



MIPS32™ Architecture for Programmers
Volume IV-a: The MIPS16e™
Application-Specific Extension to the MIPS32™
Architecture

Document Number: MD00076

Revision 0.96

November 12, 2001

MIPS Technologies, Inc.
1225 Charleston Road
Mountain View, CA 94043-1353

Copyright © 2000-2001 MIPS Technologies, Inc. All rights reserved.

Unpublished rights reserved under the Copyright Laws of the United States of America.

This document contains information that is proprietary to MIPS Technologies, Inc. (“MIPS Technologies”). Any copying, modifying or use of this information (in whole or in part) which is not expressly permitted in writing by MIPS Technologies or a contractually-authorized third party is strictly prohibited. At a minimum, this information is protected under unfair competition laws and the expression of the information contained herein is protected under federal copyright laws. Violations thereof may result in criminal penalties and fines.

MIPS Technologies or any contractually-authorized third party reserves the right to change the information contained in this document to improve function, design or otherwise. MIPS Technologies does not assume any liability arising out of the application or use of this information. Any license under patent rights or any other intellectual property rights owned by MIPS Technologies or third parties shall be conveyed by MIPS Technologies or any contractually-authorized third party in a separate license agreement between the parties.

The information contained in this document constitutes one or more of the following: commercial computer software, commercial computer software documentation or other commercial items. If the user of this information, or any related documentation of any kind, including related technical data or manuals, is an agency, department, or other entity of the United States government (“Government”), the use, duplication, reproduction, release, modification, disclosure, or transfer of this information, or any related documentation of any kind, is restricted in accordance with Federal Acquisition Regulation 12.212 for civilian agencies and Defense Federal Acquisition Regulation Supplement 227.7202 for military agencies. The use of this information by the Government is further restricted in accordance with the terms of the license agreement(s) and/or applicable contract terms and conditions covering this information from MIPS Technologies or any contractually-authorized third party.

MIPS, R3000, R4000, R5000, R8000 and R10000 are among the registered trademarks of MIPS Technologies, Inc., and R4300, R20K, MIPS16, MIPS32, MIPS64, MIPS-3D, MIPS I, MIPS II, MIPS III, MIPS IV, MIPS V, MDMX, SmartMIPS, 4K, 4Kc, 4Km, 4Kp, 5K, 5Kc, 20K, 20Kc, EC, MGB, SOC-it, SEAD, YAMON, ATLAS, JALGO, CoreLV and MIPS-based are among the trademarks of MIPS Technologies, Inc.

All other trademarks referred to herein are the property of their respective owners.

Table of Contents

Chapter 1 About This Book	1
1.1 Typographical Conventions	1
1.1.1 Italic Text	1
1.1.2 Bold Text	1
1.1.3 Courier Text	1
1.2 UNPREDICTABLE and UNDEFINED	2
1.2.1 UNPREDICTABLE	2
1.2.2 UNDEFINED	2
1.3 Special Symbols in Pseudocode Notation	2
1.4 For More Information	5
Chapter 2 Guide to the Instruction Set	7
2.1 Understanding the Instruction Fields	7
2.1.1 Instruction Fields	8
2.1.2 Instruction Descriptive Name and Mnemonic	9
2.1.3 Format Field	9
2.1.4 Purpose Field	10
2.1.5 Description Field	10
2.1.6 Restrictions Field	10
2.1.7 Operation Field	11
2.1.8 Exceptions Field	11
2.1.9 Programming Notes and Implementation Notes Fields	11
2.2 Operation Section Notation and Functions	12
2.2.1 Instruction Execution Ordering	12
2.2.2 Pseudocode Functions	12
2.3 Op and Function Subfield Notation	20
2.4 FPU Instructions	20
Chapter 3 The MIPS16e™ Application-Specific Extension to the MIPS32™ Architecture	21
3.1 Base Architecture Requirements	21
3.2 Software Detection of the ASE	21
3.3 MIPS16e Overview	21
3.4 MIPS16e ASE Features	22
3.5 MIPS16e Register Set	22
3.6 MIPS16e ISA Modes	23
3.6.1 Modes Available in the MIPS16e Architecture	23
3.6.2 Defining the ISA Mode Field	24
3.6.3 Switching Between Modes When an Exception Occurs	24
3.6.4 Using MIPS16e Jump Instructions to Switch Modes	24
3.7 JALX, JR, and JALR Operations in MIPS16e and MIPS32 Mode	25
3.8 MIPS16e Instruction Summaries	25
3.9 MIPS16e PC-Relative Instructions	29
3.10 MIPS16e Extensible Instructions	29
3.11 MIPS16e Implementation-Definable Macro Instructions	31
3.12 MIPS16e Jump and Branch Instructions	31
3.13 MIPS16e Instruction Formats	31
3.13.1 I-type instruction format	33
3.13.2 RI-type instruction format	33
3.13.3 RR-type instruction format	33
3.13.4 RRI-type instruction format	33
3.13.5 RRR-type instruction format	33

3.13.6 RRI-A type instruction format	33
3.13.7 Shift instruction format	33
3.13.8 I8-type instruction format	33
3.13.9 I8_MOVR32 instruction format (used only by the MOVR32 instruction)	33
3.13.10 I8_MOV32R instruction format (used only by MOV32R instruction)	34
3.13.11 I8_SVRS instruction format (used only by the SAVE and RESTORE instructions).....	34
3.13.12 JAL and JALX instruction format	34
3.13.13 EXT-I instruction format	34
3.13.14 ASMACRO instruction format	34
3.13.15 EXT-RI instruction format.....	34
3.13.16 EXT-RRI instruction format	34
3.13.17 EXT-RRI-A instruction format.....	34
3.13.18 EXT-SHIFT instruction format.....	34
3.13.19 EXT-I8 instruction format	35
3.13.20 EXT-I8_SVRS instruction format (used only by the SAVE and RESTORE instructions).....	35
3.14 Instruction Bit Encoding	35
3.15 MIPS16e Instruction Stream Organization and Endianness	37
Chapter 4 The MIPS16e™ ASE Instruction Set	39
4.1 MIPS16e Instruction Descriptions	39
4.1.1 MIPS16e-Specific Pseudocode Functions	39
Appendix A Revision History	151

List of Figures

Figure 2-1: Example of Instruction Description	8
Figure 2-2: Example of Instruction Fields	9
Figure 2-3: Example of Instruction Descriptive Name and Mnemonic	9
Figure 2-4: Example of Instruction Format.....	9
Figure 2-5: Example of Instruction Purpose	10
Figure 2-6: Example of Instruction Description	10
Figure 2-7: Example of Instruction Restrictions	11
Figure 2-8: Example of Instruction Operation	11
Figure 2-9: Example of Instruction Exception	11
Figure 2-10: Example of Instruction Programming Notes	12
Figure 2-11: COP_LW Pseudocode Function.....	13
Figure 2-12: COP_LD Pseudocode Function.....	13
Figure 2-13: COP_SW Pseudocode Function	13
Figure 2-14: COP_SD Pseudocode Function.....	14
Figure 2-15: AddressTranslation Pseudocode Function	14
Figure 2-16: LoadMemory Pseudocode Function.....	15
Figure 2-17: StoreMemory Pseudocode Function	15
Figure 2-18: Prefetch Pseudocode Function	16
Figure 2-19: ValueFPR Pseudocode Function	17
Figure 2-20: StoreFPR Pseudocode Function	18
Figure 2-21: SyncOperation Pseudocode Function.....	18
Figure 2-22: SignalException Pseudocode Function	19
Figure 2-23: NullifyCurrentInstruction PseudoCode Function.....	19
Figure 2-24: CoprocessorOperation Pseudocode Function.....	19
Figure 2-25: JumpDelaySlot Pseudocode Function	19
Figure 2-26: FPConditionCode Pseudocode Function.....	20
Figure 2-27: SetFPConditionCode Pseudocode Function.....	20
Figure 4-1: Xlat Pseudocode Function.....	39

List of Tables

Table 1-1: Symbols Used in Instruction Operation Statements	3
Table 2-1: AccessLength Specifications for Loads/Stores	16
Table 3-1: MIPS16e General-Purpose Registers	22
Table 3-2: MIPS16e Special-Purpose Registers	23
Table 3-3: ISA Mode Bit Encodings.....	24
Table 3-4: MIPS16e Load and Store Instructions	26
Table 3-5: MIPS16e Save and Restore Instructions.....	26
Table 3-6: MIPS16e ALU Immediate Instructions	26
Table 3-7: MIPS16e Arithmetic One, Two or Three Operand Register Instructions	26
Table 3-8: MIPS16e Special Instructions.....	28
Table 3-9: MIPS16e Multiply and Divide Instructions.....	28
Table 3-10: MIPS16e Jump and Branch Instructions	28
Table 3-11: MIPS16e Shift Instructions.....	28
Table 3-12: Implementation-Definable Macro Instructions.....	29
Table 3-13: PC-Relative MIPS16e Instructions	29
Table 3-14: PC-Relative Base Used for Address Calculation	29
Table 3-15: MIPS16e Extensible Instructions	30
Table 3-16: MIPS16e Instruction Fields	32
Table 3-17: Symbols Used in the Instruction Encoding Tables.....	35
Table 3-18: MIPS16e Encoding of the Opcode Field	36
Table 3-19: MIPS16e JAL(X) Encoding of the x Field	36
Table 3-20: MIPS16e SHIFT Encoding of the f Field	36
Table 3-21: MIPS16e RRI-A Encoding of the f Field	36
Table 3-22: MIPS16e I8 Encoding of the funct Field	36
Table 3-23: MIPS16e RRR Encoding of the f Field	37
Table 3-24: MIPS16e RR Encoding of the Funct Field	37
Table 3-25: MIPS16e I8 Encoding of the s Field when funct=SVRS	37
Table 3-26: MIPS16e RR Encoding of the ry Field when funct=J(AL)R(C)	37
Table 3-27: MIPS16e RR Encoding of the ry Field when funct=CNVT.....	37

About This Book

The MIPS32™ Architecture for Programmers Volume IV-a comes as a multi-volume set.

- Volume I describes conventions used throughout the document set, and provides an introduction to the MIPS32™ Architecture
- Volume II provides detailed descriptions of each instruction in the MIPS32™ instruction set
- Volume III describes the MIPS32™ Privileged Resource Architecture which defines and governs the behavior of the privileged resources included in a MIPS32™ processor implementation
- Volume IV-a describes the MIPS16e™ Application-Specific Extension to the MIPS32™ Architecture
- Volume IV-b describes the MDMX™ Application-Specific Extension to the MIPS32™ Architecture and is not applicable to the MIPS32™ document set
- Volume IV-c describes the MIPS-3D™ Application-Specific Extension to the MIPS64™ Architecture and is not applicable to the MIPS32™ document set
- Volume IV-d describes the SmartMIPS™ Application-Specific Extension to the MIPS32™ 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

1.3 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.
$x_{y..z}$	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
$*, \times$	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
GPRLEN	The length in bits (32 or 64) of the CPU general-purpose registers
$GPR[x]$	CPU general-purpose register x . The content of $GPR[0]$ is always zero.
$FPR[x]$	Floating Point operand register x
$FCC[CC]$	Floating Point condition code CC . $FCC[0]$ has the same value as $COC[1]$.
$FPR[x]$	Floating Point (Coprocessor unit 1), general register x
$CPR[z,x,s]$	Coprocessor unit z , general register x , select s
$CCR[z,x]$	Coprocessor unit z , 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 \rightarrow Little-Endian, 1 \rightarrow 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.

Table 1-1 Symbols Used in Instruction Operation Statements

Symbol	Meaning
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 <i>RE</i> bit in the <i>Status</i> register. Thus, BigEndianCPU may be computed as (BigEndianMem 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 <i>RE</i> bit of the <i>Status</i> register. Thus, ReverseEndian may be computed as (SR _{RE} and User mode).
<i>LLbit</i>	Bit of virtual state used to specify operation for instructions that provide atomic read-modify-write. <i>LLbit</i> is set when a linked load occurs; it is tested and cleared by the conditional store. It is cleared, during other CPU operation, when a store to the location would no longer be atomic. In particular, it is cleared by exception return instructions.
I , I+n , I-n :	<p>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 I. 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 I, in which the effect of that pseudocode appears to occur. For example, an instruction may have a result that is not available until after the next instruction. Such an instruction has the portion of the instruction operation description that writes the result register in a section labeled I+1.</p> <p>The effect of pseudocode statements for the current instruction labelled I+1 appears to occur “at the same time” as the effect of pseudocode statements labeled I 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.</p>
PC	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 <i>PC</i> during an instruction time. If no value is assigned to <i>PC</i> 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 <i>PC</i> during the instruction time of the instruction in the branch delay slot.
PABITS	The number of physical address bits implemented is represented by the symbol PABITS. As such, if 36 physical address bits were implemented, the size of the physical address space would be $2^{\text{PABITS}} = 2^{36}$ bytes.
FP32RegistersMode	<p>Indicates whether the FPU has 32-bit or 64-bit floating point registers (FPRs). In MIPS32, the FPU has 32 32-bit FPRs in which 64-bit data types are stored in even-odd pairs of FPRs. In MIPS64, the FPU has 32 64-bit FPRs in which 64-bit data types are stored in any FPR.</p> <p>In MIPS32 implementations, FP32RegistersMode is always a 0. MIPS64 implementations have a compatibility mode in which the processor references the FPRs as if it were a MIPS32 implementation. In such a case FP32RegistersMode 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.</p> <p>The value of FP32RegistersMode is computed from the FR bit in the <i>Status</i> register.</p>
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>

Comments or questions on the MIPS32™ Architecture or this document should be directed to

Director of MIPS Architecture
MIPS Technologies, Inc.
1225 Charleston Road
Mountain View, CA 94043

or via E-mail to architecture@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 8
- “Instruction Descriptive Name and Mnemonic” on page 9
- “Format Field” on page 9
- “Purpose Field” on page 10
- “Description Field” on page 10
- “Restrictions Field” on page 10
- “Operation Field” on page 11
- “Exceptions Field” on page 11
- “Programming Notes and Implementation Notes Fields” on page 11

