:** Store Byte

To store a byte to memory

**Description:**  $\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{GPR}[rt]$ 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:**

```

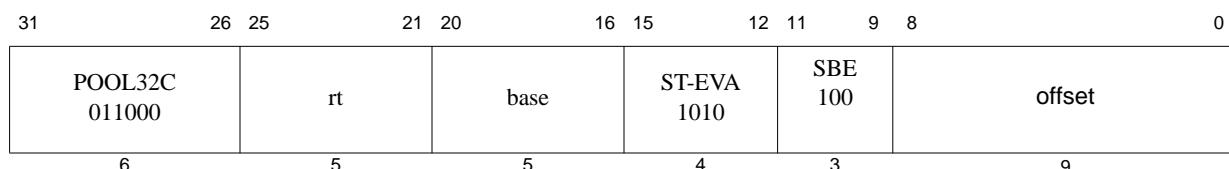
vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
bytesel ← vAddr1..0 xor BigEndianCPU2
dataword ← GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, BYTE, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error, Watch





**Format:** SBE rt, offset(base)

microMIPS

**Purpose:** Store Byte EVA

To store a byte to user mode virtual address space when executing in kernel mode.

**Description:** memory[GPR[base] + offset] ← GPR[rt]

The least-significant 8-bit byte of GPR *rt* is stored in memory at the location specified by the effective address. The 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The SBE instruction functions in exactly the same fashion as the SB instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

#### Restrictions:

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

#### Operation:

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
bytesel ← vAddr1..0 xor BigEndianCPU2
dataword ← GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, BYTE, dataword, pAddr, vAddr, DATA)

```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	SC 1011	offset	

6                    5                    5                    5                    12

**Format:** SC rt, offset(base)

microMIPS

**Purpose:** Store Conditional Word

To store a word to memory to complete an atomic read-modify-write

**Description:** if atomic\_update then memory[GPR[base] + offset]  $\leftarrow$  GPR[rt], GPR[rt]  $\leftarrow$  1  
else GPR[rt]  $\leftarrow$  0

The LL and SC instructions provide primitives to implement atomic read-modify-write (RMW) operations for synchronizable memory locations.

The 32-bit word in GPR *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 an effective address.

The SC completes the RMW sequence begun by the preceding LL instruction executed on the processor. To complete the RMW sequence atomically, the following occur:

- The 32-bit word of GPR *rt* is stored into memory at the location specified by the aligned effective address.
- A 1, indicating success, is written into GPR *rt*.

Otherwise, memory is not modified and a 0, indicating failure, is written into GPR *rt*.

If either of the following events occurs between the execution of LL and SC, the SC fails:

- A coherent store is completed by another processor or coherent I/O module into the block of synchronizable physical memory containing the word. The size and alignment of the block is implementation dependent, but it is at least one word and at most the minimum page size.
- An ERET instruction is executed.

If either 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 not predictable. Portable programs should not cause one of these events.

- A memory access instruction (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 is **UNPREDICTABLE**:

- Execution of SC must have been preceded by execution of an LL instruction.
- An RMW sequence executed without intervening events that would cause the SC to fail must use the same address in the LL and SC. The address is the same if the virtual address, physical address, and cacheability & coherency attribute are identical.

Atomic RMW is provided only for synchronizable memory locations. A synchronizable memory location is one that is associated with the state and logic necessary to implement the LL/SC semantics. Whether a memory location is synchronizable depends on the processor and system configurations, and on the memory access type used for the

location:

- **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, and they may not be mixed.
- **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*.
- **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.

#### Restrictions:

The addressed location must have a memory access type of *cached noncoherent* or *cached coherent*; if it does not, the result is **UNPREDICTABLE**.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
dataword ← GPR[rt]
if LLbit then
    StoreMemory(CCA, WORD, dataword, pAddr, vAddr, DATA)
endif
GPR[rt] ← 031 || LLbit
```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

#### Programming Notes:

LL and SC are used to atomically update memory locations, as shown 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, and 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.

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	ST-EVA 1010	SCE 110	offset	

6                    5                    5                    4                    3                    9

**Format:** SCE rt, offset(base)**microMIPS****Purpose:** Store Conditional Word EVA

To store a word to user mode virtual memory while operating in kernel mode to complete an atomic read-modify-write

**Description:** if atomic\_update then memory[GPR[base] + offset]  $\leftarrow$  GPR[rt], GPR[rt]  $\leftarrow$  1  
else GPR[rt]  $\leftarrow$  0

The LL and SC instructions provide primitives to implement atomic read-modify-write (RMW) operations for synchronizable memory locations.

The 32-bit word in GPR *rt* is conditionally stored in memory at the location specified by the aligned effective address. The 9-bit signed *offset* is added to the contents of GPR *base* to form an effective address.

The SCE completes the RMW sequence begun by the preceding LLE instruction executed on the processor. To complete the RMW sequence atomically, the following occur:

- The 32-bit word of GPR *rt* is stored into memory at the location specified by the aligned effective address.
- A 1, indicating success, is written into GPR *rt*.

Otherwise, memory is not modified and a 0, indicating failure, is written into GPR *rt*.

If either of the following events occurs between the execution of LL and SC, the SC fails:

- A coherent store is completed by another processor or coherent I/O module into the block of synchronizable physical memory containing the word. The size and alignment of the block is implementation dependent, but it is at least one word and at most the minimum page size.
- An ERET instruction is executed.

If either of the following events occurs between the execution of LLE and SCE, the SCE may succeed or it may fail; the success or failure is not predictable. Portable programs should not cause one of these events.

- A memory access instruction (load, store, or prefetch) is executed on the processor executing the LLE/SCE.
- The instructions executed starting with the LLE and ending with the SCE 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 SCE is **UNPREDICTABLE**:

- Execution of SCE must have been preceded by execution of an LLE instruction.
- An RMW sequence executed without intervening events that would cause the SCE to fail must use the same address in the LLE and SCE. The address is the same if the virtual address, physical address, and cacheability & coherency attribute are identical.

Atomic RMW is provided only for synchronizable memory locations. A synchronizable memory location is one that is associated with the state and logic necessary to implement the LLE/SCE semantics. Whether a memory location is

synchronizable depends on the processor and system configurations, and on the memory access type used for the location:

- **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, and they may not be mixed.
- **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*.
- **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 SCE instruction functions in exactly the same fashion as the SC instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5<sub>EVA</sub>* field being set to one.

#### Restrictions:

The addressed location must have a memory access type of *cached noncoherent* or *cached coherent*; if it does not, the result is **UNPREDICTABLE**.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rt]
if LLbit then
    StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
endif
GPR[rt] ← 031 || LLbit
```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch, Reserved Instruction, Coprocessor Unusable

#### Programming Notes:

LLE and SCE are used to atomically update memory locations, as shown below.

```
L1:
    LLE    T1, (T0)  # load counter
    ADDI   T2, T1, 1 # increment
    SCE    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 LLE and SCE cause SCE to fail, so persistent exceptions must be avoided. Some examples of these are arithmetic operations that trap, system calls, and floating point operations that trap or require software emulation assistance.

LLE and SCE 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.

31	26 25	16 15	6 5	0
POOL32A 000000	code - use syscall	SDBBP 1101101101	POOL32AXf 111100	6

**Format:** SDBBP code**EJTAG microMIPS****Purpose:** Software Debug Breakpoint

To cause a debug breakpoint exception

**Description:**

This instruction causes a debug exception, passing control to the debug exception handler. If the processor is executing in Debug Mode when the SDBBP instruction is executed, the exception is a Debug Mode Exception, which sets the DebugDEExcCode field to the value 0x9 (Bp). The code field can be used for passing information to the debug exception handler, and is retrieved by the debug exception handler only by loading the contents of the memory word containing the instruction, using the DEPC register. The CODE field is not used in any way by the hardware.

**Restrictions:****Operation:**

```
If DebugDM = 0 then
    SignalDebugBreakpointException()
else
    SignalDebugModeBreakpointException()
endif
```

**Exceptions:**

Debug Breakpoint Exception

Debug Mode Breakpoint Exception

31	26 25	21 20	16 15	0
SDC132 101110	ft	base	offset	

6                    5                    5                    16

**Format:** SDC1 ft, offset(base)

microMIPS

**Purpose:** Store Doubleword from Floating Point

To store a doubleword from an FPR to memory

**Description:**  $\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{FPR}[ft]$

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.

#### Restrictions:

An Address Error exception occurs if EffectiveAddress<sub>2..0</sub> ≠ 0 (not doubleword-aligned).

#### Operation:

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr2..0 ≠ 03 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
datadoubleword ← ValueFPR(ft, UNINTERPRETED_DOUBLEWORD)
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
StoreMemory(CCA, WORD, datadoubleword31..0, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
StoreMemory(CCA, WORD, datadoubleword63..32, pAddr, vAddr+4, DATA)

```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

31	26 25	21 20	16 15	12 11	0
POOL32B 110110	rt	base	SDC2 1010	offset	

6                    5                    5                    4                    12

**Format:** SDC2 rt, offset(base)

microMIPS

**Purpose:** Store Doubleword from Coprocessor 2

To store a doubleword from a Coprocessor 2 register to memory

**Description:**  $\text{memory}[\text{GPR}[\text{base}] + \text{offset}] \leftarrow \text{CPR}[2, \text{rt}, 0]$

The 64-bit doubleword in Coprocessor 2 register *rt* is stored in memory at the location specified by the aligned effective address. The 12-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

#### Restrictions:

An Address Error exception occurs if  $\text{EffectiveAddress}_{2..0} \neq 0$  (not doubleword-aligned).

#### Operation:

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr2..0 ≠ 03 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
lsw ← CPR[2,rt,0]
msw ← CPR[2,rt+1,0]
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
StoreMemory(CCA, WORD, lsw, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
StoreMemory(CCA, WORD, msw, pAddr, vAddr+4, DATA)

```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	SEB 0010101100	POOL32AXf 111100	6

**Format:** SEB rt, rs**microMIPS****Purpose:** Sign-Extend ByteTo sign-extend the least significant byte of GPR *rs* and store the value into GPR *rt*.**Description:**  $\text{GPR}[\text{rt}] \leftarrow \text{SignExtend}(\text{GPR}[\text{rs}]_{7..0})$ The least significant byte from GPR *rs* is sign-extended and stored in GPR *rt*.**Restrictions:**

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

**Operation:** $\text{GPR}[\text{rt}] \leftarrow \text{sign\_extend}(\text{GPR}[\text{rs}]_{7..0})$ **Exceptions:**

Reserved Instruction

**Programming Notes:**

For symmetry with the SEB and SEH instructions, one would expect that there would be ZEB and ZEH instructions that zero-extend the source operand. Similarly, one would expect that the SEW and ZEW instructions would exist to sign- or zero-extend a word to a doubleword. These instructions do not exist because there are functionally-equivalent instructions already in the instruction set. The following table shows the instructions providing the equivalent functions.

Expected Instruction	Function	Equivalent Instruction
ZEB rx, ry	Zero-Extend Byte	ANDI rx, ry, 0xFF
ZEH rx, ry	Zero-Extend Halfword	ANDI rx, ry, 0xFFFF



31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	SEH 0011101100	POOL32AXf 111100	6

**Format:** SEH rt, rs**microMIPS****Purpose:** Sign-Extend HalfwordTo sign-extend the least significant halfword of GPR *rs* and store the value into GPR *rt*.**Description:**  $\text{GPR}[\text{rt}] \leftarrow \text{SignExtend}(\text{GPR}[\text{rs}]_{15..0})$ The least significant halfword from GPR *rs* is sign-extended and stored in GPR *rt*.**Restrictions:**

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

**Operation:** $\text{GPR}[\text{rt}] \leftarrow \text{sign\_extend}(\text{GPR}[\text{rs}]_{15..0})$ **Exceptions:**

Reserved Instruction

**Programming Notes:**

The SEH instruction can be used to convert two contiguous halfwords to sign-extended word values in three instructions. For example:

```

lw      t0, 0(a1)          /* Read two contiguous halfwords */
seh    t1, t0              /* t1 = lower halfword sign-extended to word */
sra    t0, t0, 16           /* t0 = upper halfword sign-extended to word */

```

Zero-extended halfwords can be created by changing the SEH and SRA instructions to ANDI and SRL instructions, respectively.

For symmetry with the SEB and SEH instructions, one would expect that there would be ZEB and ZEH instructions that zero-extend the source operand. Similarly, one would expect that the SEW and ZEW instructions would exist to sign- or zero-extend a word to a doubleword. These instructions do not exist because there are functionally-equivalent instructions already in the instruction set. The following table shows the instructions providing the equivalent functions.

Expected Instruction	Function	Equivalent Instruction
ZEB rx, ry	Zero-Extend Byte	ANDI rx, ry, 0xFF
ZEH rx, ry	Zero-Extend Halfword	ANDI rx, ry, 0xFFFF



31	26 25	21 20	16 15	0
SH32 001110	rt	base	offset	

6                    5                    5                    16

**Format:** SH rt, offset(base)**microMIPS****Purpose:** Store Halfword

To store a halfword to memory

**Description:** memory[GPR[base] + offset]  $\leftarrow$  GPR[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.

**Operation:**

```

vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr0  $\neq$  0 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation(vAddr, DATA, STORE)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
bytesel  $\leftarrow$  vAddr1..0 xor (BigEndianCPU || 0)
dataword  $\leftarrow$  GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory(cca, HALFWORD, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	ST-EVA 1010	SHE 101	offset	

6                    5                    5                    4                    3                    9

**Format:** SHE rt, offset(base)

microMIPS

**Purpose:** Store Halfword EVA

To store a halfword to user mode virtual address space when executing in kernel mode.

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

The least-significant 16-bit halfword of register *rt* is stored in memory at the location specified by the aligned effective address. The 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The SHE instruction functions in exactly the same fashion as the SH instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the *Config5\_EVA* field being set to one.

#### Restrictions:

Only usable in kernel mode when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

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

#### Operation:

```
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, STORE)
pAddr  $\leftarrow$  pAddrPSIZE-1..2 || (pAddr1..0 xor (ReverseEndian || 0))
bytesel  $\leftarrow$  vAddr1..0 xor (BigEndianCPU || 0)
dataword  $\leftarrow$  GPR[rt]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, HALFWORD, dataword, pAddr, vAddr, DATA)
```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	sa	0	SLL32 0000000000

6                    5                    5                    5                    1                    10

**Format:** SLL rt, rs, sa

microMIPS

**Purpose:** Shift Word Left Logical

To left-shift a word by a fixed number of bits

**Description:** GPR[rt]  $\leftarrow$  GPR[rs]  $\ll$  sa

The contents of the low-order 32-bit word of GPR rs are shifted left, inserting zeros into the emptied bits; the word result is placed in GPR rt. The bit-shift amount is specified by sa.