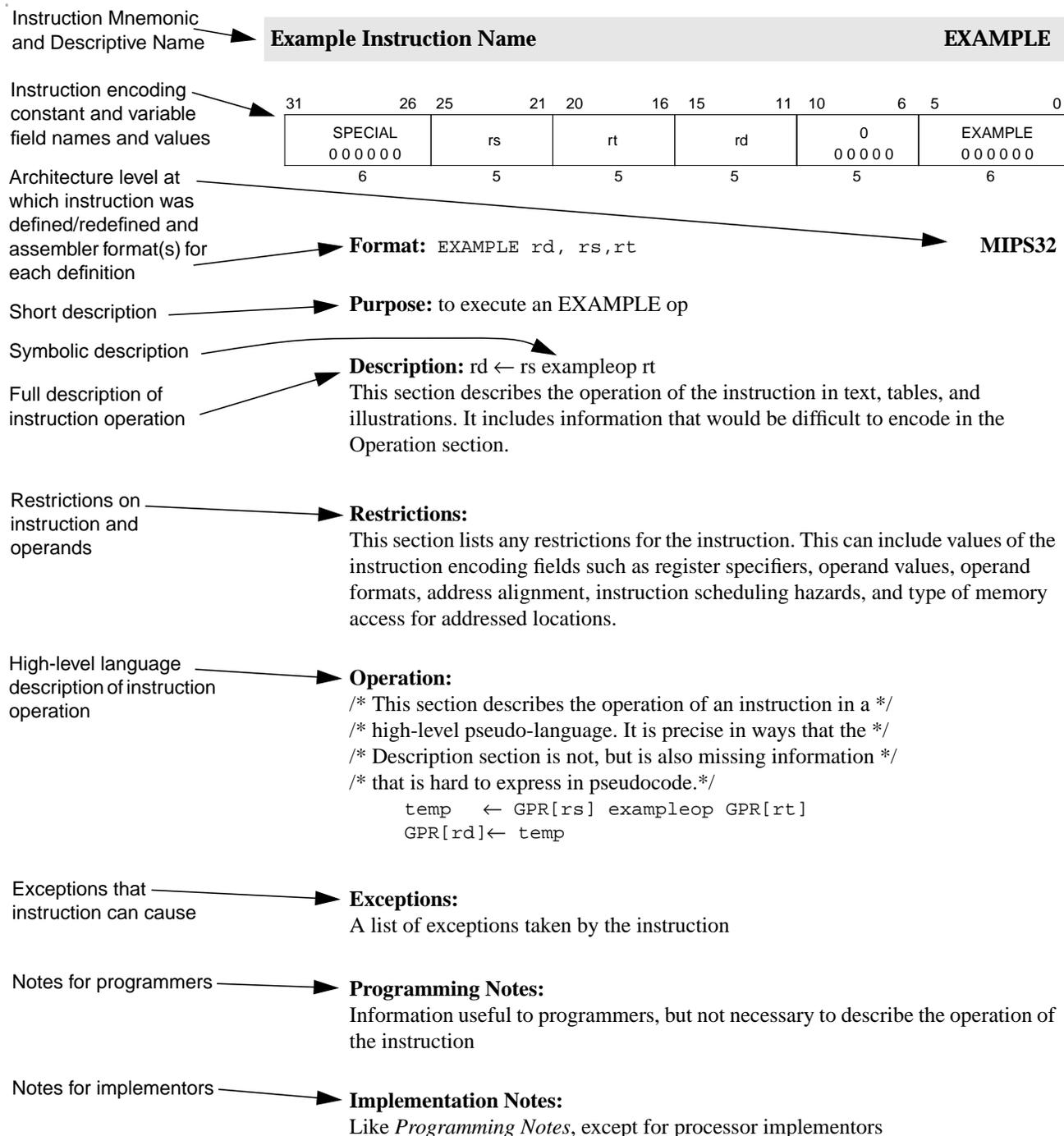


Figure 2-1 Example of Instruction Description

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**.

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	

Figure 2-2 Example of Instruction Fields

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.

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

Figure 2-3 Example of Instruction Descriptive Name and Mnemonic

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.

Format: ADD rd, rs, rt

MIPS32 (MIPS I)

Figure 2-4 Example of Instruction Format

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. If the instruction was originally defined in the MIPS I through MIPS V levels of the architecture, that information is enclosed in parentheses.

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.

2.1.4 Purpose Field

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

Purpose:

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

Figure 2-5 Example of Instruction Purpose

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.

Description: $rd \leftarrow rs + rt$

The 32-bit word value in GPR *rt* is added to the 32-bit value in GPR *rs* to produce a 32-bit result.

- If the addition results in 32-bit 2's complement arithmetic overflow, 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*

Figure 2-6 Example of Instruction Description

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*. “CPI 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 DADD)
- 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)

Restrictions:

None

Figure 2-7 Example of Instruction Restrictions**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.

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
```

Figure 2-8 Example of Instruction Operation

See Section 2.2 , "Operation Section Notation and Functions" on page 12 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.

Exceptions:

Integer Overflow

Figure 2-9 Example of Instruction Exception

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.

Programming Notes:

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

Figure 2-10 Example of Instruction Programming Notes

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 12
- “Pseudocode Functions” on page 12

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 12
- “Load Memory and Store Memory Functions” on page 14
- “Access Functions for Floating Point Registers” on page 16
- “Miscellaneous Functions” on page 18

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*.

```

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

```

Figure 2-11 COP_LW Pseudocode Function***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*.

```

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

```

Figure 2-12 COP_LD Pseudocode Function***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*.

```

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

```

Figure 2-13 COP_SW Pseudocode Function***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*.

```

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

```

Figure 2-14 COP_SD Pseudocode Function

2.2.2.2 Load Memory and Store Memory Functions

Regardless of byte ordering (big- or little-endian), the address of a halfword, word, or doubleword is the smallest byte address 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 cache coherence algorithm, describing the mechanism used to resolve the memory reference.

Given the virtual address *vAddr*, and whether the reference is to Instructions or Data (*IorD*), find the corresponding physical address (*pAddr*) and the cache coherence algorithm (*CCA*) used to resolve the reference. If the virtual address is in one of the unmapped address spaces, the physical address and *CCA* are determined directly by the virtual address. If the virtual address is in one of the mapped address spaces then the TLB 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.

```

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

  /* pAddr: physical address */
  /* CCA: Cache Coherence Algorithm, the method used to access caches*/
  /* and memory and resolve the reference */

  /* vAddr: virtual address */
  /* 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

```

Figure 2-15 AddressTranslation Pseudocode Function

LoadMemory

The *LoadMemory* function loads a value from memory.

This action uses cache and main memory as specified in both the Cache Coherence Algorithm (*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.

```
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:      Cache Coherence Algorithm, the method used to access caches */
/*           and memory and resolve the reference */

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

endfunction LoadMemory
```

Figure 2-16 LoadMemory Pseudocode Function

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 Cache Coherence Algorithm (*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.

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

/* CCA:      Cache Coherence Algorithm, 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
```

Figure 2-17 StoreMemory Pseudocode Function

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.

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

/* CCA: Cache Coherence Algorithm, 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
```

Figure 2-18 Prefetch Pseudocode Function

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

2.2.2.3 Access Functions for Floating Point Registers

The pseudocode shown in 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.

```

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, */
/*        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]

  D, UNINTERPRETED_DOUBLEWORD:
    if (fpr0 ≠ 0) then
      valueFPR ← UNPREDICTABLE
    else
      valueFPR ← FPR[fpr+1] || FPR[fpr]
    endif

  DEFAULT:
    valueFPR ← UNPREDICTABLE

endcase
endfunction ValueFPR

```

Figure 2-19 ValueFPR Pseudocode Function

StoreFPR

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 (fpr, fmt, value)

/* fpr:   The FPR number */
/* fmt:   The format of the data, one of: */
/*        S, D, W, */
/*        OB, QH, */
/*        UNINTERPRETED_WORD, */
/*        UNINTERPRETED_DOUBLEWORD */
/* value: The formatted 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 (fpr0 ≠ 0) then
      UNPREDICTABLE
    else
      FPR[fpr] ← value
      FPR[fpr+1] ← value
    endif

endcase

endfunction StoreFPR

```

Figure 2-20 StoreFPR Pseudocode Function

2.2.2.4 Miscellaneous Functions

This section lists miscellaneous functions not covered in previous sections.

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.

```

SyncOperation(stype)

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

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

endfunction SyncOperation

```

Figure 2-21 SyncOperation Pseudocode Function

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.

```
SignalException(Exception, argument)

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

endfunction SignalException
```

Figure 2-22 SignalException Pseudocode Function

NullifyCurrentInstruction

The NullifyCurrentInstruction function nullifies the current instruction.

The instruction is aborted. For branch-likely instructions, nullification kills the instruction in the delay slot during its execution.

```
NullifyCurrentInstruction()

endfunction NullifyCurrentInstruction
```

Figure 2-23 NullifyCurrentInstruction PseudoCode Function

CoprocessorOperation

The CoprocessorOperation function performs the specified Coprocessor operation.

```
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
```

Figure 2-24 CoprocessorOperation Pseudocode Function

JumpDelaySlot

The JumpDelaySlot function is used in the pseudocode for the four PC-relative instructions. 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.

```
JumpDelaySlot(vAddr)

/* vAddr:Virtual address */

endfunction JumpDelaySlot
```

Figure 2-25 JumpDelaySlot Pseudocode Function

FPConditionCode

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

```

tf ← FPConditionCode(cc)

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

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

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

endfunction FPConditionCode

```

Figure 2-26 FPConditionCode Pseudocode Function

SetFPConditionCode

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

```

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

```

Figure 2-27 SetFPConditionCode Pseudocode Function

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*=COPI 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 Section 2.3 , "Op and Function Subfield Notation" on page 20 for a description of the *op* and *function* subfields.

The MIPS16e™ Application-Specific Extension to the MIPS32™ Architecture

This chapter describes the purpose and key features of the MIPS16e™ Application-Specific Extension (ASE) to the MIPS32™ Architecture. The MIPS16e ASE is an enhancement to the previous MIPS16™ ASE which provides additional instructions to improve the compaction of the code.

3.1 Base Architecture Requirements

The MIPS16e ASE requires the following base architecture support:

- **The MIPS32 or MIPS64 Architecture:** The MIPS16e ASE requires a compliant implementation of the MIPS32 or MIPS64 Architecture.

3.2 Software Detection of the ASE

Software may determine if the MIPS16e ASE is implemented by checking the state of the CA bit in the *Config1* CP0 register.

3.3 MIPS16e Overview

The MIPS16e ASE allows embedded designs to substantially reduce system cost by reducing overall memory requirements. The MIPS16e ASE is compatible with any combination of the MIPS32 or MIPS64 Architectures, and existing MIPS binaries can be run without modification on any embedded processor implementing the MIPS16e ASE.

The MIPS16e ASE must be implemented as part of a MIPS based host processor that includes an implementation of the MIPS Privileged Resource Architecture, and the other components in a typical MIPS based system.

This volume describes only the MIPS16e ASE, and does not include information about any specific hardware implementation such as processor-specific details, because these details may vary with implementation. For this information, please refer to the specific processor's user manual.

This chapter presents specific information about the following topics:

- “MIPS16e ASE Features” on page 22
- “MIPS16e Register Set” on page 22
- “MIPS16e ISA Modes” on page 23
- “JALX, JR, and JALR Operations in MIPS16e and MIPS32 Mode” on page 25
- “MIPS16e Instruction Summaries” on page 25
- “MIPS16e PC-Relative Instructions” on page 29
- “MIPS16e Extensible Instructions” on page 29
- “MIPS16e Implementation-Definable Macro Instructions” on page 31

- “MIPS16e Jump and Branch Instructions” on page 31
- “MIPS16e Instruction Formats” on page 31
- “Instruction Bit Encoding” on page 35
- “MIPS16e Instruction Stream Organization and Endianness” on page 37

3.4 MIPS16e ASE Features

The MIPS16e ASE includes the following features:

- allows MIPS16e instructions to be intermixed with existing MIPS instruction binaries
- is compatible with the MIPS32 and MIPS64 instruction sets
- allows switching between MIPS16e and 32-bit MIPS Mode
- supports 8, 16, 32, and 64-bit data types (64-bit only in conjunction with MIPS64)
- defines eight general-purpose registers, as well as a number of special-purpose registers
- defines special instructions to increase code density (Extend, PC-relative instructions)

The MIPS16e ASE contains some instructions that are available on MIPS64 host processors only. These instructions must cause a Reserved Instruction exception on 32-bit processors, or on 64-bit processors on which 64-bit operations have not been enabled.

3.5 MIPS16e Register Set

The MIPS16e register set is listed in [Table 3-1](#) and [Table 3-2](#). This register set is a true subset of the register set available in 32-bit mode; the MIPS16e ASE can directly access 8 of the 32 registers available in 32-bit mode.

In addition to the eight general-purpose registers, 0-7, listed in [Table 3-1](#), specific instructions in the MIPS16e ASE reference the stack pointer register (*sp*), the return address register (*ra*), the condition code register (*t8*), and the program counter (*PC*). Of these, [Table 3-1](#) lists *sp*, *ra*, and *t8*, and [Table 3-2](#) lists the MIPS16e special-purpose registers, including *PC*.

The MIPS16e ASE also contains two move instructions that provide access to all 32 general-purpose registers.

Table 3-1 MIPS16e General-Purpose Registers

MIPS16e Register Encoding ^a	32-Bit MIPS Register Encoding ^b	Symbolic Name (From <i>ArchDefs.h</i>) ^c	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

Table 3-1 MIPS16e General-Purpose Registers

MIPS16e Register Encoding ^a	32-Bit MIPS Register Encoding ^b	Symbolic Name (From <i>ArchDefs.h</i>) ^c	Description
6	6	a2	General-purpose register
7	7	a3	General-purpose register
N/A	24	t8	MIPS16e <i>Condition Code</i> register; implicitly referenced by the BTEQZ, BTNEZ, CMP, CMPI, SLT, SLTU, SLTI, and SLTIU instructions
N/A	29	sp	Stack pointer register
N/A	31	ra	Return address register

- a. “0-7” correspond to the register’s MIPS16e binary encoding and show how that encoding relates to the MIPS registers. “0-7” never refer to the registers, except within the binary MIPS16e 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 MIPS16e binary encoding for this register is 001.
- b. General registers not shown in the above table are not accessible through the MIPS16e instruction set, except by using the Move instructions. The MIPS16e Move instructions can access all 32 general-purpose registers.
- c. The MIPS16e condition code register is referred to as T, t8, or \$24 throughout this document, depending on the context. All three names refer to the same physical register.

Table 3-2 MIPS16e Special-Purpose Registers

Symbolic Name	Purpose
PC	Program counter. The PC-relative Add and Load instructions 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.

3.6 MIPS16e ISA Modes

This section describes the following:

- the ISA modes available in the architecture, page 23
- the purpose of the *ISA Mode* field, page 24
- how to switch between 32-bit MIPS and MIPS16e modes, page 24
- the role of the jump instructions when switching modes, page 24

3.6.1 Modes Available in the MIPS16e Architecture

There are two ISA modes defined in the MIPS16e Architecture, as follows:

- MIPS 32-bit mode (32-bit instructions)
- MIPS16e mode (16-bit instructions)

3.6.2 Defining the ISA Mode Field

The *ISA Mode* bit controls the type of code that is executed, as follows:

Table 3-3 ISA Mode Bit Encodings

Encoding	Mode
2#0	MIPS 32-bit mode. In this mode, the processor executes 32-bit MIPS instructions.
2#1	MIPS16e mode. In this mode, the processor executes MIPS16e instructions.

In MIPS 32-bit mode and MIPS16e mode, the JALX, JR, JALR, JALRC, and JRC instructions can change the *ISA Mode* bit, as described in Section 3.6.4, "Using MIPS16e Jump Instructions to Switch Modes".

3.6.3 Switching Between Modes When an Exception Occurs

When an exception occurs (including a Reset exception), the *ISA Mode* bit is cleared so that exceptions are handled by 32-bit code.

After the processor switches to 32-bit mode following a Reset exception, the processor starts execution at the 32-bit mode Reset exception vector.

3.6.4 Using MIPS16e Jump Instructions to Switch Modes

The MIPS16e application-specific extension supports procedure calls and returns from both MIPS16e and 32-bit MIPS code to both MIPS16e and 32-bit MIPS code. The following instructions are used:

- The JAL instruction supports calls to the same ISA.
- The JALX instruction supports calls that change the ISA.
- The JALR and JALRC instructions support calls to either ISA.
- The JR and JRC instructions support returns to either ISA.

The JAL, JALR, JALRC, and JALX instructions save the *ISA Mode* bit in bit 0 of the general register containing the return address. The contents of this general register may be used by a future JR, JRC, JALR, or JALRC instruction to return and restore the *ISA Mode*.

The JALX instruction in both modes switches to the other ISA (it changes 2#0 → 2#1 and 2#1 → 2#0).

The JR and JALR instructions in both modes load the *ISA Mode* bit from bit 0 of the general register holding the target address. Bit 0 of the general register is not part of the target address; bit 0 of PC is loaded with a 0 so that no address exceptions can occur.

The JRC and JALRC instructions in MIPS16e mode load the *ISA Mode* bit from bit 0 of the general register holding the target address. Bit 0 of the general register is not part of the target address; bit 0 of PC is loaded with a 0 so that no address exceptions can occur.

3.7 JALX, JR, and JALR Operations in MIPS16e and MIPS32 Mode

The behavior of three of the 32-bit MIPS instructions—JALX, JR, JALR—differs between those processors that implement MIPS16e and those processors that do not.

In processors that implement the MIPS16e ASE, the three instructions behave as follows:

- The JALX instruction executes a JAL and switches to the other mode.
- JR and JALR instructions load the *ISA Mode* bit from bit 0 of the source register. Bit 0 of PC is loaded with a 0, and no Address exception can occur when bit 0 of the source register is a 1 (MIPS16e mode).

In CPUs that do not implement the MIPS16e ASE, the three instructions behave as follows:

- JALX instructions cause a Reserved Instruction exception.
- JR or JALR instructions cause an Address exception on the target instruction fetch when bit 0 of the source register is a 1.

3.8 MIPS16e Instruction Summaries

This section describes the various instruction categories and then summarizes the MIPS16e instructions included in each category. Extensible instructions are also identified.

There are six instruction categories:

- **Loads and Stores**—These instructions move data between memory and the GPRs.
- **Save and Restore**—These instructions create and tear down stack frames.
- **Computational**—These instructions perform arithmetic, logical, and shift operations on values in registers.
- **Jump and Branch**—These instructions change the control flow of a program.
- **Special**—This category includes the Break and Extend instructions. Break transfers control to an exception handler, and Extend enlarges the *immediate* field of the next instruction.
- **Implementation-Definable Macro Instructions**—This category includes the capability of defining macros that are replaced at execution time by a set of 32-bit MIPS instructions, with appropriate parameter substitution.

Tables 3-4 through 3-12 list the MIPS16e instruction set.

Table 3-4 MIPS16e Load and Store Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
LB	Load Byte	Yes	No
LBU	Load Byte Unsigned	Yes	No
LH	Load Halfword	Yes	No
LHU	Load Halfword Unsigned	Yes	No
LW	Load Word	Yes	No
SB	Store Byte	Yes	No
SH	Store Halfword	Yes	No
SW	Store Word	Yes	No

Table 3-5 MIPS16e Save and Restore Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
RESTORE	Restore Registers and Deallocate Stack Frame	Yes	No
SAVE	Save Registers and SetUp Stack Frame	Yes	No

Table 3-6 MIPS16e ALU Immediate Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
ADDIU	Add Immediate Unsigned	Yes	No
CMPI	Compare Immediate	Yes	No
LI	Load Immediate	Yes	No
SLTI	Set on Less Than Immediate	Yes	No
SLTIU	Set on Less Than Immediate Unsigned	Yes	No

Table 3-7 MIPS16e Arithmetic One, Two or Three Operand Register Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
ADD	Add Unsigned	No	No
AND	AND	No	No
CMP	Compare	No	No
MOVE	Move	No	No
NEG	Negate	No	No
NOT	Not	No	No
OR	OR	No	No
SEB	Sign-Extend Byte	No	No
SEH	Sign-Extend Halfword	No	No
SLT	Set on Less Than	No	No

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
SLTU	Set on Less Than Unsigned	No	No
SUBU	Subtract Unsigned	No	No
XOR	Exclusive OR	No	No
ZEB	Zero-extend Byte	No	No
ZEH	Zero-Extend Halfword	No	No

Table 3-8 MIPS16e Special Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
BREAK	Breakpoint	No	No
EXTEND	Extend	No	No

Table 3-9 MIPS16e Multiply and Divide Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
DIV	Divide	No	No
DIVU	Divide Unsigned	No	No
MFHI	Move From HI	No	No
MFLO	Move From LO	No	No
MULT	Multiply	No	No
MULTU	Multiply Unsigned	No	No

Table 3-10 MIPS16e Jump and Branch Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
B	Branch Unconditional	Yes	No
BEQZ	Branch on Equal to Zero	Yes	No
BNEZ	Branch on Not Equal to Zero	Yes	No
BTEQZ	Branch on T Equal to Zero	Yes	No
BTNEZ	Branch on T Not Equal to Zero	Yes	No
JAL ^a	Jump and Link	No	No
JALR	Jump and Link Register	No	No
JALRC	Jump and Link Register Compact	No	No
JALX ^a	Jump and Link Exchange	No	No
JR	Jump Register	No	No
JRC	Jump Register Compact	No	No

a. The JAL and JALX instructions are not extensible because they are inherently 32-bit instructions.

Table 3-11 MIPS16e Shift Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
SRA	Shift Right Arithmetic	Yes	No
SRAV	Shift Right Arithmetic Variable	No	No
SLL	Shift Left Logical	Yes	No
SLLV	Shift Left Logical Variable	No	No
SRL	Shift Right Logical	Yes	No
SRLV	Shift Right Logical Variable	No	No

Table 3-12 Implementation-Definable Macro Instructions

Mnemonic	Instruction	Extensible Instruction?	Implemented Only on MIPS64 Processors?
ASMACRO	Implementation-Definable Macro Instructions	Yes ^a	No

a. The Implementation-Definable Macro Instructions are always extended instructions. There are no 16-bit macro instruction

3.9 MIPS16e PC-Relative Instructions

The MIPS16e ASE provides PC-relative addressing for four instructions, in both extended and non-extended versions. The two instructions are listed in [Table 3-13](#).

Table 3-13 PC-Relative MIPS16e Instructions

Instruction	Use
Load Word	LW rx, offset(pc)
Add Immediate Unsigned	ADDIU rx, pc, immediate

These instructions use the PC value of either the PC-relative instruction itself or the PC value for the preceding instruction as the base for address calculation.

[Table 3-14](#) summarizes the address calculation base used for the various instruction combinations.

Table 3-14 PC-Relative Base Used for Address Calculation

Instruction	BasePC Value
Non-extended PC-relative instruction not in Jump Delay Slot	Address of instruction
Extended PC-relative instruction	Address of Extend instruction
Non-extended PC-relative instruction in JR or JALR jump delay slot	Address of JR or JALR instruction
Non-extended PC-relative instruction in JAL or JALX jump delay slot	Address of first JAL or JALX halfword

The JRC and JALRC instructions do not have delay slots and do not affect the PC-relative base address calculated for an instruction immediately following the JRC or JALRC.

In the descriptive summaries of PC-relative instructions, located in [Tables 3-13](#) and [3-14](#), the PC value used as the basis for calculating the address is referred to as the BasePC value. The BasePC equals the *Exception Program Counter (EPC)* value associated with the PC-relative instruction.

3.10 MIPS16e Extensible Instructions

This section explains the purpose of an *Extend* instruction, how to use it, and which MIPS16e instructions are extensible.

The Extend instruction allows you to enlarge the *immediate* field of any MIPS16e instruction whose *immediate* field is smaller than the *immediate* field in the equivalent 32-bit MIPS instruction. The Extend instruction must always immediately precede the instruction whose *immediate* field you want to extend. Every extended instruction uses 4 bytes in program memory instead of 2 bytes (2 bytes for Extend and 2 bytes for the instruction being extended), and it can cross a word boundary. The PC value of an extended instruction is the address of the halfword containing the Extend.

For example, the following MIPS16e instruction contains a five-bit *immediate*.

```
LW ry, offset(rx)
```

The *immediate* expands to 16 bits (2#000000000 || offset || 2#00) before execution in the pipeline. This allows 32 different offset values of 0, 4, 8, and up through 124, in increments of 4. Once extended, this instruction can hold any of the 65,536 values in the range -32768 through 32767 that are also available with the 32-bit MIPS version of the LW instruction.

Shift instructions are extended to unsigned *immediates* of 5 bits. All other immediate instructions expand to either signed or unsigned 16-bit immediates. There is only one exception which can be extended to a 15-bit signed *immediate*:

```
ADDIU ry, rx, immediate
```

Unlike most other extended instructions, an extended RESTORE or SAVE instruction provides both a larger frame size adjustment, and the ability to save and restore more registers than the non-extended version.

There is only one restriction on the location of extensible instructions: They may not be placed in jump delay slots. Doing so causes **UNPREDICTABLE** results.

Table 3-15 lists the MIPS16e extensible instructions, the size of their *immediate*, and how much each *immediate* can be extended when preceded with an Extend instruction.

Table 3-15 MIPS16e Extensible Instructions

Mnemonic	MIPS16e Instruction	MIPS16e Immediate	Extended Immediate
ADDIU	Add Immediate Unsigned	4 (ADDIU ry, rx, imm) 8	15 (ADDIU ry, rx, imm) 16
B	Branch Unconditional	11	16
BEQZ	Branch on Equal to Zero	8	16
BNEZ	Branch on Not Equal to Zero	8	16
BTEQZ	Branch on T Equal to Zero	8	16
BTNEZ	Branch on T Not Equal to Zero	8	16
CMPI	Compare Immediate	8	16
LB	Load Byte	5	16
LBU	Load Byte Unsigned	5	16
LD	Load Doubleword	5	16
LH	Load Halfword	5	16
LHU	Load Halfword Unsigned	5	16
LI	Load Immediate	8	16
LW	Load Word	5 (or 8)	16
RESTORE	Restore Registers and Deallocate Stack Frame	4	8
SAVE	Save Registers and Set Up Stack Frame	4	8
SB	Store Byte	5	16
SH	Store Halfword	5	16
SLL	Shift Left Logical	3	5

Mnemonic	MIPS16e Instruction	MIPS16e Immediate	Extended Immediate
SLTI	Set on Less Than Immediate	8	16
SLTIU	Set on Less Than Immediate Unsigned	8	16
SRA	Shift Right Arithmetic	3	5
SRL	Shift Right Logical	3	5
SW	Store Word	5 (or 8)	16

3.11 MIPS16e Implementation-Definable Macro Instructions

Previous revisions of the MIPS16e ASE assumed that most MIPS16e instructions mapped to a single 32-bit MIPS instruction. However, there are several MIPS16e instructions for which there is no corresponding 32-bit MIPS instruction equivalent. The addition of the SAVE and RESTORE instructions introduced the possibility that a single MIPS16e instruction expand to a fixed sequence of multiple 32-bit instructions. The obvious extension to this capability is the ability to define a *Macro* capability in which a single extended MIPS16e instruction can be expanded into a sequence of 32-bit MIPS instructions, with parameter substitution done between fields of the macro instruction and fields of the expanded instructions. This is the concept behind the addition of Implementation-Definable Macro Instructions to the MIPS16e ASE.

The term “Implementation-Definable” refers to the fact that the macro definitions are created when the processor is implemented, rather than via a programmable mechanism that is available to the user of the processor. The macro definitions, expansions, and parameter substitutions are defined when the processor is implemented, and is therefore implementation-dependent. The programmer visible representation of this macro capability is provided by the ASMACRO (for Application Specific Macro) instruction, as defined in the next chapter.

3.12 MIPS16e Jump and Branch Instructions

Jump and Branch instructions change the control flow of a program.

The JAL, JALR, JALX, and JR instructions occur with a one-instruction delay. That is, the instruction immediately following the jump is always executed, whether or not the jump is taken.

Branch instructions and the JALRC and JRC jump instructions do not have a delay slot. If a branch or jump is taken, the instruction immediately following the branch or jump is never executed. If the branch or jump is not taken, the instruction following the branch or jump is always executed.

Branch, jump and extended instructions may not be placed in jump delay slots. Doing so causes **UNPREDICTABLE** results.