**Restrictions:**

None

**Operation:**

```

s  $\leftarrow$  sa
temp  $\leftarrow$  GPR[rs](31-s)... || 0s
GPR[rt]  $\leftarrow$  temp

```

**Exceptions:**

None

**Programming Notes:**

SLL r0, r0, 0, expressed as NOP, is the assembly idiom used to denote no operation.

SLL r0, r0, 1, expressed as SSNOP, is the assembly idiom used to denote no operation that causes an issue break on superscalar processors.

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	SLLV 00000010000

**Format:** SLLV rd, rt, rs**microMIPS****Purpose:** Shift Word Left Logical Variable

To left-shift a word by a variable number of bits

**Description:** GPR[rd]  $\leftarrow$  GPR[rt]  $<<$  rs

The contents of the low-order 32-bit word of GPR rt are shifted left, inserting zeros into the emptied bits; the result word is placed in GPR rd. The bit-shift amount is specified by the low-order 5 bits of GPR rs.

**Restrictions:**

None

**Operation:**

```

s  $\leftarrow$  GPR[rs]4..0
temp  $\leftarrow$  GPR[rt]_{(31-s)..0} || 0^s
GPR[rd]  $\leftarrow$  temp

```

**Exceptions:**

None

**Programming Notes:**

None

31	26 25	21 20	16 15	11 10	0
POOL32A 000000	rt	rs	rd	0	SLT 1101010000

6                    5                    5                    5                    1                    10

**Format:** SLT rd, rs, rt**microMIPS****Purpose:** Set on Less Than

To record the result of a less-than comparison

**Description:**  $GPR[rd] \leftarrow (GPR[rs] < GPR[rt])$ Compare the contents of GPR *rs* and GPR *rt* as 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, it is 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

**Restrictions:**

None

**Operation:**

```

if GPR[rs] < GPR[rt] then
    GPR[rd] ← 0GPRLEN-1 || 1
else
    GPR[rd] ← 0GPRLEN
endif

```

**Exceptions:**

None

31	26 25	21 20	16 15	0
SLTI32 100100	rt	rs	immediate	

6                    5                    5                    16

**Format:** SLTI rt, rs, immediate**microMIPS****Purpose:** Set on Less Than Immediate

To record the result of a less-than comparison with a constant

**Description:**  $GPR[rt] \leftarrow (GPR[rs] < \text{immediate})$ Compare the contents of 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, it is 0 (false).

The arithmetic comparison does not cause an Integer Overflow exception.

**Restrictions:**

None

**Operation:**

```

if GPR[rs] < sign_extend(immediate) then
    GPR[rt] ← 0GPRLEN-1 || 1
else
    GPR[rt] ← 0GPRLEN
endif

```

**Exceptions:**

None

31	26 25	21 20	16 15	0
SLTIU32 101100	rt	rs	immediate	

6                    5                    5                    16

**Format:** SLTIU rt, rs, immediate

microMIPS

**Purpose:** Set on Less Than Immediate Unsigned

To record the result of an unsigned less-than comparison with a constant

**Description:**  $GPR[rt] \leftarrow (GPR[rs] < \text{immediate})$ 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, it is 0 (false).Because the 16-bit *immediate* is sign-extended before comparison, the instruction can 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[rt] ← 0GPRLEN-1 || 1
else
    GPR[rt] ← 0GPRLEN
endif

```

**Exceptions:**

None

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	SLTU 1110010000

**Format:** SLTU rd, rs, rt**microMIPS****Purpose:** Set on Less Than Unsigned

To record the result of an unsigned less-than comparison

**Description:**  $GPR[rd] \leftarrow (GPR[rs] < GPR[rt])$ 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, it is 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] ← 0GPRLEN-1 || 1
else
    GPR[rd] ← 0GPRLEN
endif

```

**Exceptions:**

None

31	26 25	21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	SQRT(fmt 00101000)	POOL32FXf 111011

**Format:** SQRT(fmt  
SQRT.S ft, fs  
SQRT.D ft, fs)

**Purpose:** Floating Point Square Root

To compute the square root of an FP value

**Description:** FPR[ft]  $\leftarrow$  SQRT(FPR[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 *ft*. The operand and result are values in format *fmt*.

If the value in FPR *fs* corresponds to –0, the result is –0.

#### Restrictions:

If the value in FPR *fs* is less than 0, an Invalid Operation condition is raised.

The fields *fs* and *ft* must specify FPRs valid for operands of type *fmt*; if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

#### Operation:

```
StoreFPR(ft, fmt, SquareRoot(ValueFPR(fs, fmt)))
```

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Invalid Operation, Inexact, Unimplemented Operation



31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	sa	0	SRA 0010000000

6                    5                    5                    5                    1                    10

**Format:** SRA rt, rs, sa

microMIPS

**Purpose:** Shift Word Right Arithmetic

To execute an arithmetic right-shift of a word by a fixed number of bits

**Description:**  $\text{GPR}[rt] \leftarrow \text{GPR}[rs] \gg sa$  (arithmetic)The contents of the low-order 32-bit word of GPR *rs* are shifted right, duplicating the sign-bit (bit 31) in the emptied bits; the word result is placed in GPR *rt*. The bit-shift amount is specified by *sa*.**Restrictions:****None****Operation:**

```

s ← sa
temp ← (GPR[rs]31)s || GPR[rs]31..s
GPR[rt] ← temp

```

**Exceptions:**

None

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	SRAV 0010010000

**Format:** SRAV rd, rt, rs**microMIPS****Purpose:** Shift Word Right Arithmetic Variable

To execute an arithmetic right-shift of a word by a variable number of bits

**Description:**  $GPR[rd] \leftarrow GPR[rt] \gg rs$  (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 amount is specified by the low-order 5 bits of GPR *rs*.**Restrictions:****None****Operation:**

$$\begin{aligned}
 s &\leftarrow GPR[rs]_{4..0} \\
 \text{temp} &\leftarrow (GPR[rt]_{31})^s \mid\mid GPR[rt]_{31..s} \\
 GPR[rd] &\leftarrow \text{temp}
 \end{aligned}$$
**Exceptions:**

None

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	sa	0	SRL32 0001000000

6                    5                    5                    5                    1                    10

**Format:** SRL rt, rs, sa**microMIPS****Purpose:** Shift Word Right Logical

To execute a logical right-shift of a word by a fixed number of bits

**Description:** GPR[rt]  $\leftarrow$  GPR[rs]  $\gg$  sa (logical)

The contents of the low-order 32-bit word of GPR rs are shifted right, inserting zeros into the emptied bits; the word result is placed in GPR rt. The bit-shift amount is specified by sa.

**Restrictions:****None****Operation:**

```

s  $\leftarrow$  sa
temp  $\leftarrow$  0s || GPR[rs]31..s
GPR[rt]  $\leftarrow$  temp

```

**Exceptions:**

None

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	SRLV 00010010000

**Format:** SRLV rd, rt, rs**microMIPS****Purpose:** Shift Word Right Logical Variable

To execute a logical right-shift of a word by a variable number of bits

**Description:**  $GPR[rd] \leftarrow GPR[rt] \gg GPR[rs]$  (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 amount is specified by the low-order 5 bits of GPR *rs*.**Restrictions:****None****Operation:**

```

s ← GPR[rs]4..0
temp ← 0s || GPR[rt]31..s
GPR[rd] ← temp

```

**Exceptions:**

None

31	26 25			11 10	6 5	0
POOL32A 000000	0 00000	0 00000	1 00001	0 0000	SLL32 000000	6

6                    5                    5                    5                    5                    6

**Format:** SSNOP**microMIPS****Purpose:** Superscalar No Operation

Break superscalar issue on a superscalar processor.

**Description:**

SSNOP is the assembly idiom used to denote superscalar no operation. The actual instruction is interpreted by the hardware as SLL r0, r0, 1.

This instruction alters the instruction issue behavior on a superscalar processor by forcing the SSNOP instruction to single-issue. The processor must then end the current instruction issue between the instruction previous to the SSNOP and the SSNOP. The SSNOP then issues alone in the next issue slot.

On a single-issue processor, this instruction is a NOP that takes an issue slot.

**Restrictions:**

None

**Operation:****None****Exceptions:**

None

**Programming Notes:**

SSNOP is intended for use primarily to allow the programmer control over CP0 hazards by converting instructions into cycles in a superscalar processor. For example, to insert at least two cycles between an MTC0 and an ERET, one would use the following sequence:

```
mfc0    x,y
ssnop
ssnop
eret
```

Based on the normal issues rules of the processor, the MTC0 issues in cycle T. Because the SSNOP instructions must issue alone, they may issue no earlier than cycle T+1 and cycle T+2, respectively. Finally, the ERET issues no earlier than cycle T+3. Note that although the instruction after an SSNOP may issue no earlier than the cycle after the SSNOP is issued, that instruction may issue later. This is because other implementation-dependent issue rules may apply that prevent an issue in the next cycle. Processors should not introduce any unnecessary delay in issuing SSNOP instructions.

31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	SUB 0110010000

**Format:** SUB rd, rs, rt**microMIPS****Purpose:** Subtract Word

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

**Description:**  $GPR[rd] \leftarrow GPR[rs] - GPR[rt]$ 

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:**

None

**Operation:**

```

temp ← (GPR[rs]31 || GPR[rs]31..0) - (GPR[rt]31 || GPR[rt]31..0)
if temp32 ≠ temp31 then
    SignalException(IntegerOverflow)
else
    GPR[rd] ← temp31..0
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 9 8 7	5	0
POOL32F 010101	ft	fs	fd	0 fmt	SUB(fmt 01110000)	8

**Format:** SUB(fmt

SUB.S fd, fs, ft

microMIPS

SUB.D fd, fs, ft

microMIPS

SUB.PS fd, fs, ft

microMIPS

**Purpose:** Floating Point Subtract

To subtract FP values

**Description:**  $FPR[fd] \leftarrow FPR[fs] - FPR[ft]$ 

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*. SUB.PS subtracts the upper and lower halves of FPR *fs* and FPR *ft* independently, and ORs together any generated exceptional conditions.

**Restrictions:**

The fields *fs*, *ft*, and *fd* must specify FPRs valid for operands of type *fmt*. If they are not valid, the result is **UNPREDICTABLE**.

The operands must be values in format *fmt*; if they are not, the result is **UNPREDICTABLE** and the value of the operand FPRs becomes **UNPREDICTABLE**.

The result of SUB.PS is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```
StoreFPR (fd, fmt, ValueFPR(fs, fmt) -fmt ValueFPR(ft, fmt))
```

**CPU Exceptions:**

Coprocessor Unusable, Reserved Instruction

**FPU Exceptions:**

Inexact, Overflow, Underflow, Invalid Op, Unimplemented Op



31	26 25	21 20	16 15	11 10	6 5	0
POOL32A 000000	rt	rs	rd	0	SUBU32 0111010000	10

**Format:** SUBU rd, rs, rt

microMIPS

**Purpose:** Subtract Unsigned Word

To subtract 32-bit integers

**Description:**  $GPR[rd] \leftarrow GPR[rs] - GPR[rt]$

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:

None

#### Operation:

```
temp ← GPR[rs] - GPR[rt]
GPR[rd] ← 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 unsigned arithmetic, 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 9 8	0
POOL32F 010101	index	base	fd	00	SUXC1 110001000

6                    5                    5                    5                    2                    9

**Format:** SUXC1 fd, index(base)**microMIPS****Purpose:** Store Doubleword Indexed Unaligned from Floating Point

To store a doubleword from an FPR to memory (GPR+GPR addressing) ignoring alignment

**Description:** memory[ (GPR[base] + GPR[index])<sub>PSIZE-1..3</sub>] ← FPR[fd]

The contents of the 64-bit doubleword in FPR *fd* is stored at the memory location specified by the effective address. The contents of GPR *index* and GPR *base* are added to form the effective address. The effective address is double-word-aligned; EffectiveAddress<sub>2..0</sub> are ignored.

**Restrictions:**

The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

**Operation:**

```

vAddr ← (GPR[base]+GPR[index])63..3 || 03
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
datadoubleword ← ValueFPR(fd, UNINTERPRETED_DOUBLEWORD)
paddr ← paddr xor ((BigEndianCPU xor ReverseEndian) || 02)
StoreMemory(CCA, WORD, datadoubleword31..0, pAddr, vAddr, DATA)
paddr ← paddr xor 0b100
StoreMemory(CCA, WORD, datadoubleword63..32, pAddr, vAddr+4, DATA)

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, TLB Modified, Watch

31	26 25	21 20	16 15	0
SW32 111110	rt	base	offset	

6                    5                    5                    16

**Format:** SW rt, offset(base)

microMIPS

**Purpose:** Store Word

To store a word to memory

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

The least-significant 32-bit word of 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 either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr  $\leftarrow$  sign_extend(offset) + GPR[base]
if vAddr1..0  $\neq$  02 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation (vAddr, DATA, STORE)
dataword  $\leftarrow$  GPR[rt]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
```

#### Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

31	26 25	21 20	16 15	0
SWC132 100110	ft	base	offset	

SWC1 ft, offset(base)

microMIPS

**Purpose:** Store Word from Floating Point

To store a word from an FPR to memory

**Description:** `memory[GPR[base] + offset] ← FPR[ft]`The low 32-bit word from 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.**Restrictions:**An Address Error exception occurs if EffectiveAddress<sub>1..0</sub> ≠ 0 (not word-aligned).**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 03 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
dataword ← ValueFPR(ft, UNINTERPRETED_WORD)
StoreMemory(CCA, WORD, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch

31	26 25	21 20	16 15	0
POOL32B 001000	rt	base	SWC2 1000	offset

6                    5                    5                    16

**Format:** SWC2 rt, offset(base)**microMIPS****Purpose:** Store Word from Coprocessor 2

To store a word from a COP2 register to memory

**Description:**  $\text{memory}[\text{GPR}[\text{base}] + \text{offset}] \leftarrow \text{CPR}[2, \text{rt}, 0]$ The low 32-bit word from COP2 (Coprocessor 2) 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:**An Address Error exception occurs if EffectiveAddress<sub>1..0</sub> ≠ 0 (not word-aligned).**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
dataword ← CPR[2,rt,0]
StoreMemory(CCA, WORD, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

Coprocessor Unusable, Reserved Instruction, TLB Refill, TLB Invalid, TLB Modified, Address Error, Watch



31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	ST-EVA 1010	SWE 111	offset	

**Format:** SWE rt, offset(base)

microMIPS

#### Purpose:

To store a word to user mode virtual address space when executing in kernel mode.

#### Description:

$\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{GPR}[rt]$

The least-significant 32-bit word of GPR *rt* is stored in memory at the location specified by the aligned effective address. The 9-bit signed *offset* is added to the contents of GPR *base* to form the effective address.

The SWE instruction functions in exactly the same fashion as the SW instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $\text{Config5}_{EVA}$  field being set to one.

#### Restrictions:

Only usable in kernel mode when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

#### Operation:

```
vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[rt]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)
```

#### Exceptions:

TLB Refill

TLB Invalid

Bus Error

Address Error

Watch

Reserved Instruction

Coprocessor Unusable

31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	SWL 1000	offset	

6                    5                    5                    5                    12

**Format:** SWL rt, offset(base)

microMIPS

**Purpose:** Store Word Left

To store the most-significant part of a word to an unaligned memory address

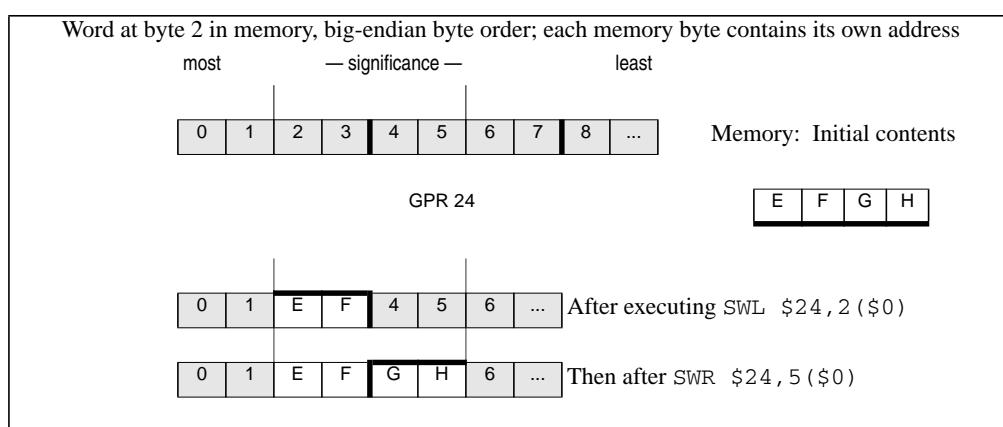
**Description:**  $\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{GPR}[rt]$

The 12-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

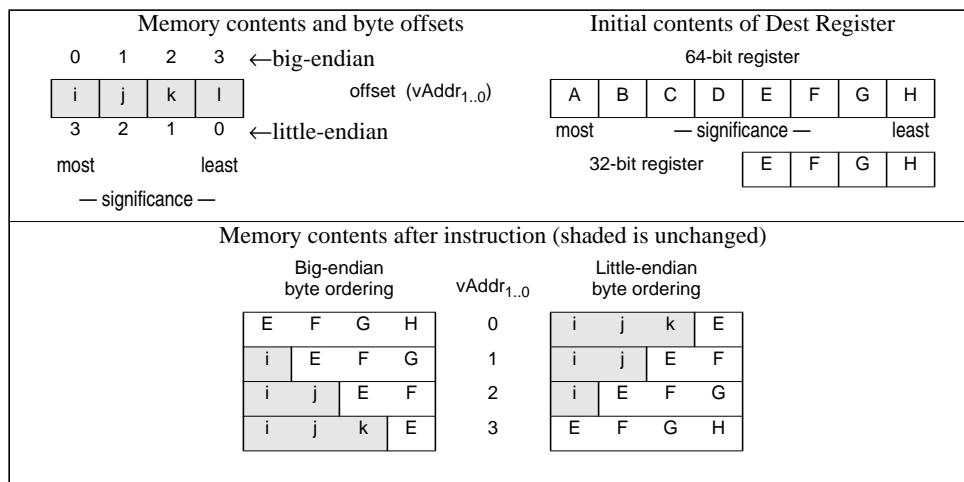
A part of *W*, the most-significant 1 to 4 bytes, is in the aligned word containing *EffAddr*. The same number of the most-significant (left) bytes from the word in GPR *rt* are stored into these bytes of *W*.

The following figure illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is located in the aligned word containing the most-significant byte at 2. First, SWL stores the most-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWR stores the remainder of the unaligned word.

**Figure 5.14 Unaligned Word Store Using SWL and SWR**



The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address ( $vAddr_{1..0}$ )—and the current byte-ordering mode of the processor (big- or little-endian). The following figure shows the bytes stored for every combination of offset and byte ordering.

**Figure 5.15 Bytes Stored by an SWL Instruction****Restrictions:**

None

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
If BigEndianMem = 0 then
    pAddr ← pAddrPSIZE-1..2 || 02
endif
byte ← vAddr1..0 xor BigEndianCPU2
dataword ← 024-8*byte || GPR[rt]31..24-8*byte
StoreMemory(CCA, byte, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error , Watch

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	ST-EVA 1010	SWLE 000	offset	

6                    5                    5                    4                    3                    9

**Format:** SWLE rt, offset(base)

microMIPS

**Purpose:** Store Word Left EVA

To store the most-significant part of a word to an unaligned user mode virtual address while operating in kernel mode.

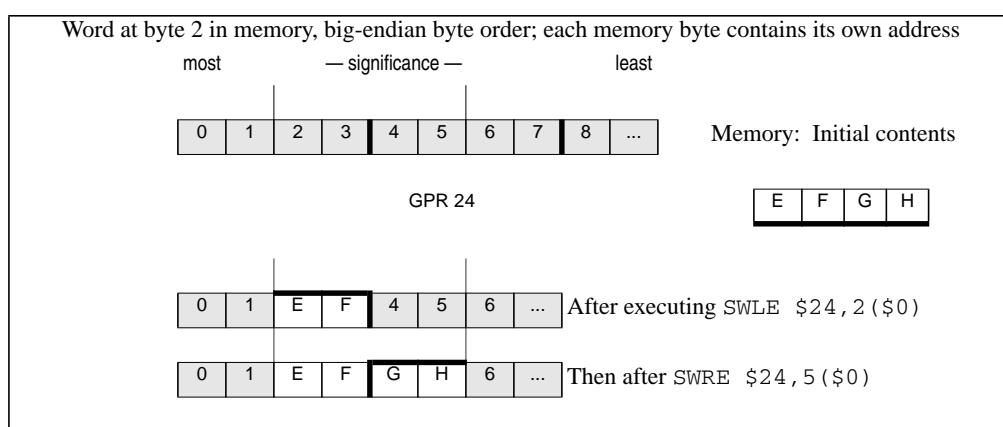
**Description:** memory[GPR[base] + offset]  $\leftarrow$  GPR[rt]

The 9-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

A part of *W*, the most-significant 1 to 4 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*.

The following figure illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is located in the aligned word containing the most-significant byte at 2. First, SWLE stores the most-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWRE stores the remainder of the unaligned word.

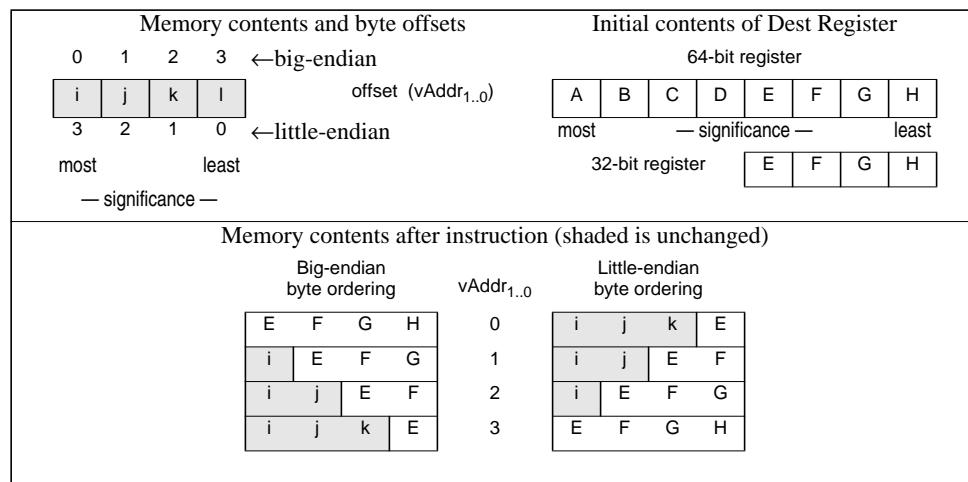
**Figure 5.16 Unaligned Word Store Using SWLE and SWRE**



The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address ( $vAddr_{1..0}$ )—and the current byte-ordering mode of the processor (big- or little-endian). The following figure shows the bytes stored for every combination of offset and byte ordering.

The SWLE instruction functions in exactly the same fashion as the SWL instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $Config5_{EVA}$  field being set to one.

**Figure 5.17 Bytes Stored by an SWLE Instruction****Restrictions:**

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

```

 $vAddr \leftarrow sign\_extend(offset) + GPR[base]$ 
 $(pAddr, CCA) \leftarrow AddressTranslation(vAddr, DATA, STORE)$ 
 $pAddr \leftarrow pAddr_{PSIZE-1..2} || (pAddr_{1..0} \oplus ReverseEndian^2)$ 
If BigEndianMem = 0 then
     $pAddr \leftarrow pAddr_{PSIZE-1..2} || 0^2$ 
endif
byte  $\leftarrow vAddr_{1..0} \oplus BigEndianCPU^2$ 
dataword  $\leftarrow 0^{24-8*byte} || GPR[rt]_{31..24-8*byte}$ 
StoreMemory(CCA, byte, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

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

31	26 25	21 20	16 15	12 11	0
POOL32C 011000	rt	base	SWR 1001	offset	

6                    5                    5                    5                    12

**Format:** SWR rt, offset(base)

microMIPS

**Purpose:** Store Word Right

To store the least-significant part of a word to an unaligned memory address

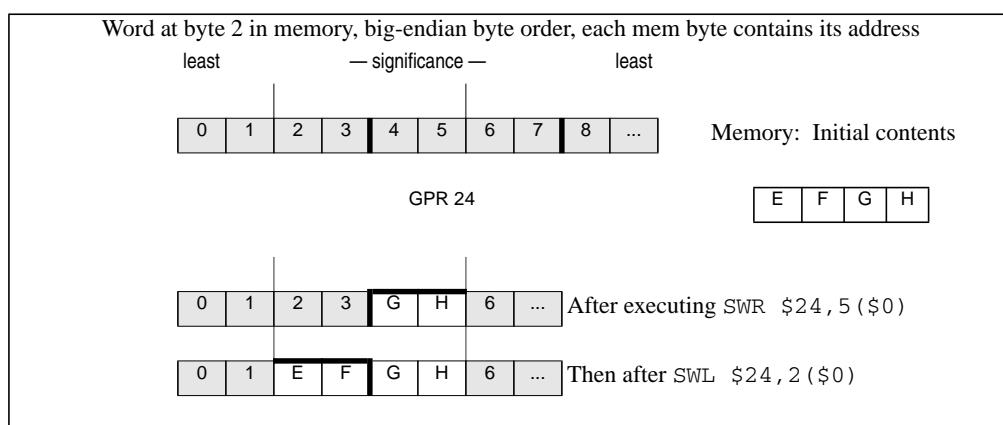
**Description:**  $\text{memory}[\text{GPR}[base] + \text{offset}] \leftarrow \text{GPR}[rt]$

The 12-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

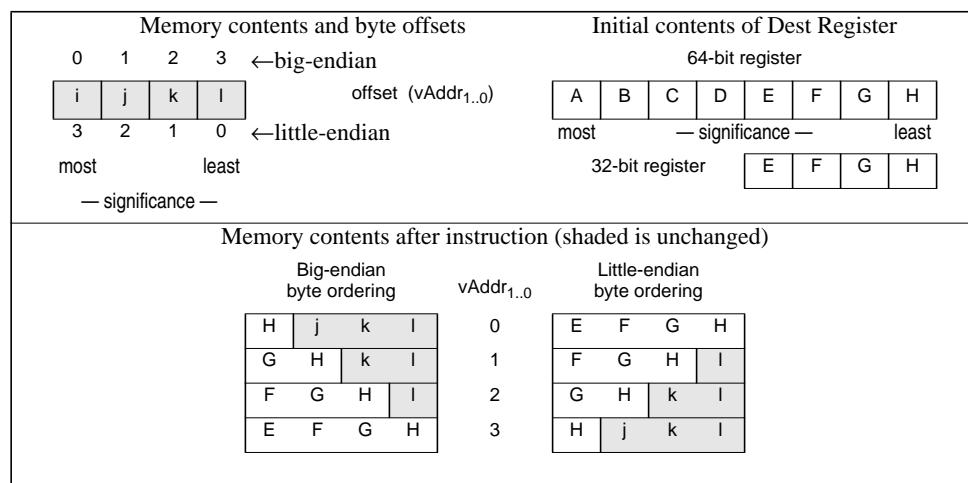
A part of *W*, the least-significant 1 to 4 bytes, is in the aligned word containing *EffAddr*. The same number of the least-significant (right) bytes from the word in GPR *rt* are stored into these bytes of *W*.

The following figure illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is contained in the aligned word containing the least-significant byte at 5. First, SWR stores the least-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWL stores the remainder of the unaligned word.

**Figure 5.18 Unaligned Word Store Using SWR and SWL**



The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address ( $vAddr_{1..0}$ )—and the current byte-ordering mode of the processor (big- or little-endian). The following figure shows the bytes stored for every combination of offset and byte-ordering.