3.13 MIPS16e Instruction Formats

This section defines the format¹ for each MIPS16e instruction type and includes formats for both normal and extended instructions.

Every MIPS16e instruction consists of 16 bits aligned on a halfword boundary. All variable subfields in an instruction format (such as `rx`, `ry`, `rz`, and `immediate`) are shown in lowercase letters.

¹ As used here, the term *format* means the layout of the MIPS16e instruction word.

The two instruction subfields `op` and `funct` have constant values for specific instructions. These values are given in their uppercase mnemonic names. For example, `op` is `LB` in the Load Byte instruction; `op` is `RRR` and `function` is `ADDU` in the Add Unsigned instruction.

Definitions for the fields that appear in the instruction formats are summarized in [Table 3-16](#).

Table 3-16 MIPS16e Instruction Fields

Field	Definition
<code>funct</code> or <code>f</code>	Function field
<code>immediate</code> or <code>imm</code>	4-, 5-, 8-, or 11-bit immediate, branch displacement, or address displacement
<code>op</code>	5-bit major operation code
<code>rx</code>	3-bit source or destination register specifier
<code>ry</code>	3-bit source or destination register specifier
<code>rz</code>	3-bit source or destination register specifier
<code>sa</code>	3- or 5-bit shift amount

3.13.1 I-type instruction format

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

3.13.2 RI-type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
op				rx				immediate							

3.13.3 RR-type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RR					rx			ry ^a		funct					

- a. When the funct field is either *CNVT* or *J(AL)R(C)*, the *ry* field encodes a sub-function to be performed rather than a register number

3.13.4 RRI-type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
op				rx				ry		immediate					

3.13.5 RRR-type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RRR					rx			ry		rz		f			

3.13.6 RRI-A type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RRI-A				rx				ry		f	immediate				

3.13.7 Shift instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SHIFT					rx			ry		sa ^a		f			

- a. The three-bit *sa* field can encode a shift amount of 0 through 7. 0 bit shifts (NOPs) are not possible; a 0 value translates to a shift amount of 8.

3.13.8 I8-type instruction format

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I8				funct				immediate							

3.13.9 I8_MOVR32 instruction format (used only by the MOVR32 instruction)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I8				funct				ry		r32[4:0]					

3.13.10 I8_MOV32R instruction format (used only by MOV32R instruction)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
I8				funct				r32[2:0,4:3] ^a				rz			

- a. The *r32* field uses special bit encoding. For example, the encoding for \$7 (00111) is 11100 in the *r32* field.

3.13.11 I8_SVRS instruction format (used only by the SAVE and RESTORE instructions)

15	14	13	12	11	10	9	8	7	6	5	4	3	0		
I8				SVRS				s	ra	s0	s1	framesize			

3.13.12 JAL and JALX instruction format

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

- a. If *x*=0, instruction is JAL. If *x*=1, instruction is JALX.

3.13.13 EXT-I instruction format

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

3.13.14 ASMACRO instruction format

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTEND		select	p4		p3			RRR			p2		p1		p0																

3.13.15 EXT-RI instruction format

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

3.13.16 EXT-RRI instruction format

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

3.13.17 EXT-RRI-A instruction format

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTEND		immediate 10:4				imm 14:11				RRI-A			rx		ry		f	imm 3:0													

3.13.18 EXT-SHIFT instruction format

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTEND		sa 4:0		s5 ^a	0	0	0	0	0	SHIFT			rx		ry		0	0	0	f											

- a. *s5* is equivalent to *sa5*, the most significant bit of the 6-bit shift amount (*sa*) field. For extended DSLR shifts, this bit may be either 0 or 1. For all 32-bit extended shifts, *s5* must be 0. None of the extended shift instructions perform the 0-to-8 mapping, so 0 bit shifts are possible using the extended format.

3.13.19 EXT-I8 instruction format

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTEND				immediate 10:5					immediate 15:11					I8			funct		0	0	0	immediate 4:0									

3.13.20 EXT-I8_SVRS instruction format (used only by the SAVE and RESTORE instructions)

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EXTEND				xsregs		framesize 7:4			0	aregs			I8			SVRS		s	ra	s0	s1	framesize 3:0									

3.14 Instruction Bit Encoding

Table 3-18 through Table 3-25 describe the encoding used for the MIPS16e ASE. Table 3-17 describes the meaning of the symbols used in the tables.

Table 3-17 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.
δ	(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.
β	Operation or field codes marked with this symbol represent a valid encoding for a higher-order MIPS ISA level. Executing such an instruction must cause a Reserved Instruction Exception.
\perp	Operation or field codes marked with this symbol represent instructions which are not legal if the processor is configured to be backward compatible with MIPS32 processors. If the processor is executing in Kernel Mode, Debug Mode, or 64-bit instructions are enabled, execution proceeds normally. 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).
θ	Operation or field codes marked with this symbol are available to licensed MIPS partners. To avoid multiple conflicting instruction definitions, the partner must notify MIPS Technologies, Inc. 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).
σ	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.
ϵ	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.
ϕ	Operation or field codes marked with this symbol are obsolete and will be removed from a future revision of the MIPS64 ISA. Software should avoid using these operation or field codes.

Table 3-18 MIPS16e Encoding of the Opcode Field

opcode		bits 13..11							
		0	1	2	3	4	5	6	7
bits 15..14		000	001	010	011	100	101	110	111
0	00	ADDIUSP ^a	ADDIUPC ^b	B	JAL(X) δ	BEQZ	BNEZ	SHIFT δ	β
1	01	RRI-A δ	ADDIU8 ^c	SLTI	SLTIU	I8 δ	LI	CMPI	β
2	10	LB	LH	LWSP ^d	LW	LBU	LHU	LWPC ^e	β
3	11	SB	SH	SWSP ^f	SW	RRR δ	RR δ	EXTEND δ	β

- The ADDIUSP opcode is used by the ADDIU rx, sp, immediate instruction
- The ADDIUPC opcode is used by the ADDIU rx, pc, immediate instruction
- The ADDIU8 opcode is used by the ADDIU rx, immediate instruction
- The LWSP opcode is used by the LW rx, offset(sp) instruction
- The LWPC opcode is used by the LW rx, offset(pc) instruction
- The SWSP opcode is used by the SW rx, offset(sp) instruction

Table 3-19 MIPS16e JAL(X) Encoding of the x Field

x	bit 26	
	0	1
	JAL	JALX

Table 3-20 MIPS16e SHIFT Encoding of the f Field

f	bits 1..0			
	0	1	2	3
	00	01	10	11
	SLL	β	SRL	SRA

Table 3-21 MIPS16e RRI-A Encoding of the f Field

f	bit 4	
	0	1
	ADDIU ^a	β

- The ADDIU function is used by the ADDIU ry, rx, immediate instruction

Table 3-22 MIPS16e I8 Encoding of the funct Field

funct	bits 10..8							
	0	1	2	3	4	5	6	7
	000	001	010	011	100	101	110	111
	BTEQZ	BTNEZ	SWRASP ^a	ADJSP ^b	SVRS δ	MOV32R ^c	*	MOVR32 ^d

- The SWRASP function is used by the SW ra, offset(sp) instruction
- The ADJSP function is used by the ADDIU sp, immediate instruction
- The MOV32R function is used by the MOVE r32, rz instruction
- The MOVR32 function is used by the MOVE ry, r32 instruction

Table 3-23 MIPS16e RRR Encoding of the f Field

f	bits 1..0			
	0	1	2	3
	00	01	10	11
	β	ADDU	β	SUBU

Table 3-24 MIPS16e RR Encoding of the Funct Field

funct	bits 2..0								
	0	1	2	3	4	5	6	7	
bits 4..3	000	001	010	011	100	101	110	111	
0	00	$J(AL)R(C) \delta$	SDBBP	SLT	SLTU	SLLV	BREAK	SRLV	SRAV
1	01	β	*	CMP	NEG	AND	OR	XOR	NOT
2	10	MFHI	$CNVT \delta$	MFLO	β	β	*	β	β
3	11	MULT	MULTU	DIV	DIVU	β	β	β	β

Table 3-25 MIPS16e I8 Encoding of the s Field when funct=SVRS

s	bit 7	
	0	1
	RESTORE	SAVE

Table 3-26 MIPS16e RR Encoding of the ry Field when funct=J(AL)R(C)

ry	bits 7..5							
	0	1	2	3	4	5	6	7
	000	001	010	011	100	101	110	111
	JR rx	JR ra	JALR		JRC rx	JRC ra	JALRC	

Table 3-27 MIPS16e RR Encoding of the ry Field when funct=CNVT

ry	bits 7..5							
	0	1	2	3	4	5	6	7
	000	001	010	011	100	101	110	111
	ZEB	ZEH	β	*	SEB	SEH	β	*

3.15 MIPS16e Instruction Stream Organization and Endianness

The instruction halfword is 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
- 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 all extended instructions, since they consist of two 16-bit halfwords. Similarly, JAL and JALX instructions should be viewed as consisting of two 16-bit halfwords, which means this rule also applies to them.

For a 16-bit-instruction sequence, instructions are placed in memory so that an LH instruction with the PC as an argument fetches the instruction independent of system endianness.

The MIPS16e™ ASE Instruction Set

4.1 MIPS16e Instruction Descriptions

This chapter provides an alphabetical listing of the instructions listed in [Table 3-4](#) through [Table 3-12](#). Instructions that are legal only in 64-bit implementations are not listed, as they are not part of a MIPS32 implementation of MIPS16e.

4.1.1 MIPS16e-Specific Pseudocode Functions

This section defines the pseudocode functions that are specific to the MIPS16e ASE. These functions are used in the Operation section of each MIPS16e instruction description.

4.1.1.1 Xlat

The Xlat function translates the MIPS16e register field index to the correct 32-bit MIPS physical register index. It is used to assure that a value of 2#000 in a MIPS16e register field maps to GPR 16, and a value of 2#001 maps to GPR 17. All other values (2#010 through 2#111) map directly.

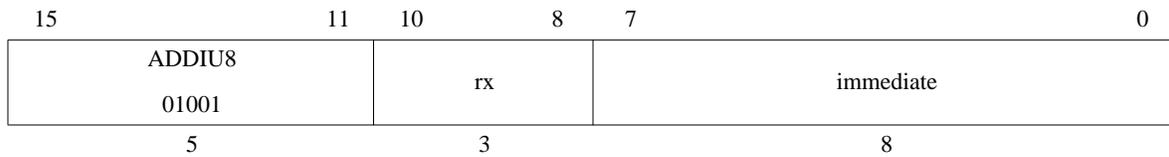
```
PhyReg ← Xlat(i)

/* PhyReg:   Physical register index, in the range 0..7 */
/* i:       Opcode register field index */

if (i < 2) then
  Xlat ← i + 16
else
  Xlat ← i
endif

endfunction Xlat
```

Figure 4-1 Xlat Pseudocode Function

Add Immediate Unsigned Word (2-Operand)**ADDIU****Format:** ADDIU *rx*, *immediate***MIPS16e****Purpose:**

To add a constant to a 32-bit integer.

Description: $rx \leftarrow rx + immediate$ The 8-bit *immediate* is sign-extended and then added to the contents of GPR *rx* to form a 32-bit result. The result is placed in GPR *rx*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← GPR[Xlat(rx)] + sign_extend(immediate)
GPR[Xlat(rx)] ← temp
```

Exceptions:

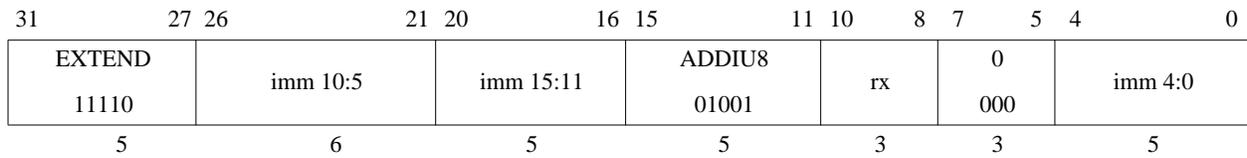
None

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.

Add Immediate Unsigned Word (2-Operand, Extended)

ADDIU



Format: ADDIU *rx*, *immediate*

MIPS16e

Purpose:

To add a constant to a 32-bit integer.

Description: $rx \leftarrow rx + \text{immediate}$

The 16-bit *immediate* is sign-extended and then added to the contents of GPR *rx* to form a 32-bit result. The result is placed in GPR *rx*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

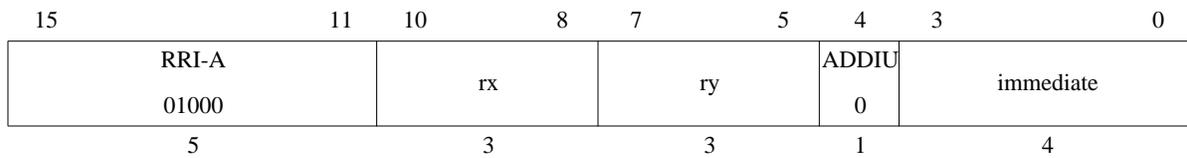
```
temp ← GPR[Xlat(rx)] + sign_extend(immediate)
GPR[Xlat(rx)] ← temp
```

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.

Add Immediate Unsigned Word (3-Operand)**ADDIU****Format:** ADDIU *ry*, *rx*, *immediate***MIPS16e****Purpose:**

To add a constant to a 32-bit integer.

Description: $ry \leftarrow rx + \text{immediate}$ The 4-bit *immediate* is sign-extended and then added to the contents of GPR *rx* to form a 32-bit result. The result is placed into GPR *ry*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