**Figure 5.19 Bytes Stored by SWR Instruction****Restrictions:**

None

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
If BigEndianMem = 0 then
    pAddr ← pAddrPSIZE-1..2 || 02
endif
byte ← vAddr1..0 xor BigEndianCPU2
dataword ← GPR[rt]31-8*byte || 08*byte
StoreMemory(CCA, WORD-byte, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error, Watch

31	26 25	21 20	16 15	12 11	9 8	0
POOL32C 011000	rt	base	ST-EVA 1010	SWRE 001	offset	

6                    5                    5                    4                    3                    9

**Format:** SWRE rt, offset(base)

microMIPS

**Purpose:** Store Word Right EVA

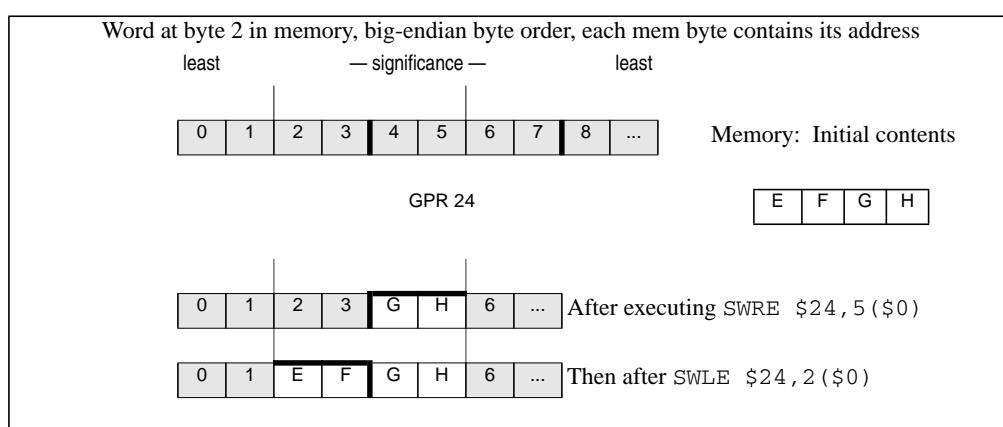
To store the least-significant part of a word to an unaligned user mode virtual address while operating in kernel mode.

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

The 9-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 4 consecutive bytes forming a word (*W*) in memory starting at an arbitrary byte boundary.

A part of *W*, the least-significant 1 to 4 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*.

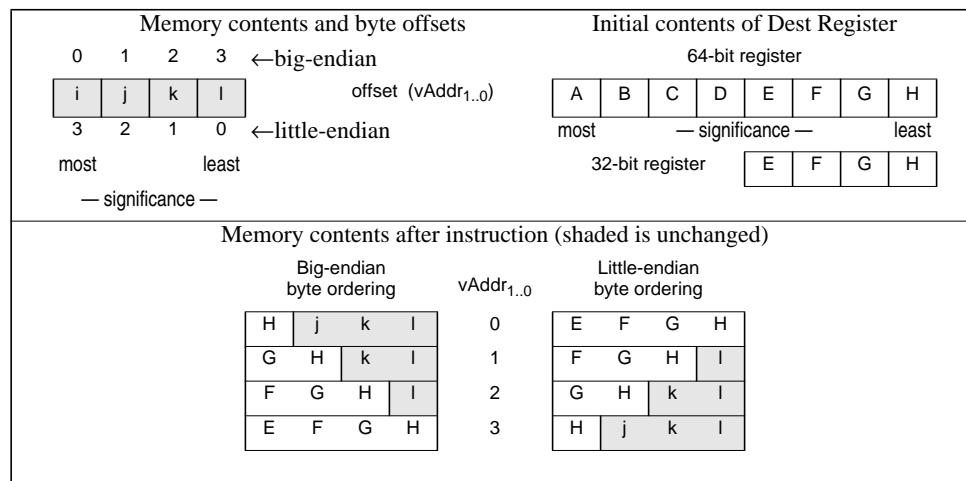
The following figure illustrates this operation using big-endian byte ordering for 32-bit and 64-bit registers. The 4 consecutive bytes in 2..5 form an unaligned word starting at location 2. A part of *W*, 2 bytes, is contained in the aligned word containing the least-significant byte at 5. First, SWRE stores the least-significant 2 bytes of the low word from the source register into these 2 bytes in memory. Next, the complementary SWLE stores the remainder of the unaligned word.

**Figure 5.20 Unaligned Word Store Using SWRE and SWLE**

The bytes stored from the source register to memory depend on both the offset of the effective address within an aligned word—that is, the low 2 bits of the address ( $vAddr_{1..0}$ )—and the current byte-ordering mode of the processor (big- or little-endian). The following figure shows the bytes stored for every combination of offset and byte-ordering.

The LWE instruction functions in exactly the same fashion as the LW instruction, except that address translation is performed using the user mode virtual address space mapping in the TLB when accessing an address within a memory segment configured to use the MUSUK access mode. Memory segments using UUSK or MUSK access modes are also accessible. Refer to Volume III, Enhanced Virtual Addressing section for additional information.

Implementation of this instruction is specified by the  $Config5_{EVA}$  field being set to one.

**Figure 5.21 Bytes Stored by SWRE Instruction****Restrictions:**

Only usable when access to Coprocessor0 is enabled and when accessing an address within a segment configured using UUSK, MUSK or MUSUK access mode.

**Operation:**

```

vAddr ← sign_extend(offset) + GPR[base]
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
pAddr ← pAddrPSIZE-1..2 || (pAddr1..0 xor ReverseEndian2)
If BigEndianMem = 0 then
    pAddr ← pAddrPSIZE-1..2 || 02
endif
byte ← vAddr1..0 xor BigEndianCPU2
dataword ← GPR[rt]31-8*byte || 08*byte
StoreMemory(CCA, WORD-byte, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Bus Error, Address Error, Watch, Coprocessor Unusable

31	26 25	21 20	16 15	11 10 9 8	0
POOL32F 010101	index	base	fd	00	SWXC1 010001000

6                    5                    5                    5                    2                    9

**Format:** SWXC1 fd, index(base)microMIPS  
microMIPS**Purpose:** Store Word Indexed from Floating Point

To store a word from an FPR to memory (GPR+GPR addressing)

**Description:** memory[GPR[base] + GPR[index]]  $\leftarrow$  FPR[fd]The low 32-bit word from FPR *fd* 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:**An Address Error exception occurs if EffectiveAddress<sub>1..0</sub>  $\neq$  0 (not word-aligned).**Operation:**

```

vAddr  $\leftarrow$  GPR[base] + GPR[index]
if vAddr1..0  $\neq$  03 then
    SignalException(AddressError)
endif
(pAddr, CCA)  $\leftarrow$  AddressTranslation(vAddr, DATA, STORE)
dataword  $\leftarrow$  ValueFPR(fd, UNINTERPRETED_WORD)
StoreMemory(CCA, WORD, dataword, pAddr, vAddr, DATA)

```

**Exceptions:**

TLB Refill, TLB Invalid, TLB Modified, Address Error, Reserved Instruction, Coprocessor Unusable, Watch

31	26 25		16 15		6 5	0
POOL32A 000000	0 0000000000	stype	SYNC 0110101101		POOL32AXf 111100	6

**Format:** SYNC (stype = 0 implied)  
SYNC stype

microMIPS  
microMIPS

**Purpose:** To order loads and stores for shared memory.

#### Description:

These types of ordering guarantees are available through the SYNC instruction:

- Completion Barriers
- Ordering Barriers

#### Simple Description for Completion Barrier:

- The barrier affects only *uncached* and *cached coherent* loads and stores.
- The specified memory instructions (loads or stores or both) that occur before the SYNC instruction must be completed before the specified memory instructions 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.

#### Detailed Description for Completion Barrier:

- Every synchronizable specified memory instruction (loads or stores or both) that occurs in the instruction stream before the SYNC instruction must be already globally performed before any synchronizable specified memory instructions that occur after the SYNC are allowed to be performed, with respect to any other processor or coherent I/O module.
- The barrier does not guarantee the order in which instruction fetches are performed.
- A stype value of zero will always be defined such that it performs the most complete set of synchronization operations that are defined. This means stype zero always does a completion barrier that affects both loads and stores preceding the SYNC instruction and both loads and stores that are subsequent to the SYNC instruction. Non-zero values of stype may be defined by the architecture or specific implementations to perform synchronization behaviors that are less complete than that of stype zero. If an implementation does not use one of these non-zero values to define a different synchronization behavior, then that non-zero value of stype must act the same as stype zero completion barrier. This allows software written for an implementation with a lighter-weight barrier to work on another implementation which only implements the stype zero completion barrier.
- A completion barrier is required, potentially in conjunction with SSNOP (in Release 1 of the Architecture) or EHB (in Release 2 of the Architecture), to guarantee that memory reference results are visible across operating mode changes. For example, a completion barrier is required on some implementations on entry to and exit from Debug Mode to guarantee that memory effects are handled correctly.

*SYNC behavior when the stype field is zero:*

- A completion barrier that affects preceding loads and stores and subsequent loads and stores.

*Simple Description for Ordering Barrier:*

- The barrier affects only *uncached* and *cached coherent* loads and stores.
- The specified memory instructions (loads or stores or both) that occur before the SYNC instruction must always be ordered before the specified memory instructions after the SYNC.
- Memory instructions which are ordered before other memory instructions are processed by the load/store datapath first before the other memory instructions.

*Detailed Description for Ordering Barrier:*

- Every synchronizable specified memory instruction (loads or stores or both) that occurs in the instruction stream before the SYNC instruction must reach a stage in the load/store datapath after which no instruction re-ordering is possible before any synchronizable specified memory instruction which occurs after the SYNC instruction in the instruction stream reaches the same stage in the load/store datapath.
- If any memory instruction before the SYNC instruction in program order, generates a memory request to the external memory and any memory instruction after the SYNC instruction in program order also generates a memory request to external memory, the memory request belonging to the older instruction must be globally performed before the time the memory request belonging to the younger instruction is globally performed.
- The barrier does not guarantee the order in which instruction fetches are performed.

As compared to the completion barrier, the ordering barrier is a lighter-weight operation as it does not require the specified instructions before the SYNC to be already completed. Instead it only requires that those specified instructions which are subsequent to the SYNC in the instruction stream are never re-ordered for processing ahead of the specified instructions which are before the SYNC in the instruction stream. This potentially reduces how many cycles the barrier instruction must stall before it completes.

The Acquire and Release barrier types are used to minimize the memory orderings that must be maintained and still have software synchronization work.

Implementations that do not use any of the non-zero values of stype to define different barriers, such as ordering barriers, must make those stype values act the same as stype zero.

For the purposes of this description, the CACHE, PREF and PREFIX instructions are treated as loads and stores. That is, these instructions and the memory transactions sourced by these instructions obey the ordering and completion rules of the SYNC instruction.

Table 5.28 lists the available completion barrier and ordering barriers behaviors that can be specified using the stype field..

**Table 5.28 Encodings of the Bits[10:6] of the SYNC instruction; the SType Field**

Code	Name	Older instructions which must reach the load/store ordering point before the SYNC instruction completes.	Younger instructions which must reach the load/store ordering point only after the SYNC instruction completes.	Older instructions which must be globally performed when the SYNC instruction completes	Compliance
0x0	SYNC or SYNC 0	Loads, Stores	Loads, Stores	Loads, Stores	Required
0x4	SYNC_WMB or SYNC 4	Stores	Stores		Optional
0x10	SYNC_MB or SYNC 16	Loads, Stores	Loads, Stores		Optional
0x11	SYNC_ACQUIRE or SYNC 17	Loads	Loads, Stores		Optional
0x12	SYNC_RELEASE or SYNC 18	Loads, Stores	Stores		Optional
0x13	SYNC_RMB or SYNC 19	Loads	Loads		Optional
0x1-0x3, 0x5-0xF					Implementation-Specific and Vendor Specific Sync Types
0x14 - 0x1F	RESERVED				Reserved for MIPS Technologies for future extension of the architecture.

#### Terms:

*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 is 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*.

*Load/Store Datapath:* The portion of the processor which handles the load/store data requests coming from the processor pipeline and processes those requests within the cache and memory system hierarchy.

### Restrictions:

The effect of SYNC on the global order of loads and stores for memory access types other than *uncached* and *cached coherent* is **UNPREDICTABLE**.

### Operation:

```
SyncOperation(stype)
```

### Exceptions:

None

### Programming Notes:

A processor executing load and store instructions observes the order in which loads and stores using the same memory access type occur in the instruction stream; this is known as *program order*.

A *parallel program* has multiple instruction streams that can execute simultaneously 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 store—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 neither is it 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 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 effect of all loads and stores in one group is seen by all processors before the effect of any load or store in the subsequent 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 implementation of 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 generally does not operate on a system that is not strongly ordered. However, a program that does use SYNC works on both types of systems. (System-specific documentation describes the actions needed to reliably

share data in parallel programs for that system.)

The behavior of a load or store using one memory access type is **UNPREDICTABLE** 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 appear to all processors; it does 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.

```
# Processor A (writer)
# Conditions at entry:
# The value 0 has been stored in FLAG and that value is observable by B
SW      R1, DATA          # change shared DATA value
LI      R2, 1
SYNC
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 read
LW      R1, DATA    # Read (valid) shared DATA value
```

The code fragments above shows 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.

Software written to use a SYNC instruction with a non-zero stype value, expecting one type of barrier behavior, should only be run on hardware that actually implements the expected barrier behavior for that non-zero stype value or on hardware which implements a superset of the behavior expected by the software for that stype value. If the hardware does not perform the barrier behavior expected by the software, the system may fail.



31	26 25	21 20	16 15	0
POOL32I 010000	SYNCI 10000	base	offset	

6                    5                    5                    16

**Format:** SYNCI offset (base)**microMIPS****Purpose:** Synchronize Caches to Make Instruction Writes Effective

To synchronize all caches to make instruction writes effective.

**Description:**

This instruction is used after a new instruction stream is written to make the new instructions effective relative to an instruction fetch, when used in conjunction with the SYNC and JALR.HB, JR.HB, or ERET instructions, as described below. Unlike the CACHE instruction, the SYNCI instruction is available in all operating modes in an implementation of Release 2 of the architecture.

The 16-bit offset is sign-extended and added to the contents of the base register to form an effective address. The effective address is used to address the cache line in all caches which may need to be synchronized with the write of the new instructions. The operation occurs only on the cache line which may contain the effective address. One SYNCI instruction is required for every cache line that was written. See the Programming Notes below.

A TLB Refill and TLB Invalid (both with cause code equal TLBL) exception can occur as a byproduct of this instruction. This instruction never causes TLB Modified exceptions nor TLB Refill exceptions with a cause code of TLBS. This instruction never causes Execute-Inhibit nor Read-Inhibit exceptions.

A Cache Error exception may occur as a byproduct of this instruction. For example, if a writeback operation detects a cache or bus error during the processing of the operation, that error is reported via a Cache Error exception. Similarly, a Bus Error Exception may occur if a bus operation invoked by this instruction is terminated in an error.

An Address Error Exception (with cause code equal AdEL) may occur if the effective address references a portion of the kernel address space which would normally result in such an exception. It is implementation dependent whether such an exception does occur.

It is implementation dependent whether a data watch is triggered by a SYNCI instruction whose address matches the Watch register address match conditions. In multiprocessor implementations where instruction caches are not coherently maintained by hardware, the SYNCI instruction may optionally affect all coherent icaches within the system. If the effective address uses a coherent Cacheability and Coherency Attribute (CCA), then the operation may be *globalized*, meaning it is broadcast to all of the coherent instruction caches within the system. If the effective address does not use one of the coherent CCAs, there is no broadcast of the SYNCI operation. If multiple levels of caches are to be affected by one SYNCI instruction, all of the affected cache levels must be processed in the same manner - either all affected cache levels use the globalized behavior or all affected cache levels use the non-globalized behavior.

In multiprocessor implementations where instruction caches are coherently maintained by hardware, the SYNCI instruction should behave as a NOP instruction.

**Restrictions:**

The operation of the processor is **UNPREDICTABLE** if the effective address references any instruction cache line that contains instructions to be executed between the SYNCI and the subsequent JALR.HB, JR.HB, or ERET instruction required to clear the instruction hazard.

The SYNCI instruction has no effect on cache lines that were previously locked with the CACHE instruction. If correct software operation depends on the state of a locked line, the CACHE instruction must be used to synchronize the caches.

The SYNCI instruction acts on the current processor at a minimum. It is implementation specific whether it affects

the caches on other processors in a multi-processor system, except as required to perform the operation on the current processor (as might be the case if multiple processors share an L2 or L3 cache).

Full visibility of the new instruction stream requires execution of a subsequent SYNC instruction, followed by a JALR.HB, JR.HB, DERET, or ERET instruction. The operation of the processor is **UNPREDICTABLE** if this sequence is not followed.

#### Operation:

```
vaddr ← GPR[base] + sign_extend(offset)
SynchronizeCacheLines(vaddr)      /* Operate on all caches */
```

#### Exceptions:

Reserved Instruction Exception (Release 1 implementations only)

TLB Refill Exception

TLB Invalid Exception

Address Error Exception

Cache Error Exception

Bus Error Exception

#### Programming Notes:

When the instruction stream is written, the SYNCI instruction should be used in conjunction with other instructions to make the newly-written instructions effective. The following example shows a routine which can be called after the new instruction stream is written to make those changes effective. Note that the SYNCI instruction could be replaced with the corresponding sequence of CACHE instructions (when access to Coprocessor 0 is available), and that the JR.HB instruction could be replaced with JALR.HB, ERET, or DERET instructions, as appropriate. A SYNC instruction is required between the final SYNCI instruction in the loop and the instruction that clears instruction hazards.

```
/*
 * This routine makes changes to the instruction stream effective to the
 * hardware. It should be called after the instruction stream is written.
 * On return, the new instructions are effective.
 *
 * Inputs:
 *      a0 = Start address of new instruction stream
 *      a1 = Size, in bytes, of new instruction stream
 */

    beq    a1, zero, 20f      /* If size==0, */
    nop                /* branch around */
    addu   a1, a0, a1      /* Calculate end address + 1 */
    rdhwr  v0, HW_SYNCI_Step /* Get step size for SYNCI from new */
                           /* Release 2 instruction */
    beq    v0, zero, 20f      /* If no caches require synchronization, */
    nop                /* branch around */
10: synci  0(a0)          /* Synchronize all caches around address */
    addu   a0, a0, v0      /* Add step size in delay slot */
    sltu   v1, a0, a1      /* Compare current with end address */
    bne    v1, zero, 10b    /* Branch if more to do */
    nop                /* branch around */
    sync               /* Clear memory hazards */
20: jr.hb  ra             /* Return, clearing instruction hazards */
    nop
```



31	26 25	16 15	6 5	0
POOL32A 000000	code	SYSCALL 1000101101	POOL32AXf 111100	6

**Format:** SYSCALL

microMIPS

**Purpose:** System Call

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

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TEQ 000000	POOL32AXf 111100	6

**Format:** TEQ rs, rt

microMIPS

**Purpose:** Trap if Equal

To compare GPRs and do a conditional trap

**Description:** if GPR[rs] = GPR[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

31	26 25	21 20	16 15	0
POOL32I 010000	TEQI 01110	rs	immediate	

6                    5                    5                    16

**Format:** TEQI rs, immediate**microMIPS****Purpose:** Trap if Equal Immediate

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs] = immediate then TrapCompare 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:**

Trap

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TGE 001000	POOL32AXf 111100	6

**Format:** TGE rs, rt

microMIPS

**Purpose:** Trap if Greater or Equal

To compare GPRs and do a conditional trap

**Description:** if GPR[rs]  $\geq$  GPR[rt] then TrapCompare 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]  $\geq$  GPR[rt] then
    SignalException(Trap)
endif

```

**Exceptions:**

Trap

31	26 25	21 20	16 15	0
POOL32I 010000	TGEI 01001	rs	immediate	

6                    5                    5                    16

**Format:** TGEI rs, immediate**microMIPS****Purpose:** Trap if Greater or Equal Immediate

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs]  $\geq$  immediate then TrapCompare the contents of GPR *rs* and the 16-bit signed *immediate* as signed integers; if GPR *rs* is greater than or equal to *immediate*, then take a Trap exception.**Restrictions:**

None

**Operation:**

```

if GPR[rs]  $\geq$  sign_extend(immediate) then
    SignalException(Trap)
endif

```

**Exceptions:**

Trap

31	26 25	21 20	16 15	0
POOL32I 010000	TGEIU 01011	rs	immediate	

6                    5                    5                    16

**Format:** TGEIU rs, immediate**microMIPS****Purpose:** Trap if Greater or Equal Immediate Unsigned

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs]  $\geq$  immediate then TrapCompare 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 can 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:**

Trap

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TGEU 010000	POOL32AXf 111100	6

**Format:** TGEU rs, rt

microMIPS

**Purpose:** Trap if Greater or Equal Unsigned

To compare GPRs and do a conditional trap

**Description:** if GPR[rs]  $\geq$  GPR[rt] then TrapCompare 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])  $\geq$  (0 || GPR[rt]) then
    SignalException(Trap)
endif

```

**Exceptions:**

Trap

31	26 25	16 15	6 5	0
POOL32A 000000	0 0000000000	TLBP 0000001101	POOL32AXf 111100	6

**Format:** TLBP**microMIPS****Purpose:** Probe TLB for Matching Entry

To find a matching entry in the TLB.

**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. In Release 1 of the Architecture, it is implementation dependent whether multiple TLB matches are detected on a TLBP. However, implementations are strongly encouraged to report multiple TLB matches only on a TLB write. In Release 2 of the Architecture, multiple TLB matches may only be reported on a TLB write. In Release 3 of the Architecture, multiple TLB matches may be reported on either TLB write or TLB probe.

**Restrictions:**

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

**Operation:**

```

Index ← 1 || UNPREDICTABLE31
for i in 0...TLBEntries-1
    if ((TLB[i]VPN2 and not (TLB[i]Mask) =
        (EntryHiVPN2 and not (TLB[i]Mask))) and
        ((TLB[i]G = 1) or (TLB[i]ASID = EntryHiASID)) then
            Index ← i
    endif
endfor

```

**Exceptions:**

Coprocessor Unusable

Machine Check

31	26 25	16 15	6 5	0
POOL32A 000000	0 0000000000	TLBR 0001001101	POOL32AXf 111100	6

**Format:** TLBR

microMIPS

**Purpose:** Read Indexed TLB Entry

To read an entry from the TLB.

**Description:**

The *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers are loaded with the contents of the TLB entry pointed to by the *Index* register. In Release 1 of the Architecture, it is implementation dependent whether multiple TLB matches are detected on a TLBR. However, implementations are strongly encouraged to report multiple TLB matches only on a TLB write. In Release 2 of the Architecture, multiple TLB matches may only be reported on a TLB write. In Release 3 of the Architecture, multiple TLB matches may be detected on a TLBR.

In an implementation supporting TLB entry invalidation ( $\text{Config4}_{\text{IE}} = 2$  or  $\text{Config4}_{\text{IE}} = 3$ ), reading an invalidated TLB entry causes 0 to be written to *EntryHi*, *EntryLo0*, *EntryLo1* registers and the *PageMask<sub>MASK</sub>* register field.

Note that the value written to the *EntryHi*, *EntryLo0*, and *EntryLo1* registers may be different from that originally written to the TLB via these registers in that:

- The value returned in the VPN2 field of the *EntryHi* register may have those bits set to zero corresponding to the one bits in the Mask field of the TLB entry (the least significant bit of VPN2 corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed after a TLB entry is written and then read.
- The value returned in the PFN field of the *EntryLo0* and *EntryLo1* registers may have those bits set to zero corresponding to the one bits in the Mask field of the TLB entry (the least significant bit of PFN corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed after a TLB entry is written and then read.
- The value returned in the G bit in both the *EntryLo0* and *EntryLo1* registers comes from the single G bit in the TLB entry. Recall that this bit was set from the logical AND of the two G bits in *EntryLo0* and *EntryLo1* when the TLB was written.

**Restrictions:**

The operation is **UNDEFINED** if the contents of the Index register are greater than or equal to the number of TLB entries in the processor.

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

**Operation:**

```
i ← Index
if i > (TLBEntries - 1) then
    UNDEFINED
endif
if ( (Config4IE = 2 or Config4IE = 3) and TLB[i].VPN2_invalid = 1) then
    PagemaskMASK ← 0
    EntryHi ← 0
    EntryLo1 ← 0
    EntryLo0 ← 0
```

```
EntryHiEHINV ← 1
else
    PageMaskMask ← TLB[i]Mask
    EntryHi ←
        (TLB[i]VPN2 and not TLB[i]Mask) || # Masking implem dependent
        05 || TLB[i]ASID
    EntryLo1 ← 02 ||
        (TLB[i]PFN1 and not TLB[i]Mask) || # Masking mplem dependent
        TLB[i]C1 || TLB[i]D1 || TLB[i]V1 || TLB[i]G
    EntryLo0 ← 02 ||
        (TLB[i]PFN0 and not TLB[i]Mask) || # Masking mplem dependent
        TLB[i]C0 || TLB[i]D0 || TLB[i]V0 || TLB[i]G
endif
```

**Exceptions:**

Coprocessor Unusable

Machine Check

31	26 25	16 15	6 5	0
POOL32A 000000	0000000000	TLBWI 0010001101	POOL32Ax 111100	6

6                    10                    10                    6

**Format:** TLBWI**microMIPS****Purpose:** Write Indexed TLB EntryTo write or invalidate a TLB entry indexed by the *Index* register.**Description:**If  $Config4_{IE} < 2$  or  $EntryHi_{EHINV}=0$ :

The TLB entry pointed to by the Index register is written from the contents of the *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers. It is implementation dependent whether multiple TLB matches are detected on a TLBWI. In such an instance, a Machine Check Exception is signaled. In Release 2 of the Architecture, multiple TLB matches may only be reported on a TLB write. The information written to the TLB entry may be different from that in the *EntryHi*, *EntryLo0*, and *EntryLo1* registers, in that:

- The value written to the VPN2 field of the TLB entry may have those bits set to zero corresponding to the one bits in the Mask field of the *PageMask* register (the least significant bit of VPN2 corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed during a TLB write.
- The value written to the PFN0 and PFN1 fields of the TLB entry may have those bits set to zero corresponding to the one bits in the Mask field of *PageMask* register (the least significant bit of PFN corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed during a TLB write.
- The single G bit in the TLB entry is set from the logical AND of the G bits in the *EntryLo0* and *EntryLo1* registers.

If  $Config4_{IE} > 1$  and  $EntryHi_{EHINV}=1$ :

The TLB entry pointed to by the Index register has its VPN2 field marked as invalid. This causes the entry to be ignored on TLB matches for memory accesses. No Machine Check is generated.

**Restrictions:**

The operation is **UNDEFINED** if the contents of the Index register are greater than or equal to the number of TLB entries in the processor.

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

**Operation:**

```
i ← Index
if (Config4IE = 2 or Config4IE = 3) then
    TLB[i].VPN2_invalid ← 0
    if (EntryHiEHINV=1) then
        TLB[i].VPN2_invalid ← 1
        break
    endif
endif
```

```
TLB[i].Mask ← PageMaskMask
TLB[i].VPN2 ← EntryHiVPN2 and not PageMaskMask # Implementation dependent
TLB[i].ASID ← EntryHiASID
TLB[i].G ← EntryLo1G and EntryLo0G
TLB[i].PFN1 ← EntryLo1PFN and not PageMaskMask # Implementation dependent
TLB[i].C1 ← EntryLo1C
TLB[i].D1 ← EntryLo1D
TLB[i].V1 ← EntryLo1V
TLB[i].PFN0 ← EntryLo0PFN and not PageMaskMask # Implementation dependent
TLB[i].C0 ← EntryLo0C
TLB[i].D0 ← EntryLo0D
TLB[i].V0 ← EntryLo0V
```

**Exceptions:**

Coprocessor Unusable

Machine Check

31	26 25	16 15	6 5	0
POOL32A 000000	0000000000	TLBWR 0011001101	POOL32Ax 111100	6

**Format:** TLBWR**microMIPS****Purpose:** Write Random TLB EntryTo write a TLB entry indexed by the *Random* register.**Description:**

The TLB entry pointed to by the *Random* register is written from the contents of the *EntryHi*, *EntryLo0*, *EntryLo1*, and *PageMask* registers. It is implementation dependent whether multiple TLB matches are detected on a TLBWR. In such an instance, a Machine Check Exception is signaled. In Release 2 of the Architecture, multiple TLB matches may only be reported on a TLB write. The information written to the TLB entry may be different from that in the *EntryHi*, *EntryLo0*, and *EntryLo1* registers, in that:

- The value written to the VPN2 field of the TLB entry may have those bits set to zero corresponding to the one bits in the Mask field of the *PageMask* register (the least significant bit of VPN2 corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed during a TLB write.
- The value written to the PFN0 and PFN1 fields of the TLB entry may have those bits set to zero corresponding to the one bits in the Mask field of *PageMask* register (the least significant bit of PFN corresponds to the least significant bit of the Mask field). It is implementation dependent whether these bits are preserved or zeroed during a TLB write.
- The single G bit in the TLB entry is set from the logical AND of the G bits in the *EntryLo0* and *EntryLo1* registers.

**Restrictions:**

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

**Operation:**