```
temp ← GPR[Xlat(rx)] + sign_extend(immediate)
GPR[Xlat(ry)] ← temp
```

Exceptions:

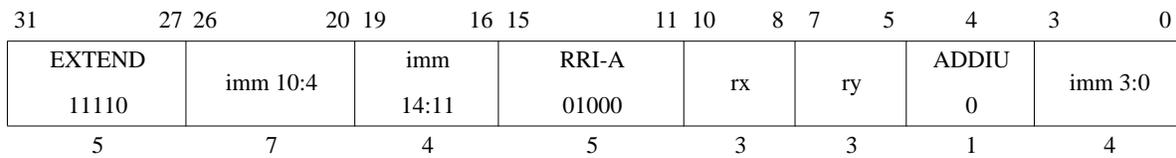
None

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.

Add Immediate Unsigned Word (3-Operand, Extended)

ADDIU



Format: ADDIU *ry*, *rx*, *immediate*

MIPS16e

Purpose:

To add a constant to a 32-bit integer.

Description: $ry \leftarrow rx + \text{immediate}$

The 15-bit *immediate* is sign-extended and then added to the contents of GPR *rx* to form a 32-bit result. The result is placed into GPR *ry*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

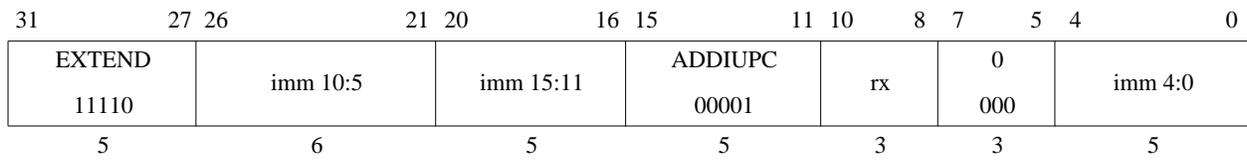
```
temp ← GPR[Xlat(rx)] + sign_extend(immediate)
GPR[Xlat(ry)] ← temp
```

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.

Add Immediate Unsigned Word (3-Operand, PC-Relative, Extended)**ADDIU****Format:** ADDIU *rx*, *pc*, *immediate***MIPS16e****Purpose:**

To add a constant to the program counter.

Description: $rx \leftarrow PC + \text{immediate}$ The 16-bit *immediate* is sign-extended and added either 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 *rx*.

No integer overflow exception occurs under any circumstances.

Restrictions:

A PC-relative, extended ADDIU may not be placed in the delay slot of a jump instruction.

Operation:

$$\text{temp} \leftarrow (PC_{\text{GPRLEN}-1..2} \parallel 0^2) + \text{sign_extend}(\text{immediate})$$

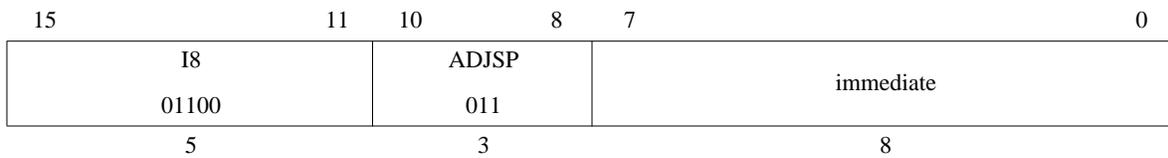
$$\text{GPR}[\text{Xlat}(rx)] \leftarrow \text{temp}$$
Exceptions:

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.

Add Immediate Unsigned Word (2-Operand, SP-Relative)**ADDIU****Format:** ADDIU *sp*, *immediate***MIPS16e****Purpose:**

To add a constant to the stack pointer.

Description: $sp \leftarrow sp + \text{immediate}$

The 8-bit *immediate* is shifted left three bits, sign-extended, and then added to the contents of GPR 29 to form a 32-bit result. The result is placed in GPR 29.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

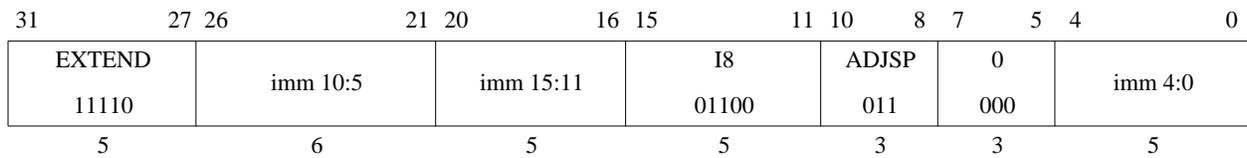
```
temp ← GPR[29] + sign_extend(immediate || 03)
GPR[29] ← temp
```

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

Add Immediate Unsigned Word (2-Operand, SP-Relative, Extended)**ADDIU****Format:** ADDIU *sp*, *immediate***MIPS16e****Purpose:**

To add a constant to the stack pointer.

Description: $sp \leftarrow sp + \text{immediate}$ The 16-bit *immediate* is sign-extended, and then added to the contents of GPR 29 to form a 32-bit result. The result is placed in GPR 29.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

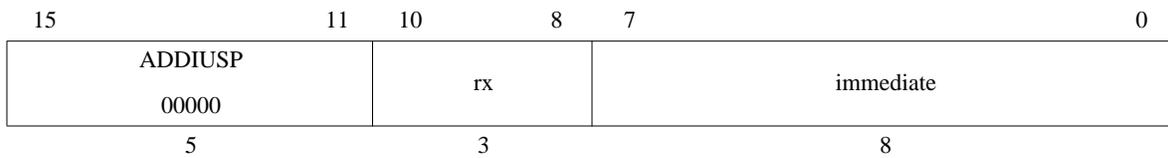
```
temp ← GPR[29] + sign_extend(immediate)
GPR[29] ← temp
```

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

Add Immediate Unsigned Word (3-Operand, SP-Relative)**ADDIU****Format:** ADDIU *rx*, *sp*, *immediate***MIPS16e****Purpose:**

To add a constant to the stack pointer.

Description: $rx \leftarrow SP + immediate$

The 8-bit *immediate* is shifted left two bits, zero-extended, and then added to the contents of GPR 29 to form a 32-bit result. The result is placed in GPR *rx*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

$$\begin{aligned} temp &\leftarrow GPR[29] + \text{zero_extend}(immediate \ll 2) \\ GPR[Xlat(rx)] &\leftarrow temp \end{aligned}$$
Exceptions:

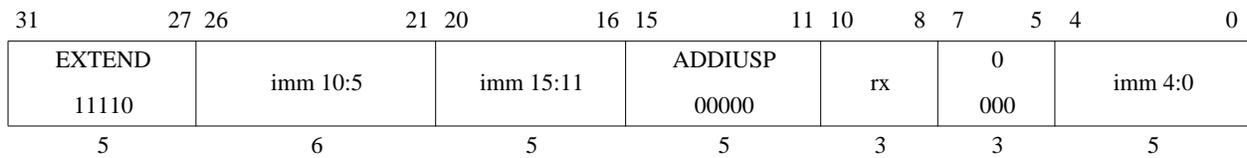
None

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.

Add Immediate Unsigned Word (3-Operand, SP-Relative, Extended)

ADDIU



Format: ADDIU *rx*, *sp*, *immediate*

MIPS16e

Purpose:

To add a constant to the stack pointer.

Description: $rx \leftarrow sp + \text{immediate}$

The 16-bit *immediate* is sign-extended and then added to the contents of GPR 29 to form a 32-bit result. The result is placed in GPR *rx*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

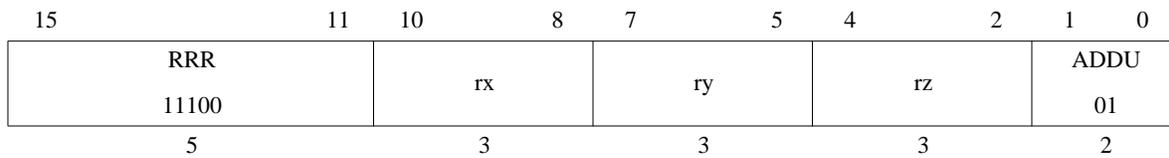
```
temp ← GPR[29] + sign_extend(immediate)
GPR[Xlat(rx)] ← temp
```

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.

Add Unsigned Word (3-Operand)**ADDU****Format:** ADDU *rz*, *rx*, *ry***MIPS16e****Purpose:**

To add 32-bit integers.

Description: $rz \leftarrow rx + ry$ The contents of GPR *rx* and GPR *ry* are added together to form a 32-bit result. The result is placed into GPR *rz*.

No integer overflow exception occurs under any circumstances.

Restrictions:

None

Operation:

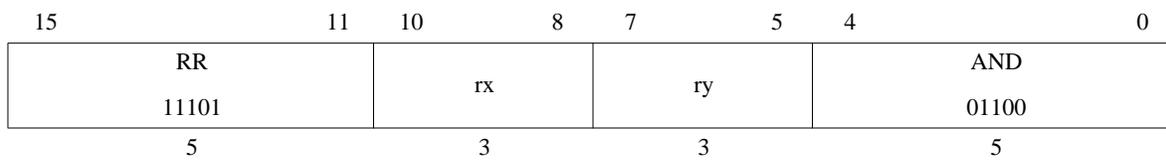
$$\text{temp} \leftarrow \text{GPR}[\text{Xlat}(rx)] + \text{GPR}[\text{Xlat}(ry)]$$

$$\text{GPR}[\text{Xlat}(rz)] \leftarrow \text{temp}$$
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.

And**AND****Format:** AND *rx*, *ry***MIPS16e****Purpose:**

To do a bitwise logical AND.

Description: $rx \leftarrow rx \text{ AND } ry$ The contents of GPR *ry* are combined with the contents of GPR *rx* in a bitwise logical AND operation. The result is placed in GPR *rx*.**Restrictions:**

None

Operation:
$$GPR[Xlat(rx)] \leftarrow GPR[Xlat(rx)] \text{ and } GPR[Xlat(ry)]$$
Exceptions:

None

31	27 26	24 23	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	select	p4	p3	RRR 11100	p2	p1	p0	
5	3	3	5	5	3	3	5	

Format: ASMACRO *select*, *p0*, *p1*, *p2*, *p3*, *p4*

MIPS16e

The format listed is the most generic assembler format and is unlikely to be used for an actual implementation of application-specific macro instructions. Rather, the assembler format is likely to represent the use of the macro, with the assembler turning that format into the appropriate bit pattern required by the instruction.

Purpose:

To execute an implementation-definable macro instruction.

Description:

The ASMACRO instruction is the programming interface to the implementation-definable macro instruction facility that is defined by the MIPS16e architecture.

The *select* field specifies which of 8 possible macros is expanded. The definition of each macro specifies how the parameters *p0*, *p1*, *p2*, *p3*, and *p4* are substituted into the 32-bit instructions with which the macro is defined. The execution of the 32-bit instructions occurs while PC remains unchanged.

It is implementation-dependent whether a processor implements any implementation-definable macro instructions and, if it does, how many. It is implementation-dependent whether the macro is executed with interrupts disabled.

Restrictions:

The 32-bit instructions with which the macro is defined must be chosen with care. Issues of atomicity, restartability of the instruction sequence, and similar factors must be considered when using the implementation-definable macro instruction facility. Failure to do so can cause **UNPREDICTABLE** behavior.

If implementation-definable macro instructions are not implemented by the processor, or if the *select* field references a specific macro which is not implemented by the processor, a Reserved Instruction exception is signaled.

Operation:

```
ExecuteMacro(sel, p0, p1, p2, p3, p4)
```

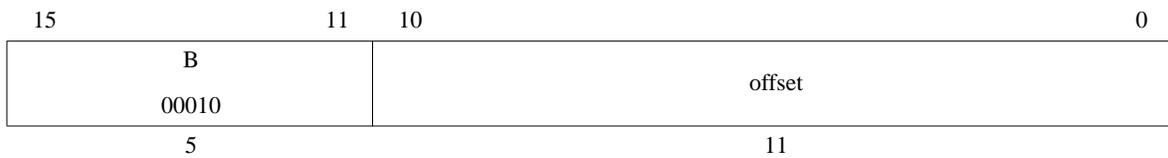
Exceptions:

Reserved Instruction

Others as may be generated by the 32-bit instructions included in each macro expansion.

Programming Notes:

Refer to the Users Guide for each processor which implements this capability for a list of macros defined and implemented by that processor.

Unconditional Branch**B****Format:** B offset**MIPS16e****Purpose:**

To do an unconditional PC-relative branch.

Description: branch

The 11-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. The program branches to the target address unconditionally.

Restrictions:

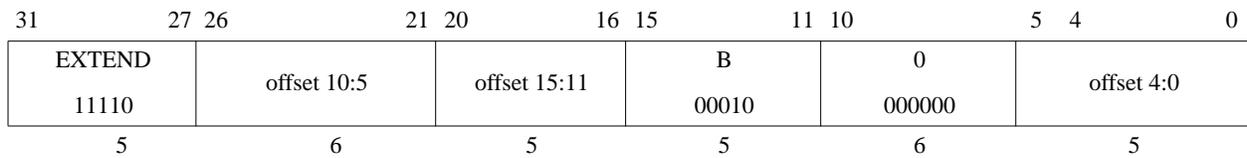
None

Operation:**I:** $PC \leftarrow PC + 2 + \text{sign_extend}(\text{offset} \ll 1)$ **Exceptions:**

None

Programming Notes:

In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Unconditional Branch (Extended)**B****Format:** B offset**MIPS16e****Purpose:**

To do an unconditional PC-relative branch.

Description: 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. The program branches to the target address unconditionally.

Restrictions:

None

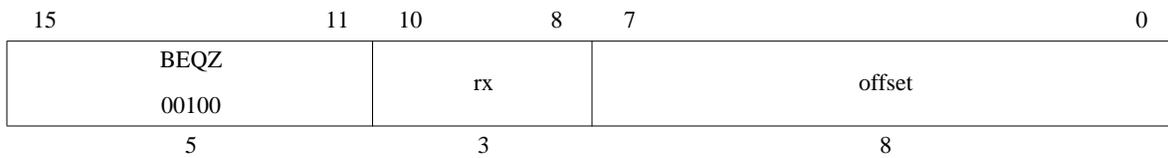
Operation:

$$\mathbf{I:} \quad \text{PC} \leftarrow \text{PC} + 4 + \text{sign_extend}(\text{offset} \ll 1)$$
Exceptions:

None

Programming Notes:

In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on Equal to Zero**BEQZ****Format:** BEQZ rx, offset**MIPS16e****Purpose:**

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

Description: if (rx = 0) then branch

The 8-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 *rx* are equal to zero, the program branches to the target address.

Restrictions:

None

Operation:

```

I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[Xlat(rx)] = 0GPRLEN)
        if condition then
            PC ← PC + 2 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:

In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on Equal to Zero (Extended)**BEQZ**

31	27 26	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	offset 10:5	offset 15:11	BEQZ 00100	rx	0 000	offset 4:0	
5	6	5	5	3	3	5	

Format: BEQZ *rx*, *offset***MIPS16e****Purpose:**

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

Description: if (*rx* = 0) then branchThe 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 *rx* are equal to zero, the program branches to the target address.**Restrictions:**

None

Operation:

```

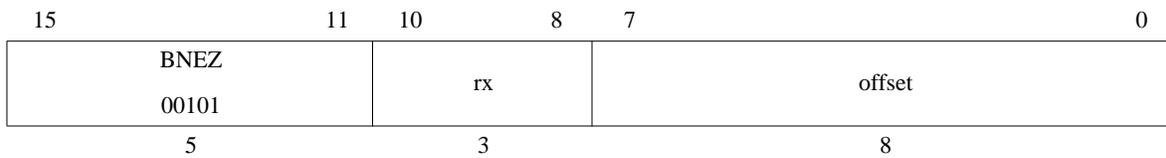
I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[Xlat(rx)] = 0GPRLEN)
        if condition then
            PC ← PC + 4 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on Not Equal to Zero**BNEZ****Format:** BNEZ *rx*, *offset***MIPS16e****Purpose:**

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

Description: if (*rx* ≠ 0) then branchThe 8-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 *rx* are not equal to zero, the program branches to the target address.**Restrictions:**

None

Operation:

```

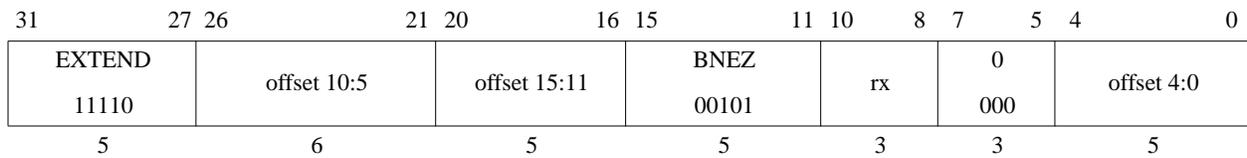
I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[Xlat(rx)] ≠ 0GPRLEN)
        if condition then
            PC ← PC + 2 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on Not Equal to Zero (Extended)**BNEZ****Format:** BNEZ *rx*, *offset***MIPS16e****Purpose:**

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

Description: if (*rx* ≠ 0) then branchThe 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 *rx* are not equal to zero, the program branches to the target address.**Restrictions:**

None

Operation:

```

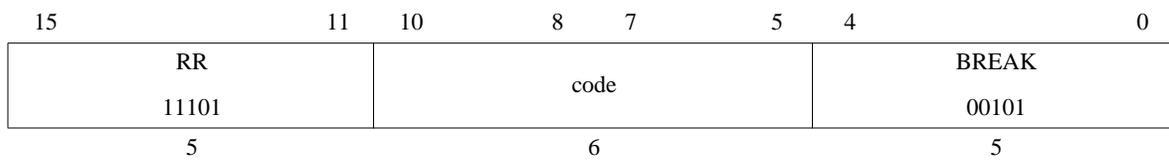
I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[Xlat(rx)] ≠ 0GPRLEN)
        if condition then
            PC ← PC + 4 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Breakpoint**BREAK****Format:** BREAK immediate**MIPS16e****Purpose:**

To cause a Breakpoint exception.

Description:

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

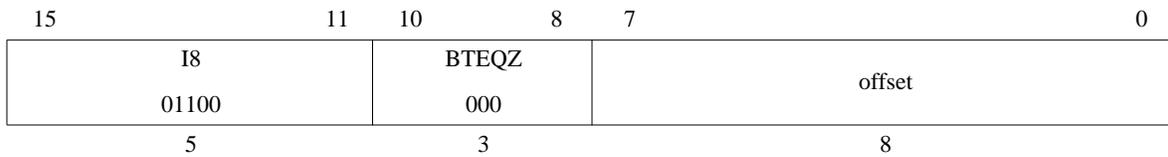
Restrictions:

None

Operation:`SignalException(Breakpoint)`**Exceptions:**

Breakpoint

Programming Notes: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 halfword containing the instruction.

Branch on T Equal to Zero**BTEQZ****Format:** BTEQZ offset**MIPS16e****Purpose:**

To test special register T then do a PC-relative conditional branch.

Description: if (T = 0) then branch

The 8-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 24 are equal to zero, the program branches to the target address.

Restrictions:

None

Operation:

```

I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[24] = 0GPRLEN)
        if condition then
            PC ← PC + 2 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:

In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on T Equal to Zero (Extended)**BTEQZ**

31	27 26	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	offset 10:5	offset 15:11	I8 01100	BTEQZ 000	000 0	offset 4:0	
5	6	5	5	3	3	5	

Format: BTEQZ offset**MIPS16e****Purpose:**

To test special register T then do a PC-relative conditional branch.

Description: if (T = 0) then branchThe 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 24 are equal to zero, the program branches to the target address.**Restrictions:**

None

Operation:

```

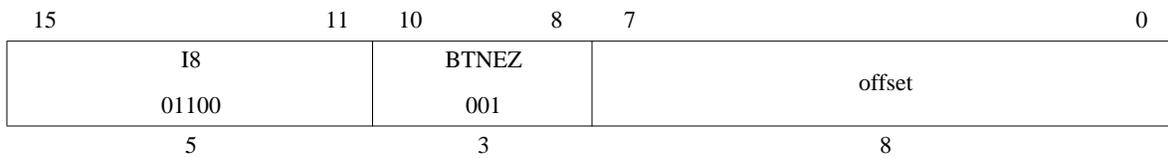
I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[24] = 0GPRLEN)
        if condition then
            PC ← PC + 4 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on T Not Equal to Zero**BTNEZ****Format:** BTNEZ offset**MIPS16e****Purpose:**

To test special register T then do a PC-relative conditional branch.

Description: if (T ≠ 0) then branch

The 8-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 24 are not equal to zero, the program branches to the target address.

Restrictions:

None

Operation:

```

I:   tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[24] ≠ 0GPRLEN)
        if condition then
            PC ← PC + 2 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:

In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.

Branch on T Not Equal to Zero (Extended)**BTNEZ**

31	27 26	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	offset 10:5	offset 15:11	I8 01100	BTNEZ 001	000 0	offset 4:0	
5	6	5	5	3	3	5	

Format: BTNEZ offset**MIPS16e****Purpose:**

To test special register T then do a PC-relative conditional branch.

Description: if (T ≠ 0) then branchThe 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 24 are not equal to zero, the program branches to the target address.**Restrictions:**

None

Operation:

```

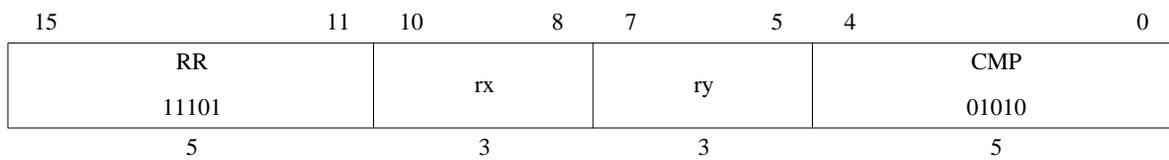
I:    tgt_offset ← sign_extend(offset || 0)
        condition ← (GPR[24] ≠ 0GPRLEN)
        if condition then
            PC ← PC + 4 + tgt_offset
        endif

```

Exceptions:

None

Programming Notes:In MIPS16e mode, the branch *offset* is interpreted as halfword-aligned. This is unlike 32-bit MIPS mode, which interprets the *offset* value as word-aligned.



Format: `CMP rx, ry`

MIPS16e

Purpose:

To compare the contents of two GPRs.

Description: $T \leftarrow rx \text{ XOR } ry$

The contents of GPR *ry* are Exclusive-ORed with the contents of GPR *rx*. The result is placed into GPR 24.

Restrictions:

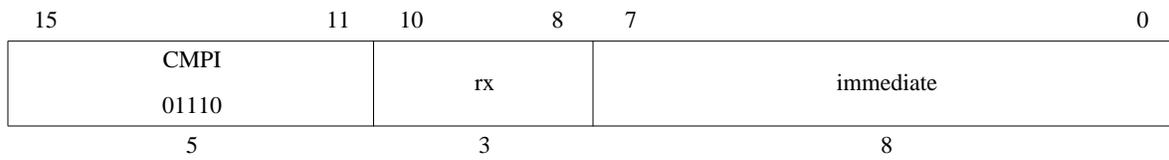
None

Operation:

$GPR[24] \leftarrow GPR[Xlat(ry)] \text{ xor } GPR[Xlat(rx)]$

Exceptions:

None

Compare Immediate**CMPI****Format:** CMPI rx, immediate**MIPS16e****Purpose:**

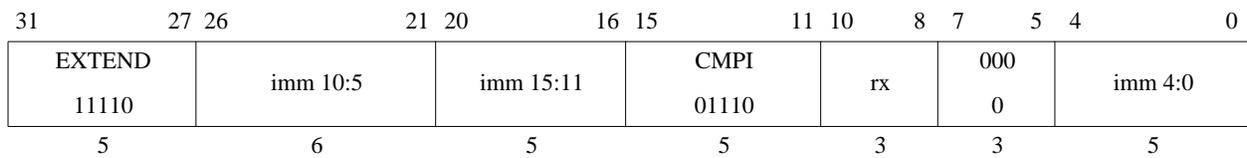
To compare a constant with the contents of a GPR.

Description: $T \leftarrow rx \text{ XOR } immediate$ The 8-bit *immediate* is zero-extended and Exclusive-ORed with the contents of GPR *rx*. The result is placed into GPR 24.**Restrictions:**

None

Operation: $GPR[24] \leftarrow GPR[Xlat(rx)] \text{ xor } zero_extend(immediate)$ **Exceptions:**

None

Compare Immediate (Extended)**CMPI****Format:** CMPI *rx*, *immediate***MIPS16e****Purpose:**

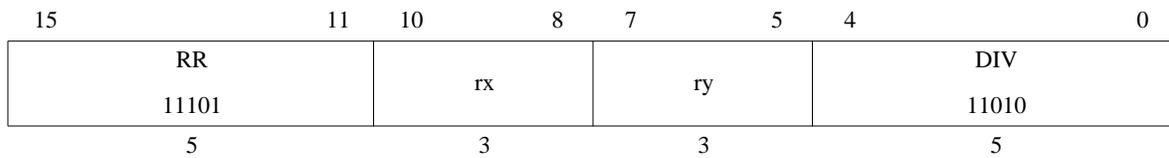
To compare a constant with the contents of a GPR.

Description: $T \leftarrow rx \text{ XOR } immediate$ The 16-bit *immediate* is zero-extended and Exclusive-ORed with the contents of GPR *rx*. The result is placed into GPR 24.**Restrictions:**

None

Operation: $GPR[24] \leftarrow GPR[Xlat(rx)] \text{ xor } zero_extend(immediate)$ **Exceptions:**

None

Divide Word**DIV****Format:** DIV *rx*, *ry***MIPS16e****Purpose:**

To divide 32-bit signed integers.

Description: (LO, HI) ← *rx* / *ry*

The 32-bit word value in GPR *rx* is divided by the 32-bit value in GPR *ry*, 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 *ry* is zero, the arithmetic result is **UNPREDICTABLE**.**Operation:**

$$q \leftarrow \text{GPR}[\text{Xlat}(rx)] \text{ div } \text{GPR}[\text{Xlat}(ry)]$$

$$r \leftarrow \text{GPR}[\text{Xlat}(rx)] \text{ mod } \text{GPR}[\text{Xlat}(ry)]$$

$$LO \leftarrow q$$

$$HI \leftarrow r$$
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.

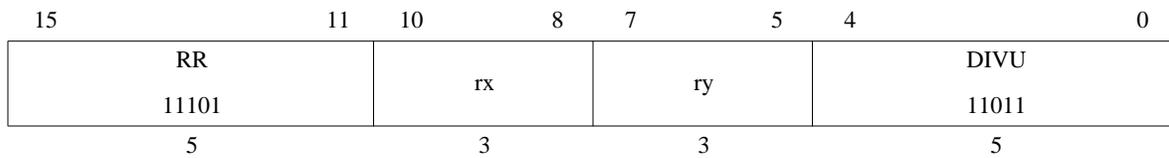
As an example, the C programming language in a UNIX[®] environment expects division by zero to either terminate the program or execute a program-specified signal handler. C does not expect overflow to cause any exceptional condition. If the C compiler uses a divide instruction, it also emits code to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

Where the size of the operands are known, software should place the shorter operand in GPR *ry*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

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 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.

Divide Unsigned Word**DIVU****Format:** DIVU *rx*, *ry***MIPS16e****Purpose:**

To divide 32-bit unsigned integers.

Description: (LO, HI) ← *rx* / *ry*

The 32-bit word value in GPR *rx* is divided by the 32-bit value in GPR *ry*, 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*.

Restrictions:If the divisor in GPR *ry* is zero, the arithmetic result is **UNPREDICTABLE**.**Operation:**

$$q \leftarrow (0 \parallel \text{GPR}[\text{Xlat}(rx)]) \text{ div } (0 \parallel \text{GPR}[\text{Xlat}(ry)])$$

$$r \leftarrow (0 \parallel \text{GPR}[\text{Xlat}(rx)]) \text{ mod } (0 \parallel \text{GPR}[\text{Xlat}(ry)])$$

$$LO \leftarrow q$$

$$HI \leftarrow r$$
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	27 26 25	21 20	16 15	0
JAL	x	target	target	target 15:0
00011	0	20:16	25:21	
5	1	5	5	16

Format: JAL target

MIPS16e

Purpose:

To execute a procedure call within the current 256 MB-aligned region and preserve the current ISA.

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 28 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 in the delay slot (not the branch itself).

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

The opcode field describes a general jump-and-link operation, with the *x* field as a variable. The individual instructions, JAL and JALX have specific values for this variables.

Restrictions:

An extended instruction should not be placed in a jump delay slot as it causes one-half of an instruction to be executed.

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

Operation:

$$\begin{aligned} \mathbf{I:} \quad & \text{GPR}[31] \leftarrow (\text{PC} + 6)_{\text{GPRLEN}-1..1} \parallel \text{ISAMode} \\ \mathbf{I+1:} \quad & \text{PC} \leftarrow \text{PC}_{\text{GPRLEN}-1..28} \parallel \text{target} \parallel 0^2 \end{aligned}$$

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 branch from anywhere in the region to anywhere in the region, an action not allowed by a signed relative *offset*.