```

i ← Random
if (Config4IE = 2 or Config4IE = 3) then
    TLB[i]VPN2_invalid ← 0
endif
TLB[i]Mask ← PageMaskMask
TLB[i]VPN2 ← EntryHiVPN2 and not PageMaskMask # Implementation dependent
TLB[i]ASID ← EntryHiASID
TLB[i]G ← EntryLo1G and EntryLo0G
TLB[i]PFN1 ← EntryLo1PFN and not PageMaskMask # Implementation dependent
TLB[i]C1 ← EntryLo1C
TLB[i]D1 ← EntryLo1D
TLB[i]V1 ← EntryLo1V
TLB[i]PFN0 ← EntryLo0PFN and not PageMaskMask # Implementation dependent
TLB[i]C0 ← EntryLo0C
TLB[i]D0 ← EntryLo0D
TLB[i]V0 ← EntryLo0V

```

**Exceptions:**

Coprocessor Unusable

Machine Check

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TLT 100000	POOL32AXf 111100	6

**Format:** TLT rs, rt

microMIPS

**Purpose:** Trap if Less Than

To compare GPRs and do a conditional trap

**Description:** if GPR[rs] < GPR[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:

Trap

31	26 25	21 20	16 15	0
POOL32I 010000	TLTI 01000	rs	immediate	

6                    5                    5                    16

**Format:** TLTI rs, immediate**microMIPS****Purpose:** Trap if Less Than Immediate

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs] < immediate then TrapCompare 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

31	26 25	21 20	16 15	0
6	5	5	16	
POOL32I 010000	TLTIU 01010	rs		immediate

**Format:** TLTIU rs, immediate**microMIPS****Purpose:** Trap if Less Than Immediate Unsigned

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs] < immediate then TrapCompare 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 can 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:**

Trap

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TLTU 101000	POOL32AXf 111100	6

**Format:** TLTU rs, rt

microMIPS

**Purpose:** Trap if Less Than Unsigned

To compare GPRs and do a conditional trap

**Description:** if GPR[rs] < GPR[rt] then TrapCompare 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

31	26 25	21 20	16 15	12 11	6 5	0
POOL32A 000000	rt	rs	code	TNE 110000	POOL32AXf 111100	6

**Format:** TNE rs, rt

microMIPS

**Purpose:** Trap if Not Equal

To compare GPRs and do a conditional trap

**Description:** if GPR[rs] ≠ GPR[rt] then TrapCompare 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:**

Trap

31	26 25	21 20	16 15	0
POOL32I 010000	TNEI 01100	rs		immediate

6                    5                    5                    16

**Format:** TNEI rs, immediate**microMIPS****Purpose:** Trap if Not Equal Immediate

To compare a GPR to a constant and do a conditional trap

**Description:** if GPR[rs] ≠ immediate then TrapCompare 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:**

Trap

31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fmt	TRUNC.L 10001100	POOL32FXf 111011

6                    5                    5                    1    1                    8                    6

**Format:** TRUNC.L fmt  
 TRUNC.L S ft, fs  
 TRUNC.L D ft, fs

microMIPS  
 microMIPS

**Purpose:** Floating Point Truncate to Long Fixed Point

To convert an FP value to 64-bit fixed point, rounding toward zero

**Description:** FPR[ft]  $\leftarrow$  convert\_and\_round(FPR[fs])

The value in FPR fs, in format fmt, is converted to a value in 64-bit long fixed point format and rounded toward zero (rounding mode 1). The result is placed in FPR ft.

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. In this case 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 ft and an Invalid Operation exception is taken immediately. Otherwise, the default result,  $2^{63}-1$ , is written to ft.

#### Restrictions:

The fields fs and ft must specify valid FPRs; fs for type fmt and fd for long fixed point; if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format fmt; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

The result of this instruction is **UNPREDICTABLE** if the processor is executing in 16 FP registers mode.

#### Operation:

StoreFPR(ft, L, ConvertFmt(ValueFPR(fs, fmt), fmt, L))

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Unimplemented Operation, Invalid Operation, Inexact



31	26 25	22 21 20	16 15 14 13	6 5	0
POOL32F 010101	ft	fs	0 fm t	TRUNC.W 10101100	POOL32FXf 111011

**Format:** TRUNC.W(fmt)  
 TRUNC.W.S ft, fs  
 TRUNC.W.D ft, fs

microMIPS  
 microMIPS

**Purpose:** Floating Point Truncate to Word Fixed Point

To convert an FP value to 32-bit fixed point, rounding toward zero

**Description:** `FPR[ft] ← convert_and_round(FPR[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 *ft*.

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. In this case 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 *ft* and an Invalid Operation exception is taken immediately. Otherwise, the default result,  $2^{31}-1$ , is written to *ft*.

#### Restrictions:

The fields *fs* and *ft* must specify valid FPRs; *fs* for type *fmt* and *fd* for word fixed point; if they are not valid, the result is **UNPREDICTABLE**.

The operand must be a value in format *fmt*; if it is not, the result is **UNPREDICTABLE** and the value of the operand FPR becomes **UNPREDICTABLE**.

#### Operation:

`StoreFPR(ft, W, ConvertFmt(ValueFPR(fs, fmt), fmt, W))`

#### Exceptions:

Coprocessor Unusable, Reserved Instruction

#### Floating Point Exceptions:

Inexact, Invalid Operation, Unimplemented Operation



## Enter Standby Mode

WAIT

31	26 25	16 15	6 5	0
POOL32A 000000	Implementation-dependent code	WAIT 1001001101	POOL32AXf 111100	6

**Format:** WAIT

microMIPS

**Purpose:** Enter Standby Mode

Wait for Event

### Description:

The WAIT instruction performs an implementation-dependent operation, usually involving a lower power mode. Software may use the code bits of the instruction to communicate additional information to the processor, and the processor may use this information as control for the lower power mode. A value of zero for code bits is the default and must be valid in all implementations.

The WAIT instruction is typically implemented by stalling the pipeline at the completion of the instruction and entering a lower power mode. The pipeline is restarted when an external event, such as an interrupt or external request occurs, and execution continues with the instruction following the WAIT instruction. It is implementation-dependent whether the pipeline restarts when a non-enabled interrupt is requested. In this case, software must poll for the cause of the restart. The assertion of any reset or NMI must restart the pipeline and the corresponding exception must be taken.

If the pipeline restarts as the result of an enabled interrupt, that interrupt is taken between the WAIT instruction and the following instruction (EPC for the interrupt points at the instruction following the WAIT instruction).

### Restrictions:

The operation of the processor is **UNDEFINED** if a WAIT instruction is placed in the delay slot of a branch or a jump.

If access to Coprocessor 0 is not enabled, a Coprocessor Unusable Exception is signaled.

### Operation:

**I:** Enter implementation dependent lower power mode  
**I+1:**/\* Potential interrupt taken here \*/

### Exceptions:

Coprocessor Unusable Exception

**Enter Standby Mode**

**WAIT**

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	WRPGPR 1111000101	POOL32AXf 111100	6

**Format:** WRPGPR rt, rs**microMIPS****Purpose:** Write to GPR in Previous Shadow Set

To move the contents of a current GPR to a GPR in the previous shadow set.

**Description:** SGPR[SRSCtl<sub>PSS</sub>, rt] ← GPR[rs]The contents of the current GPR *rs* is moved to the shadow GPR register specified by SRSCtl<sub>PSS</sub> (signifying the previous shadow set number) and *rt* (specifying the register number within that set).**Restrictions:**

In implementations prior to Release 2 of the Architecture, this instruction resulted in a Reserved Instruction Exception.

**Operation:**SGPR[SRSCtl<sub>PSS</sub>, rt] ← GPR[rs]**Exceptions:**

Coprocessor Unusable

Reserved Instruction

31	26 25	21 20	16 15	6 5	0
POOL32A 000000	rt	rs	WSBH 0111101100	POOL32AXf 111100	6

**Format:** WSBH rt, rs**microMIPS****Purpose:** Word Swap Bytes Within Halfwords

To swap the bytes within each halfword of GPR rs and store the value into GPR rt.

**Description:**  $\text{GPR}[rt] \leftarrow \text{SwapBytesWithinHalfwords}(\text{GPR}[rs])$ 

Within each halfword of GPR rs the bytes are swapped, and stored in GPR rt.

**Restrictions:**

In implementations prior to Release 2 of the architecture, this instruction resulted in a Reserved Instruction Exception.

**Operation:** $\text{GPR}[rt] \leftarrow \text{GPR}[r]_{23..16} \mid\mid \text{GPR}[r]_{31..24} \mid\mid \text{GPR}[r]_{7..0} \mid\mid \text{GPR}[r]_{15..8}$ **Exceptions:**

Reserved Instruction

**Programming Notes:**

The WSBH instruction can be used to convert halfword and word data of one endianness to another endianness. The endianness of a word value can be converted using the following sequence:

```

lw      t0, 0(a1)          /* Read word value */
wsbh   t0, t0              /* Convert endianness of the halfwords */
rotr   t0, t0, 16          /* Swap the halfwords within the words */

```

Combined with SEH and SRA, two contiguous halfwords can be loaded from memory, have their endianness converted, and be sign-extended into two word values in four instructions. For example:

```

lw      t0, 0(a1)          /* Read two contiguous halfwords */
wsbh   t0, t0              /* Convert endianness of the halfwords */
seh    t1, t0              /* t1 = lower halfword sign-extended to word */
sra    t0, t0, 16          /* t0 = upper halfword sign-extended to word */

```

Zero-extended words can be created by changing the SEH and SRA instructions to ANDI and SRL instructions, respectively.



31	26 25	21 20	16 15	11 10 9	0
POOL32A 000000	rt	rs	rd	0	XOR 1100010000

**Format:** XOR rd, rs, rt

microMIPS

**Purpose:** Exclusive OR

To do a bitwise logical Exclusive OR

**Description:**  $GPR[rd] \leftarrow GPR[rs] \text{ XOR } GPR[rt]$

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

31	26 25	21 20	16 15	0
XORI32 011100	rt	rs	immediate	

6                    5                    5                    16

**Format:** XORI rt, rs, immediate**microMIPS****Purpose:** Exclusive OR Immediate

To do a bitwise logical Exclusive OR with a constant

**Description:** GPR[rt]  $\leftarrow$  GPR[rs] XOR immediateCombine 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]  $\leftarrow$  GPR[rs] xor zero\_extend(immediate)**Exceptions:**

None



## Opcode Map

This chapter defines the bit-level encoding of all microMIPS32 instructions, using a series of opcode tables. The basic format of the tables is shown in [Figure 6.1](#). The topmost row contains the high-order opcode bits (in the example table shown here, bits 31..29), and the leftmost column of the table lists the next most-significant bits of the opcode field (bits 28..26). Decimal and binary values are shown for both rows and columns.

An instruction's encoding is the value at the intersection of a row and column. For example, the opcode value for the instruction EX1 is 33 (decimal) or 011011 (binary). Similarly, the *opcode* value for EX2 is 64 (decimal), or 110100 (binary).

**Figure 6.1 Sample Bit Encoding Table**

The diagram illustrates the bit-level encoding of microMIPS32 instructions. At the top, a horizontal bar represents the 32-bit instruction word with bit ranges 31 to 0 labeled above. Below this is a detailed breakdown of the fields:

- opcode:** 6 bits (bits 31 to 26).
- rs:** 5 bits (bits 25 to 21).
- rt:** 5 bits (bits 20 to 16).
- immediate:** 16 bits (bits 15 to 0).

Below this breakdown is a table showing the mapping of opcodes to register numbers (rs, rt) and immediate values. The table has 8 rows (0 to 7) for the MSB..MSB-2 field of the opcode, and 8 columns (0 to 7) for the MSB-3..MSB-5 field. The first two columns (000 and 001) correspond to EX1, and the last two columns (110 and 111) correspond to EX2.

MSB..MSB-2		0	1	2	3	4	5	6	7
MSB-3..MSB-5		000	001	010	011	100	101	110	111
0	000								
1	001								
2	010								
3	011								EX1
4	100								
5	101								
6	110								EX2
7	111								

Annotations provide additional context:

- Binary encoding of opcode (31..29):** Points to the first two columns of the table.
- Decimal encoding of opcode (31..29):** Points to the last two columns of the table.
- Binary encoding of opcode (28..26):** Points to the first two rows of the table.
- Decimal encoding of opcode (28..26):** Points to the last two rows of the table.

### 6.1 Major Opcodes

[Table 6.2](#) defines the major opcode for each instruction. The symbols used in the table are described in [Table 6.1](#).

Every major opcode name starting with “POOL” requires a minor opcode, as defined in [Section 6.2 “Minor Opcodes”](#). All other major opcodes refer to a particular instruction.

In the opcode tables, MSB denotes either bit 15 or 31, depending on instruction size.

**Table 6.1 Symbols Used in the Instruction Encoding Tables**

Symbol	Meaning
*	Operation or field codes marked with this symbol are reserved for future use. Executing such an instruction must cause a Reserved Instruction Exception.
$\delta$	(Also <i>italic</i> field name.) Operation or field codes marked with this symbol denotes a field class. The instruction word must be further decoded by examining additional tables that show values for another instruction field.
$\beta$	Operation or field codes marked with this symbol represent a valid encoding for a higher-order MIPS ISA level or a new revision of the Architecture. Executing such an instruction must cause a Reserved Instruction Exception.
$\nabla$	Operation or field codes marked with this symbol represent instructions which were only legal if 64-bit operations were enabled on implementations of Release 1 of the Architecture. In Release 2 of the architecture, operation or field codes marked with this symbol represent instructions which are legal if 64-bit floating point operations are enabled. In other cases, executing such an instruction must cause a Reserved Instruction Exception (non-coprocessor encodings or coprocessor instruction encodings for a coprocessor to which access is allowed) or a Coprocessor Unusable Exception (coprocessor instruction encodings for a coprocessor to which access is not allowed).
$\theta$	Operation or field codes marked with this symbol are available to licensed MIPS partners. To avoid multiple conflicting instruction definitions, MIPS Technologies will assist the partner in selecting appropriate encodings if requested by the partner. The partner is not required to consult with MIPS Technologies when one of these encodings is used. If no instruction is encoded with this value, executing such an instruction must cause a Reserved Instruction Exception ( <i>SPECIAL2</i> encodings or coprocessor instruction encodings for a coprocessor to which access is allowed) or a Coprocessor Unusable Exception (coprocessor instruction encodings for a coprocessor to which access is not allowed).
$\sigma$	Field codes marked with this symbol represent an EJTAG support instruction and implementation of this encoding is optional for each implementation. If the encoding is not implemented, executing such an instruction must cause a Reserved Instruction Exception. If the encoding is implemented, it must match the instruction encoding as shown in the table.
$\epsilon$	Operation or field codes marked with this symbol are reserved for MIPS Application-Specific Extensions. If the ASE is not implemented, executing such an instruction must cause a Reserved Instruction Exception.

**Table 6.2 microMIPS32 Encoding of Major Opcode Field**

Major		MSB..MSB-2							
		0	1	2	3	4	5	6	7
MSB-3.. MSB-5		000	001	010	011	100	101	110	111
0	000	POOL32A δ	POOL32B δ	POOL32I δ	POOL32C δ	*	*	*	*
1	001	POOL16A δ	POOL16B δ	POOL16C δ	LWGP16	POOL16F	*	*	*
2	010	LBU16	LHU16	LWSP16	LW16	SB16	SH16	SWSP16	SW16
3	011	MOVE16	ANDI16	POOL16D δ	POOL16E δ	BEQZ16	BNEZ16	B16	LI16
4	100	ADDI32	ADDIU32	ORI32	XORI32	SLTI32	SLTIU32	ANDI32	JALX32
5	101	LBU32	LHU32	POOL32F δ	JALS32	BEQ32	BNE32	J32	JAL32
6	110	SB32	SH32	β	ADDIUPC	SWC132	SDC132	β	SW32
7	111	LB32	LH32	β	*	LWC132	LDC132	β	LW32

Examples:

1. The 32-bit instruction LW32 is assigned to the major opcode LW32 with the encoding “111111”.
2. The 16-bit instruction SUBU16 is assigned to the major opcode POOL16A with the encoding “000001”.

## 6.2 Minor Opcodes

While major opcodes have a fixed length of 6 bits, minor opcodes are variable in length. The minor opcodes are defined by opcode tables of one, two, or three dimensions, depending on the size of the opcode. Minor opcodes less than four bits are represented in a one-dimensional table (see [Table 6.13](#)), from four to six bits in a two-dimensional table (shown in [Figure 6.1](#) and [Table 6.9](#)), and from 7 to 10 bits in a three-dimensional table ([Table 6.4](#)). In a three-dimensional table, the two-dimensional table is expanded to include a column on the right side that encodes the extra bits. In the case of minor opcodes requiring multiple table cells, the instruction name appears in all cells, but the additional entries have a black background to indicate that this opcode is blocked (see [Table 6.4](#) and the legend shown in [Table 6.3](#)).

Example:

```
SRL r1, r1, 7      binary opcode fields: 000000 00001 00001 00111 00001 000000
                           interpretation: POOL32A   r1     r1    7       SRL
                           hex representation: 0021 3840
```

All minor opcode fields are right-aligned except those in 16-bit instructions and in 32-bit instructions with a 16-bit immediate field. These left-aligned fields are defined in a bit-reverse order, which is why, in order to accomodate the variable length of the field to the right, a given row and column in POOL32I represents bit 20..22 and 23..25 instead of bit 22..20 and 25..23.

If table entries are marked grey, then not all available bits of the instruction have been used for the encoding, leaving a field of empty bits. The empty bits are shown in the instruction tables in [Chapter 5, “microMIPS Re-encoded Instructions” on page 50](#).

**Table 6.3 Legend for Minor Opcode Tables**

Symbol	Meaning
OPCODE	Occupied by Opcode
OPCODE	Space Utilized by another Opcode

**Table 6.4 POOL32A Encoding of Minor Opcode Field**

Minor	bit 5..3								bit 9..6	
bit 2..0	0	1	2	3	4	5	6	7		
	000	001	010	011	100	101	110	111		
0 000	SLL32	*	SLLV	MOVN	*	*	*	*	0000	0
0 000	SRL32	*	SRLV	MOVZ	*	*	*	*	0001	1
0 000	SRA	*	SRAV	*	*	*	*	*	0010	2
0 000	ROTR	*	ROTRV	*	*	*	*	*	0011	3
0 000	*	*	ADD	LWXS	*	*	*	*	0100	4
0 000	*	*	ADDU32	*	*	*	*	*	0101	5
0 000	*	*	SUB	*	*	*	*	*	0110	6
0 000	*	*	SUBU32	*	*	*	*	*	0111	7
0 000	*	*	MUL	*	*	*	*	*	1000	8
0 000	*	*	AND	*	*	*	*	*	1001	9
0 000	*	*	OR32	*	*	*	*	*	1010	a
0 000	*	*	NOR	*	*	*	*	*	1011	b
0 000	*	*	XOR32	*	*	*	*	*	1100	c
0 000	*	*	SLT	*	*	*	*	*	1101	d
0 000	*	*	SLTU	*	*	*	*	*	1110	e
0 000	*	*	*	*	*	*	*	*	1111	f
1 001	SPECIAL2 0	SPECIAL2 0	*							
2 010	COP2 0	COP2 0								
3 011	UDI 0	UDI 0								
4 100	*	INS	*	*	*	EXT	*	POOL32Ax $\delta$		
5 101	$\epsilon$	$\epsilon$								
6 110	$\epsilon$	$\epsilon$								
7 111	BREAK32	*	*	*	$\epsilon$	*	*	*	*	

Not Shown

SLL r0, r0, r0 = NOP  
 SLL r0, r0, 1 = SSNOP  
 SLL r0, r0, 3 = EHB  
 SLL, r0, r0, 5 = PAUSE

## Opcode Map

**Table 6.5 POOL32Ax<sub>f</sub> Encoding of Minor Opcode Extension Field**

Extension	bit 11..9							
bit 8..6	0	1	2	3	4	5	6	7
	000	001	010	011	100	101	110	111
0	000	TEQ	TGE	TGEU	*	TLT	TLTU	TNE
1	001	ε	ε	*	ε	ε	ε	*
2	010	ε	ε	ε	ε	ε	ε	ε
3	011	MFC0	MTC0	*	*	MFC0	MTC0	
bit15..12								
4	100	ε	ε	*	*	*	*	JALR / JR
4	100	ε	ε	*	*	*	*	JALR.HB
4	100	ε	*	*	*	*	SEB	*
4	100	ε	*	*	*	*	SEH	*
4	100	ε	*	*	*	*	CLO	MFC2
4	100	ε	*	*	*	*	CLZ	MTC2
4	100	ε	*	*	*	*	RDHWR	β
4	100	ε	ε	*	*	*	WSBH	β
4	100		*	*	*	*	MULT	MFHC2
4	100	ε	ε	*	*	*	MULTU	MTHC2
4	100		*	*	*	*	DIV	*
4	100	ε	ε	*	*	*	DIVU	*
4	100	*	*	*	*	*	MADD	CFC2
4	100	ε	ε	*	*	*	MADDU	CTC2
4	100	*	*	*	*	*	MSUB	*
4	100	ε	*	*	*	*	MSUBU	*
bit15..12								
5	101	*	TLBP	ε	*	*	*	MFHI32
5	101	*	TLBR	ε	*	*	*	MFLO32
5	101	*	TLBWI	ε	*	*	*	MTHI
5	101	*	TLBWR	ε	*	*	*	MTLO
5	101	*	*	*	DI	*	*	*
5	101	*	*	*	EI	*	*	*
5	101	*	*	*	*	*	SYNC	*
5	101	*	*	*	*	*	SYSCALL	*

**Table 6.5 POOL32Ax<sub>f</sub> Encoding of Minor Opcode Extension Field (Continued)**

5	101	*	WAIT	*	*	*	*	*	*	1001	9
5	101	*	*	*	*	*	*	*	*	1010	a
5	101	*	*	*	*	*	*	*	*	1011	b
5	101	*	*	*	*	*	*	*	*	1100	c
5	101	*	ε	*	*	*	SDBBP	*	*	1101	d
5	101	RDPGPR	DERET	*	*	*	*	*	*	1110	e
5	101	WRPGPR	ERET	*	*	*	*	*	*	1111	f

6	110	ε	ε	*	*	ε	*	*	*	*
---	-----	---	---	---	---	---	---	---	---	---

7	111	ε	ε	ε	*	*	*	*	*	*
---	-----	---	---	---	---	---	---	---	---	---

Not Shown: JR = JALR r0

**Table 6.6 POOL32F Encoding of Minor Opcode Field**

Minor	bit 5..3								bit 8..6	
	0	1	2	3	4	5	6	7		
bit 2..0	000	001	010	011	100	101	110	111		
0	000	*	*	*	ε	MOVF.fmt	*	ADD.fmt	MOVN.fmt	000 0
0	000	*	LWXC1	*	ε	MOVT.fmt	*	SUB.fmt	MOVZ.fmt	001 1
0	000	PLL.PS ▽	SWXC1	*	ε	*	*	MUL.fmt	*	010 2
0	000	PLU.PS ▽	LDXC1	*	ε	*	*	DIV.fmt	*	011 3
0	000	PUL.PS ▽	SDXC1	*		*	*	ADD.fmt	MOVN.fmt	100 4
0	000	PUU.PS ▽	LUXC1	*		*	*	SUB.fmt	MOVZ.fmt	101 5
0	000	CVT.PS.S ▽	SUXC1	*	*	PREFIX	*	MUL.fmt	*	110 6
0	000	*	*	*	*	*	*	DIV.fmt	*	111 7
1	001	MADD.S	MADD.D	MADD.PS ▽	ALNV.PS ▽	MSUB.S	MSUB.D	MSUB.PS ▽	*	
2	010	NMADD.S	NMADD.D	NMADD.PS ▽	*	NMSUB.S	NMSUB.D	NMSUB.PS ▽	*	
3	011	*	*	*	*	*	*	*	*	POOL32Fx <sub>f</sub> δ
4	100	*	*	*	ε	*	*	*	*	C.cond(fmt)
5	011	*	*	*	*	*	*	*	*	
6	100	*	*	*	*	*	*	*	*	
7	100	*	*	*	*	*	*	*	*	

## Opcode Map

**Table 6.7 POOL32Fx Encoding of Minor Opcode Extension Field**

Extension	bit 10..8									
bit 7..6	0	1	2	3	4	5	6	7		
	000	001	010	011	100	101	110	111		
0 00	*	CVT.L(fmt) $\nabla$	RSQRT(fmt)	FLOOR.L(fmt) $\nabla$	*	*	*	$\varepsilon$	000	0
0 00	*	CVT.W(fmt)	SQRT(fmt)	FLOOR.W(fmt)	*	*	*	$\varepsilon$	001	1
0 00	CFC1	*	RECIP(fmt)	CEIL.L(fmt) $\nabla$	*	*	*	*	010	2
0 00	CTC1	*	*	CEIL.W(fmt)	*	*	*	*	011	3
0 00	MFC1	CVT.S.PL $\nabla$	*	TRUNC.L(fmt) $\nabla$	$\beta$	*		*	100	4
0 00	MTC1	CVT.S.PU $\nabla$	*	TRUNC.W(fmt)	$\beta$	*	*	*	101	5
0 00	MFHC1 $\nabla$	*	*	ROUND.L(fmt) $\nabla$		*	*	*	110	6
0 00	MTHC1 $\nabla$	*	*	ROUND.W(fmt)	*	*	*	*	111	7
bit 13..11										
1 01	MOV(fmt)	MOVF	*	ABS(fmt)	*	*	*	$\varepsilon$	00	0
1 01	*	MOVT	*	NEG(fmt)	*	*	*	*	01	1
1 01	*	*	*	CVT.D(fmt)	*	*	*	$\varepsilon$	10	2
1 01	*	*	*	CVT.S(fmt)	*	*	*	*	11	3
*										
2 10	*	*	*	*	*	*	*	*	*	*
3 11	*	*	*	*	*	*	*	*	*	*

**Table 6.8 POOL32B Encoding of Minor Opcode Field**

Minor	bit 15	
	0	1
bit 14..12	0	1
	0	1
0 000	LWC2	SWC2
1 001	LWP	SWP
2 010	$\beta$	$\beta$
3 011	$\varepsilon$	$\varepsilon$
4 100	$\beta$	$\beta$
5 101	LWM32	SWM32
6 110	CACHE	*
7 111	$\beta$	$\beta$

**Table 6.9 POOL32C Encoding of Minor Opcode Field**

Minor		bit 15	
		0	1
		0	1
0	000	LWL	SWL
1	001	LWR	SWR
2	010	PREF	ST-EVA $\delta$
3	011	LL	SC
4	100	$\beta$	$\beta$
5	101	$\beta$	$\beta$
6	110	LD-EVA $\delta$	$\beta$
7	111	$\beta$	$\beta$

**Table 6.10 LD-EVA Encoding of Minor Opcode Field**

Minor		
bit 11..9		
0	000	LBUE
1	001	LHUE
2	010	LWLE
3	011	LWRE
4	100	LBE
5	101	LHE
6	110	LLE
7	111	LWE

**Table 6.11 ST-EVA Encoding of Minor Opcode Field**

Minor		
bit 11..9		
0	000	SWLE
1	001	SWRE
2	010	PREFE
3	011	CACHEE
4	100	SBE
5	101	SHE
6	110	SCE
7	111	SWE

**Table 6.12 POOL32I Encoding of Minor Opcode Field**

Minor	bit 22..21			
	0	1	2	3
bit 25..23	00	01	10	11
0   000	BLTZ	BLTZAL	BGEZ	BGEZAL
1   001	BLEZ	BNEZC	BGTZ	BEQZC
2   010	TLTI	TGEI	TLTIU	TGEIU
3   011	TNEI	LUI	TEQI	*
4   100	SYNCI	BLTZALS	*	BGEZALS
5   101	BC2F	BC2T	*	*
6   110	*	*	$\epsilon$	$\epsilon$
bit 16				
7   111	BC1F	BC1T	*	*
7   111	$\epsilon$	$\epsilon$	$\epsilon$	$\epsilon$
			0	1

**Table 6.13 POOL16A Encoding of Minor Opcode Field**

Minor	
bit 0	
0 ADDU16	
1 SUBU16	

**Table 6.14 POOL16B Encoding of Minor Opcode Field**

Minor	
bit 0	
0 SLL16	
1 SRL16	

**Table 6.15 POOL16C Encoding of Minor Opcode Field**

Minor	bit 6..4							
	0	1	2	3	4	5	6	7
bit 9..7	000	001	010	011	100	101	110	111
0	000	NOT16	NOT16	NOT16	NOT16	XOR16	XOR16	XOR16
1	001	AND16	AND16	AND16	AND16	OR16	OR16	OR16
2	010	LWM16	LWM16	LWM16	LWM16	SWM16	SWM16	SWM16
3	011	JR16	JR16	JRC	JRC	JALR16	JALR16	JALRS16
4	100	MFHI16	MFHI16	*	*	MFLO16	MFLO16	*
5	101	BREAK16	*	*	*	SDBBP16 $\sigma$	*	*
6	110	JRADDIUSP	JRADDIUSP	*	*	*	*	*
7	111	*	*	*	*	*	*	*

**Table 6.16 POOL16D Encoding of Minor Opcode Field**

Minor
bit 0
0 ADDIUS5
1 ADDIUSP

**Table 6.17 POOL16E Encoding of Minor Opcode Field**

Minor
bit 0
0 ADDIUR2
1 ADDIUR1SP

**Table 6.18 POOL16F Encoding of Minor Opcode Field**

Minor	
bit 0	
0	MOVEP
1	*

## 6.3 Floating Point Unit Instruction Format Encodings

Instruction format encodings for the floating point unit are presented in this section.

If the instruction allows Single, Double and Pair-Single formats, the following encoding is used:

**Table 6.19 Floating Point Unit Format Encodings - S, D, PS**

fmt field		Mnemonic	Name	Bit Width	Data Type
Decimal	Hex				
0	0	S	Single	32	Floating Point
1	1	D	Double	64	Floating Point
2	2	PS	Paired Single	2 × 32	Floating Point
3	3	Reserved for future use by the architecture.			

If the instruction only allows Single and Double formats, the following encoding is used:

**Table 6.20 Floating Point Unit Format Encodings - S, D 1-bit**

fmt field		Mnemonic	Name	Bit Width	Data Type
Decimal	Hex				
0	0	S	Single	32	Floating Point
1	1	D	Double	64	Floating Point

**Table 6.21 Floating Point Unit Instruction Format Encodings - S, D 2-bits**

<i>fmt field</i>		<b>Mnemonic</b>	<b>Name</b>	<b>Bit Width</b>	<b>Data Type</b>
<b>Decimal</b>	<b>Hex</b>				
0	0	S	Single	32	Floating Point
1	1	D	Double	64	Floating Point
2, 3	2, 3	Reserved for future use by the architecture.			

If the instruction allows Single, Word and Long formats, the following encoding is used:

**Table 6.22 Floating Point Unit Format Encodings - S, W, L**

<i>fmt field</i>		<b>Mnemonic</b>	<b>Name</b>	<b>Bit Width</b>	<b>Data Type</b>
<b>Decimal</b>	<b>Hex</b>				
0	0	S	Single	32	Floating Point
1	1	W	Word	32	Integer
2	2	L	Long	64	Integer
3	3	Reserved for future use by the architecture.			

If the instruction allows Double, Word and Long formats, the following encoding is used:

**Table 6.23 Floating Point Unit Format Encodings - D, W, L**

<i>fmt field</i>		<b>Mnemonic</b>	<b>Name</b>	<b>Bit Width</b>	<b>Data Type</b>
<b>Decimal</b>	<b>Hex</b>				
0	0	D	Double	64	Floating Point
1	1	W	Word	32	Integer
2	2	L	Long	64	Integer
3	3	Reserved for future use by the architecture.			

# Compatibility

This chapter covers various aspects of compatibility. microMIPS32 is the preferred replacement for the existing MIPS16e ASE and uses the same mode-switch mechanism. Although microMIPS includes almost all MIPS32 instructions and therefore does not require the original MIPS32 encodings, initially it will be implemented together with MIPS32-encoded instruction execution.

## 7.1 Assembly-Level Compatibility

microMIPS32 includes a re-encoding of the MIPS32 instructions, including all ASEs and UDI space. Therefore, microMIPS provides assembly-level compatibility. Only the following cases cause some side effects:

- **Re-encoded MIPS32 instructions with reduced operand fields**

There are 3 classes of reduced fields:

1. *Reserved or unsupported bits and encodings.* This category is not a problem because utilizing a reserved or unsupported field causes an exception, no operation, or undefined behavior, and often these cannot be accessed by the compiler anyway. An example of this category is the ‘fmt’ field.
2. *Bit fields and ranges which are defined but typically never used.* This category is usually not a problem. The assembler generates an error message if a constant is outside of the re-defined range.
3. *Bit fields which are used but were reduced in order to utilize the new opcode map most efficiently.* The handling of these cases is similar to category 2 above—compilers do not generate such scenarios, and assemblers generate error messages. In the latter case, the programmer has to either fix the code or switch to the MIPS32encoding.

- **Re-encoded Branch and Jump instructions**

Branch instructions support 16-bit aligned branch target addresses, providing full flexibility for microMIPS. Because the offset field size of the 32-bit encoded branch instructions is the same as the MIPS32-encoded instructions, and because all branch target addresses of the MIPS32 encoding are 32-bit aligned, the branch range in microMIPS is smaller. This is partially compensated by the smaller code size of microMIPS.

Jump instructions also support 16-bit aligned target addresses. This reduces the addressable target region for J, JAL to 128 MB instead of 256 MB. For these instructions, the effective target address is in the ‘current’ 128 MB-aligned region. For larger ranges, the jump register instructions (JR, JRC, and JRADDIUSP) can be used.

- **MIPS32 assembly instructions manually encoded using the .WORD directive**

Manual encoding of MIPS32 assembly instructions can be used in assembly code as well as assembly macros in C functions. To differentiate between microMIPS-encoded instructions and other encoded instructions or data, the following compiler directives have been introduced:

```
.set micromips ; instruction stream is microMIPS
.set nomicromips ; instruction stream is MIPS32
.insn          ; If in microMIPS instruction stream mode, the location associated
; with the previous label is aligned to 16-bit bits instead of
; 32-bits
; If in microMIPS instruction stream mode and if the previous
; label is loaded to a register as the target of a jump or branch,
; the ISAMode bit is set within the branch/jump register value.
```

The programmer must use these directives to encode instructions in microMIPS.

For example, to manually encode a microMIPS NOP:

```
.set micromips
label1:
.insn
.word 0      ; label1 location - represents microMIPS NOP32 instruction
label2:
.insn
.half 0x0c00 ; label2 location - represents microMIPS NOP16 instruction
label3:
.half 0x0c00 ; label3 location - represents data value of 3072 (decimal)
```

To manually encode a MIPS32 NOP:

```
.set nomicromips
.word 0      ; represents MIPS32 NOP instruction
```

For MIPS32 instruction stream mode, the “.insn” directive has no effect.

- **Branch likely instructions**

microMIPS does not support branch likely instructions in hardware. Assembly-level compatibility is maintained because assemblers replace branch likely instructions either by an instruction sequence or by a regular branch instruction, and they perform some instruction reordering if reordering is possible.

## 7.2 ABI Compatibility

microMIPS is compatible with the existing ABIs o32, n32, and n64 calling conventions. However, a few new relocation types need to be added to these ABIs for microMIPS support, as some of the additional offset field sizes required for microMIPS become visible to the linker. For example, the offset fields of J and SW using GP are visible to the linker, while B and SWSP are hidden within the object files.

Functions remain 32-bit aligned as in the MIPS32 encoding as well as MIPS16e. This guarantees that static and dynamic linking processes can link microMIPS object files with MIPS32 object files.

## Compatibility

Programs can be composed of both microMIPS and MIPS32 modules, using either the JALX instructions (and/or JR instructions with setting the ISAMode bit appropriately) to switch instruction set modes when calling routines compiled in an ISA different from that of the caller routine.

microMIPS provides flexibility for potential future ABIs.

## 7.3 Branch and Jump Offsets

microMIPS branch targets are half-word (16-bit) aligned to match half-word sized instructions. Please refer to [Section 3.6, "Branch and Jump Offsets."](#)

## 7.4 Relocation Types

Compiler and linker toolchains need to be modified with new relocation types to support microMIPS. Reasons for these new relocation types include:

1. The placement of instruction halfwords is determined by memory endian-ness. MIPS32 instructions are always of word size, so there were no halfword placement issues.
2. microMIPS has 7-bit, 10-bit and 16-bit PC-relative offsets.
3. Branch and Jump offset fields are left-shifted by 1 bit (instead of 2 bits in MIPS32) to create effective target addresses.
4. Some code-size optimizations can only be done at link time instead of compile time. Some new relocation types are used solely within the linker to keep track of address and data information.

## 7.5 Boot-up Code shared between microMIPS32 and MIPS32

In some systems, it would be advantageous to place both microMIPS32 and MIPS32 executables in the same boot memory. In that way, a single system could be used for either instruction set.

To enable this, a binary code sequence is required that can be run in either instruction set and change code paths depending on the instruction set that is being used.

The following binary sequence achieves this goal:

```
0x1000wxyz // where w,x,y,z represent hexadecimal digits  
0x00000000
```

For the MIPS32 instruction set, this binary sequence is interpreted as:

```
BEQ $0, $0, wxyz // branch to location of more MIPS32instructions  
NOP
```

For the microMIPS instruction set, this binary sequence is interpreted as:

```
ADDI32 $0, $0, wxyz // do nothing  
NOP // fall through to more microMIPS instructions
```

## 7.6 Coprocessor Unusable Behavior

When a coprocessor instruction is executed when the associated coprocessor has not been implemented, it is allowed for the RI exception to be signalled instead of the Coprocessor Unsuable exception. Please refer to [Section 3.7, "Coprocessor Unusable Behavior."](#)

## 7.7 Other Issues Affecting Software and Compatibility

microMIPS instructions can cross cache lines and page boundaries. Hardware must handle these cases so that software need not avoid them. Since MIPS32 requires instructions to be 32-bit aligned, there is no forward compatibility issue when transitioning to microMIPS.

## References

This appendix lists other documents available from MIPS Technologies, Inc. that are referenced elsewhere in this document. These documents may be included in the \$MIPS\_HOME/\$MIPS\_CORE/doc area of a typical *Core-Name* soft or hard core release, or in some cases may be available on the MIPS web site, <http://www.mips.com>.

1. MIPS® Architecture For Programmers, Volume I: Introduction to the MIPS32® Architecture  
MIPS document: MD0082
2. MIPS® Architecture For Programmers, Volume II: The MIPS32® Instruction Set  
MIPS document: MD0086
3. MIPS® Architecture For Programmers, Volume III: The MIPS32® and microMIPS32™ Privileged Resource Architecture  
MIPS document: MD0090



## Appendix 9

# Revision History

Change bars (vertical lines) in the margins of this document indicate significant changes in the document since its last release. Change bars are removed for changes that are more than one revision old.

This document may refer to Architecture specifications (for example, instruction set descriptions and EJTAG register definitions), and change bars in these sections indicate changes since the previous version of the relevant Architecture document.

Revision	Date	Description
1.08	November 25, 2009	<ul style="list-style-type: none"><li>Clean-up for external release.</li></ul>
1.09	January 7, 2010	<ul style="list-style-type: none"><li>Added shared boot-up code sequence in Compatibility Chapter.</li></ul>
3.00	March 25, 2010	<ul style="list-style-type: none"><li>Changed document revision numbering to match other Release 3 documents. Hopefully this will be less confusing.</li><li>Moved MIPS32/64 version of JALX to Volume II-A.</li></ul>
3.01	October 30, 2010	<ul style="list-style-type: none"><li>User mode instructions not allowed to produce UNDEFINED results.</li><li>Updated copyright page.</li><li>Removed Margin Note - "Preliminary - Subject to Change" in some chapters.</li></ul>
3.02	December 6, 2010	<ul style="list-style-type: none"><li>POOL32Sxf binary encoding was incorrect for individual instruction description pages.</li></ul>
3.03	December 10, 2010	<ul style="list-style-type: none"><li>microMIPS AFP versions security reclassification.</li></ul>
3.04	March 21, 2011	<ul style="list-style-type: none"><li>RSQRT/RECIP does not need 64-bit FPU.</li><li>MADD.fmt/NMADD.fmt/MSUB.fmt/NMSUB.fmt psuedo-code was incorrect for PS format check.</li></ul>
3.05	April 4, 2011	<ul style="list-style-type: none"><li>The text description was incorrect for the offset sizes for these instructions - CACHE, LDC2, LL, LWC2, LWL, LWR, PREF, SDC2, SWL, SWR.</li><li>CACHE &amp; WAIT instruction descriptions were using the wrong instruction bit numbers.</li><li>LWU was incorrectly included int the microMIPS32 version.</li></ul>
3.06	October 17, 2012	<ul style="list-style-type: none"><li>CVT.D.fmt and CVT.S.fmt were in wrong positions within Table POOL32Fxf.</li></ul>
3.07	October 26, 2012	<ul style="list-style-type: none"><li>Fix Figure 6.1 - columns &amp; rows were transposed from the real tables.</li></ul>
5.00	December 14, 2012	<ul style="list-style-type: none"><li>Some of the microMIPS instructions were not listed in alphabetical order. Fixed. No content change.</li><li>R5 changes: DSP and MT ASEs -&gt; Modules</li><li>NMADD.fmt, NMSUB.fmt - for IEEE2008 negate portion is arithmetic.</li></ul>

Revision	Date	Description
5.01	December 16, 2012	<ul style="list-style-type: none"><li>• No technical context change:</li><li>• Update cover with microMIPS logo</li><li>• Update copyright text.</li><li>• Update pdf filename.</li></ul>