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 jump delay slot.

15	11	10	8	7	6	5	4	0
RR	rx			nd	l	ra	J(AL)R(C)	
11101				0	1	0	00000	
5	3			1	1	1	5	

Format: JALR ra, rx

MIPS16e

Purpose:

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

Description: $ra \leftarrow \text{return_addr}$, $PC \leftarrow rx$

The program unconditionally jumps to the address contained in GPR *rx*, with a delay of one instruction. The instruction sets the *ISA Mode* bit to the value in GPR *rx* bit 0.

The address of the instruction following the delay slot is placed into GPR 31. The value stored in GPR 31 bit 0 reflects the current value of the *ISA Mode* bit.

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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is ra) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR *rx* must be naturally-aligned. If bit 0 is zero and bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

An extended instruction should not be placed in a jump delay slot, because this causes one-half of an instruction to be executed.

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

Operation:

I: $GPR[31] \leftarrow (PC + 4)_{GPRLEN-1..1} \parallel ISAMode$
I+1: $PC \leftarrow GPR[Xlat(rx)]_{GPRLEN-1..1} \parallel 0$
 $ISAMode \leftarrow GPR[Xlat(rx)]_0$

Exceptions:

None

15	11	10	8	7	6	5	4	0
RR	rx			nd	l	ra	J(AL)R(C)	
11101				1	1	0	00000	
5	3			1	1	1	5	

Format: JALRC ra, rx

MIPS16e

Purpose:

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

Description: ra ← return_addr, PC ← rx

The program unconditionally jumps to the address contained in GPR *rx*, with no delay slot instruction. The instruction sets the *ISA Mode* bit to the value in GPR *rx* bit 0.

The address of the instruction following the jump is placed into GPR 31. The value stored in GPR 31 bit 0 reflects the current value of the *ISA Mode* bit.

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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is ra) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR *rx* must be naturally-aligned. If bit 0 is zero and bit 1 is one, an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

Operation:

I: GPR[31] ← (PC + 2)_{GPRLEN-1..1} || ISAMode
 PC ← GPR[Xlat(rx)]_{GPRLEN-1..1} || 0
 ISAMode ← GPR[Xlat(rx)]₀

Exceptions:

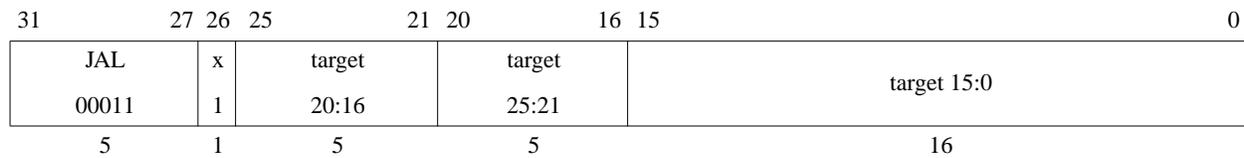
None.

Programming Notes:

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

Jump and Link Exchange (MIPS16e Format)

JALX



Format: JALX target

MIPS16e

Purpose:

To execute a procedure call within the current 256 MB-aligned region and change the ISA Mode from MIPS16e 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 28 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 in the delay slot (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.

The opcode field describes a general jump-and-link operation, with the *x* field as a variable. The individual instructions, JAL and JALX have specific values for this variables.

Restrictions:

An extended instruction should not be placed in a jump delay slot, because this causes one-half an instruction to be executed.

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

Operation:

I: $GPR[31] \leftarrow (PC + 6)_{GPRLEN-1..1} \parallel ISAMode$
I+1: $PC \leftarrow PC_{GPRLEN-1..28} \parallel target \parallel 0^2$
 $ISAMode \leftarrow (\text{not } ISAMode)$

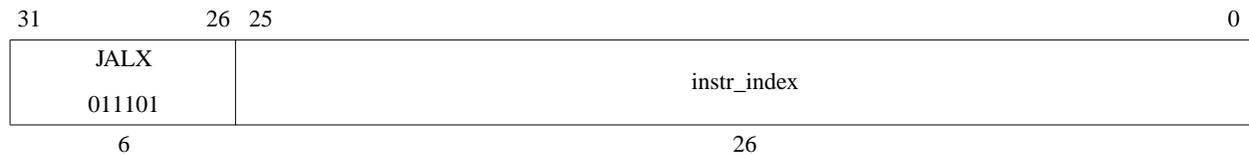
Exceptions:

None

Programming Notes:

Forming the jump target address by catenating 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 jump delay slot.



Format: JALX target

MIPS32 with MIPS16e

Purpose:

To execute a procedure call within the current 256 MB-aligned region and change the ISA Mode from 32-bit MIPS to MIPS16e.

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 28 bits of the target address is the *instr_index* field shifted left 2 bits. The remaining upper bits are the corresponding bits of the address of the instruction in the delay slot (not the branch itself).

Jump to the effective target address, toggling the ISA Mode bit. 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:    GPR[31] ← PC + 8
I+1: PC ← PCGPRLEN..28 || instr_index || 02
        ISAMode ← (not ISAMode)

```

Exceptions:

None

Programming Notes:

Forming the branch target address by concatenating PC and index bits rather than adding a signed offset to the PC is an advantage if all program code addresses fit into a 256 MB region aligned on a 256 MB boundary. It allows a branch 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 256 MB region, it can branch only to the following 256 MB region containing the branch delay slot.

15	11	10	8	7	6	5	4	0
RR	000			nd	l	ra	J(AL)R(C)	
11101				0	0	1	00000	
5	3			1	1	1	5	

Format: JR ra

MIPS16e

Purpose:

To execute a branch to the instruction address in the return address register.

Description: $PC \leftarrow ra$

The program unconditionally jumps to the address specified in GPR 31, with a delay of one instruction. 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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is ra) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR 31 must be naturally-aligned. If bit 0 is zero and bit 1 is one, then an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

An extended instruction should not be placed in a jump delay slot, because this causes one-half of an instruction to be executed.

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

Operation:

$$I+1: \quad PC \leftarrow GPR[31]_{GPRLEN-1..1} \parallel 0$$

$$ISAMode \leftarrow GPR[31]_0$$

Exceptions:

None

15	11	10	8	7	6	5	4	0
RR	rx			nd	l	ra	J(AL)R(C)	
11101				0	0	0	00000	
5	3			1	1	1	5	

Format: JR rx

MIPS16e

Purpose:

To execute a branch to an instruction address in a register.

Description: $PC \leftarrow rx$

The program unconditionally jumps to the address specified in GPR *rx*, with a delay of one instruction. The instruction sets the *ISA Mode* bit to the value in GPR *rx* 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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is *ra*) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR *rx* must be naturally aligned. If bit 0 is zero and bit 1 is one, then an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

An extended instruction should not be placed in a jump delay slot, because this causes one-half of an instruction to be executed.

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

Operation:

$$I+1: \quad PC \leftarrow GPR[Xlat(rx)]_{GPRLEN-1..1} \parallel 0$$

$$ISAMode \leftarrow GPR[Xlat(rx)]_0$$

Exceptions:

None

15	11	10	8	7	6	5	4	0
RR	000		nd	1	ra	J(AL)R(C)		
11101			1	0	1	00000		
5	3		1	1	1	5		

Format: JRC ra

MIPS16e

Purpose:

To execute a branch to the instruction address in the return address register.

Description: $PC \leftarrow ra$

The program unconditionally jumps to the address specified in GPR 31, with no delay slot instruction. 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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is ra) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR 31 must be naturally-aligned. If bit 0 is zero and bit 1 is one, then an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

Operation:

```
I:   PC ← GPR[31]GPRLEN-1..1 || 0
      ISAMode ← GPR[31]0
```

Exceptions:

None.

Programming Notes:

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

15	11	10	8	7	6	5	4	0
RR	rx			nd	l	ra	J(AL)R(C)	
11101				1	0	0	00000	
5	3			1	1	1	5	

Format: JRC *rx*

MIPS16e

Purpose:

To execute a branch to an instruction address in a register

Description: $PC \leftarrow rx$

The program unconditionally jumps to the address specified in GPR *rx*, with no delay slot instruction. The instruction sets the *ISA Mode* bit to the value in GPR *rx* 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 opcode and function field describe a general jump-thru-register operation, with the *nd* (no delay slot), *l* (link), and *ra* (source register is *ra*) fields as variables. The individual instructions, JALR, JR, JALRC, and JRC have specific values for these variables.

Restrictions:

The effective target address in GPR *rx* must be naturally-aligned. If bit 0 is zero and bit 1 is one, then an Address Error exception occurs when the jump target is subsequently fetched as an instruction.

Operation:

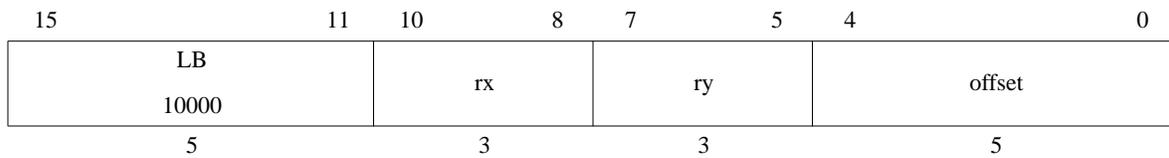
```
I:   PC ← GPR[Xlat(rx)]GPRLEN-1..1 || 0
      ISAMode ← GPR[Xlat(rx)]0
```

Exceptions:

None.

Programming Notes:

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

Load Byte**LB****Format:** LB *ry*, offset(*rx*)**MIPS16e****Purpose:**

To load a byte from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 5-bit *offset* is zero-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the byte at the memory location specified by the effective address are sign-extended and loaded into GPR *ry*.

Restrictions:

None

Operation:

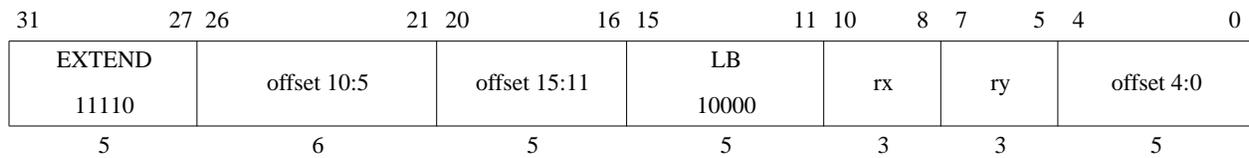
```

vAddr ← zero_extend(offset) + GPR[Xlat(rx)]
(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[Xlat(ry)] ← sign_extend(memword7+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Byte (Extended)**LB****Format:** LB *ry*, *offset(rx)***MIPS16e****Purpose:**

To load a byte from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 16-bit *offset* is sign-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the byte at the memory location specified by the effective address are sign-extended and loaded into GPR *ry*.

Restrictions:

None

Operation:

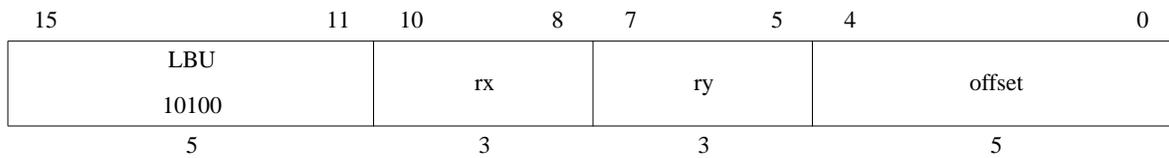
```

vAddr ← sign_extend(offset) + GPR[Xlat(rx)]
(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[Xlat(ry)] ← sign_extend(memword7+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Byte Unsigned**LBU****Format:** LBU ry, offset(rx)**MIPS16e****Purpose:**

To load a byte from memory as an unsigned value

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 5-bit *offset* is zero-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the byte at the memory location specified by the effective address are zero-extended and loaded into GPR *ry*.

Restrictions:

None

Operation:

```

vAddr ← zero_extend(offset) + GPR[Xlat(rx)]
(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[Xlat(ry)] ← zero_extend(memword7+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Byte Unsigned (Extended)**LBU**

31	27 26	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	offset 10:5	offset 15:11	LBU 10100	rx	ry	offset 4:0	
5	6	5	5	3	3	5	

Format: LBU *ry*, *offset(rx)***MIPS16e****Purpose:**

To load a byte from memory as an unsigned value

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 16-bit *offset* is sign-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the byte at the memory location specified by the effective address are zero-extended and loaded into GPR *ry*.

Restrictions:

None

Operation:

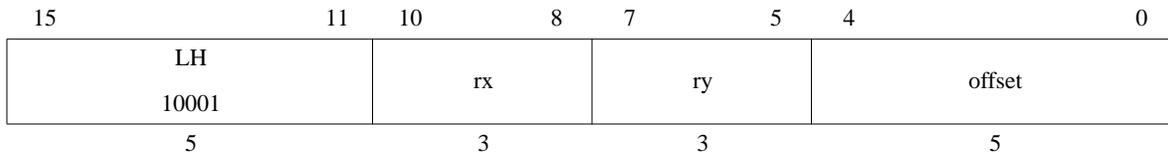
```

vAddr ← sign_extend(offset) + GPR[Xlat(rx)]
(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[Xlat(ry)] ← zero_extend(memword7+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error



Format: LH *ry*, offset(*rx*)

MIPS16e

Purpose:

To load a halfword from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 5-bit *offset* is shifted left 1 bit, zero-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the halfword at the memory location specified by the effective address are sign-extended and loaded into GPR *ry*.

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:

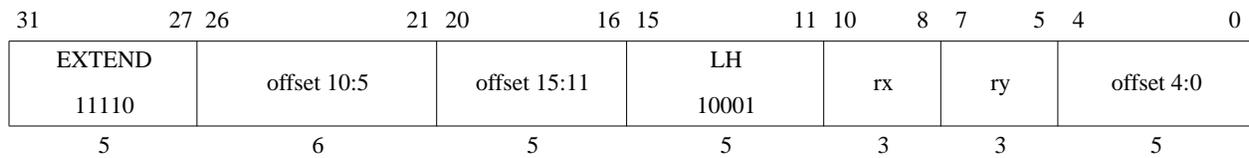
```

vAddr ← zero_extend(offset || 0) + GPR[Xlat(rx)]
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[Xlat(ry)] ← sign_extend(memword15+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Halfword (Extended)**LH****Format:** LH ry, offset(rx)**MIPS16e****Purpose:**

To load a halfword from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The contents of the halfword at the memory location specified by the effective address are sign-extended and loaded into GPR *ry*.

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:

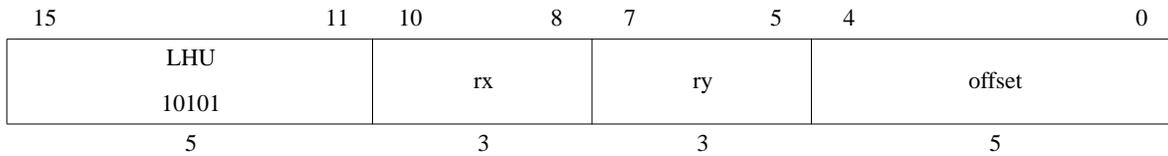
```

vAddr ← sign_extend(offset) + GPR[Xlat(rx)]
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[Xlat(ry)] ← sign_extend(memword15+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Halfword Unsigned**LHU****Format:** LHU ry, offset(rx)**MIPS16e****Purpose:**

To load a halfword from memory as an unsigned value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 5-bit *offset* is shifted left 1 bit, zero-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the halfword at the memory location specified by the effective address are zero-extended and loaded into GPR *ry*.

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:

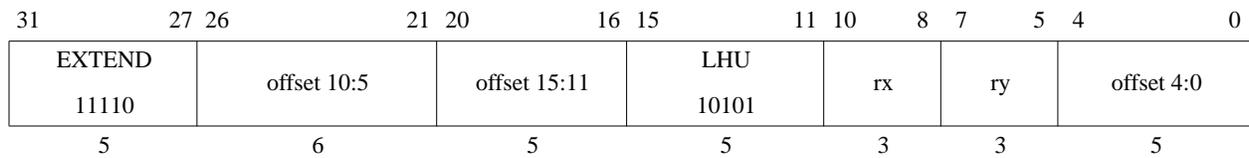
```

vAddr ← zero_extend(offset || 0) + GPR[Xlat(rx)]
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[Xlat(ry)] ← zero_extend(memword15+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Halfword Unsigned (Extended)**LHU****Format:** LHU ry, offset(rx)**MIPS16e****Purpose:**

To load a halfword from memory as an unsigned value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The contents of the halfword at the memory location specified by the effective address are zero-extended and loaded into GPR *ry*.

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:

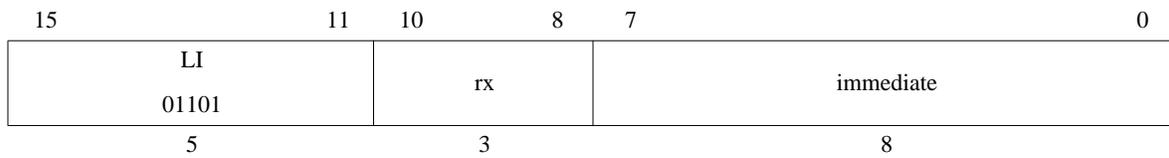
```

vAddr ← sign_extend(offset) + GPR[Xlat(rx)]
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[Xlat(ry)] ← zero_extend(memword15+8*byte..8*byte)

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Immediate**LI****Format:** LI *rx*, *immediate***MIPS16e****Purpose:**

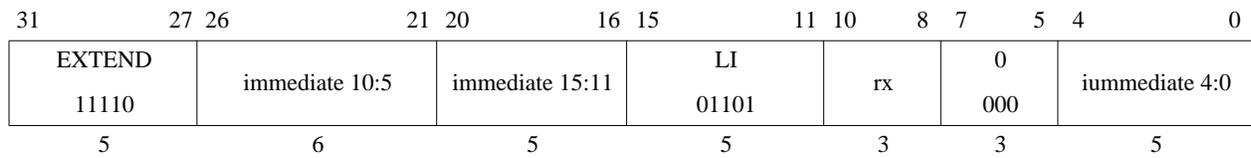
To load a constant into a GPR.

Description: $rx \leftarrow \text{immediate}$ The 8-bit *immediate* is zero-extended and then loaded into GPR *rx*.**Restrictions:**

None

Operation: $\text{GPR}[\text{Xlat}(rx)] \leftarrow \text{zero_extend}(\text{immediate})$ **Exceptions:**

None

Load Immediate (Extended)**LI****Format:** LI *rx*, *immediate***MIPS16e****Purpose:**

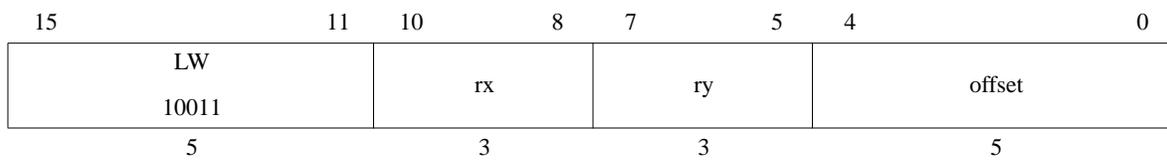
To load a constant into a GPR.

Description: $rx \leftarrow \text{immediate}$ The 16-bit *immediate* is zero-extended and then loaded into GPR *rx*.**Restrictions:**

None

Operation: $GPR[Xlat(rx)] \leftarrow \text{zero_extend}(\text{immediate})$ **Exceptions:**

None

Load Word**LW****Format:** LW *ry*, offset(*rx*)**MIPS16e****Purpose:**

To load a word from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 5-bit *offset* is shifted left 2 bits, zero-extended, then added to the contents of GPR *rx* to form the effective address. The contents of the word at the memory location specified by the effective address are loaded into GPR *ry*.

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:

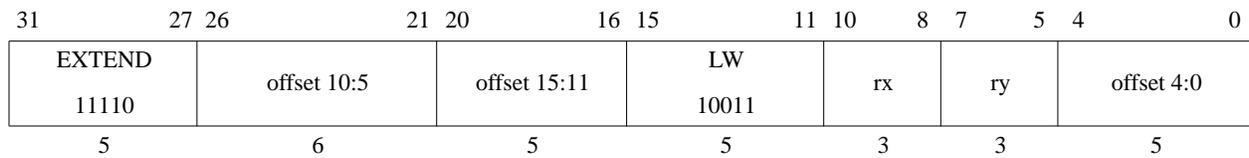
```

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

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Word (Extended)**LW****Format:** LW *ry*, offset(*rx*)**MIPS16e****Purpose:**

To load a word from memory as a signed value.

Description: $ry \leftarrow \text{memory}[rx + \text{offset}]$

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The contents of the word at the memory location specified by the effective address are loaded into GPR *ry*.

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:

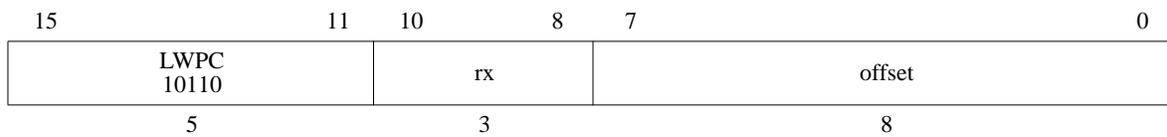
```

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

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error



Format: LW *rx*, *offset*(*pc*)

MIPS16e

Purpose:

To load a PC-relative word from memory as a signed value.

Description: $rx \leftarrow \text{memory}[PC + \text{offset}]$

The 8-bit *offset* is shifted left 2 bits, zero-extended, and added either to the address of the LW instruction or to the address of the jump instruction in whose delay slot the LW is executed. The 2 lower bits of this result are cleared to form the effective address. The contents of the 32-bit word at the memory location specified by the effective address are loaded into GPR *rx*.

Restrictions:

None

Operation:

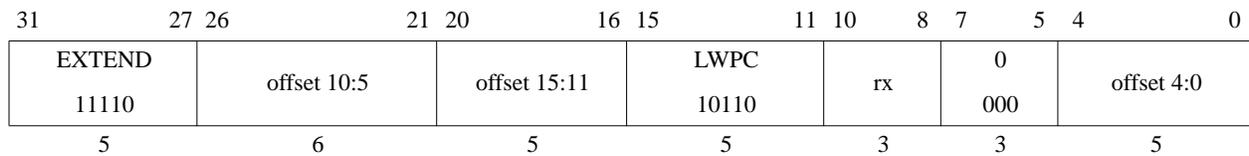
```

I-1: base_pc ← PC
I:   if not (JumpDelaySlot(PC)) then
      base_pc ← PC
    endif
vAddr ← (base_pcGPRLEN-1..2 + zero_extend(offset)) || 02
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, LOAD)
memword ← LoadMemory (CCA, WORD, pAddr, vAddr, DATA)
GPR[Xlat(rx)] ← memword

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error

Load Word (PC-Relative, Extended)**LW****Format:** LW rx, offset(pc)**MIPS16e****Purpose:**

To load a PC-relative word from memory as a signed value.

Description: $rx \leftarrow \text{memory}[\text{PC} + \text{offset}]$

The 16-bit *offset* is sign-extended and added either to the address of the LW instruction or to the address of the jump instruction in whose delay slot the LW is executed; this forms the effective address. Before the addition, the 2 lower bits of the instruction address are cleared. The contents of the 32-bit word at the memory location specified by the effective address are loaded into GPR *rx*.

Restrictions:

A PC-relative, extended LW may not be placed in the delay slot of a jump instruction.

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:

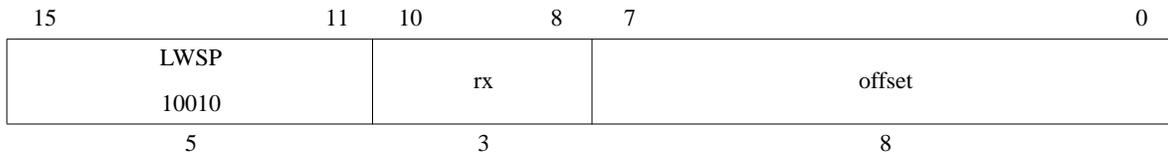
```

vAddr ← (PCGPREN-1..2 || 02) + sign_extend(offset)
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, LOAD)
memword ← LoadMemory(CCA, WORD, pAddr, vAddr, DATA)
GPR[Xlat(rx)] ← memword

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Word (SP-Relative)**LW****Format:** LW *rx*, *offset*(*sp*)**MIPS16e****Purpose:**

To load an SP-relative word from memory as a signed value.

Description: $rx \leftarrow \text{memory}[sp + \text{offset}]$

The 8-bit *offset* is shifted left 2 bits, zero-extended, then added to the contents of GPR 29 to form the effective address. The contents of the word at the memory location specified by the effective address are loaded into GPR *rx*.

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:

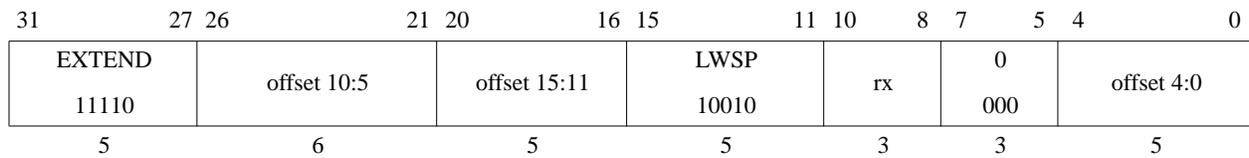
```

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[Xlat(ry)] ← memword

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Load Word (SP-Relative, Extended)**LW****Format:** LW rx, offset(sp)**MIPS16e****Purpose:**

To load an SP-relative word from memory as a signed value.

Description: $rx \leftarrow \text{memory}[sp + \text{offset}]$ The 16-bit *offset* is sign-extended and then added to the contents of GPR 29 to form the effective address. The contents of the word at the memory location specified by the effective address are loaded into GPR *rx*.**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:

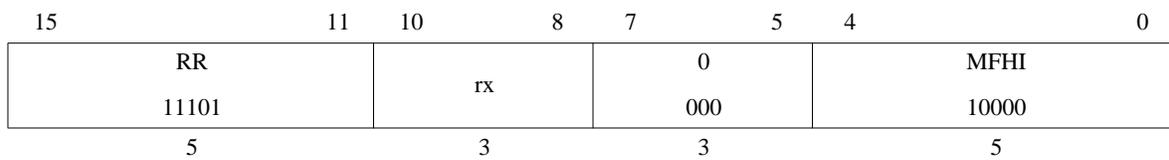
```

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

```

Exceptions:

TLB Refill, TLB Invalid, Bus Error, Address Error

Move From HI Register**MFHI****Format:** MFHI rx**MIPS16e****Purpose:**To copy the special purpose *HI* register to a GPR.**Description:** rx ← HIThe contents of special register *HI* are loaded into GPR *rx*.**Restrictions:**

None

Operation:

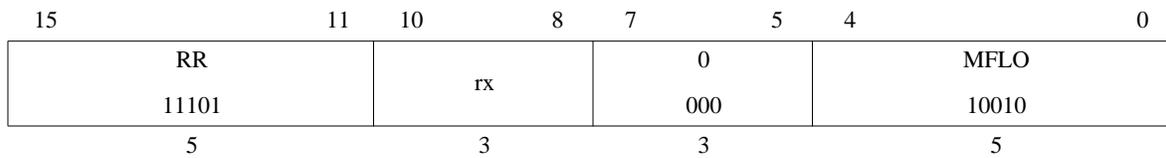
GPR[Xlat(rx)] ← HI

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.

Move From LO Register**MFLO****Format:** MFLO rx**MIPS16e****Purpose:**To copy the special purpose *LO* register to a GPR.**Description:** rx ← LOThe contents of special register *LO* are loaded into GPR *rx*.**Restrictions:**

None

Operation:

GPR[Xlat(rx)] ← 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.

15	11	10	8	7	5	4	3	2	0
I8	MOV32R			r32	r32	rz			
01100	101			2:0	4:3				
5	3			3	2	3			

Format: MOVE r32, rz

MIPS16e

Purpose:

To move the contents of a GPR to a GPR.

Description: $r32 \leftarrow rz$

The contents of GPR rz are moved into GPR r32, and r32 can specify any one of the 32 GPRs.

Restrictions:

None

Operation:

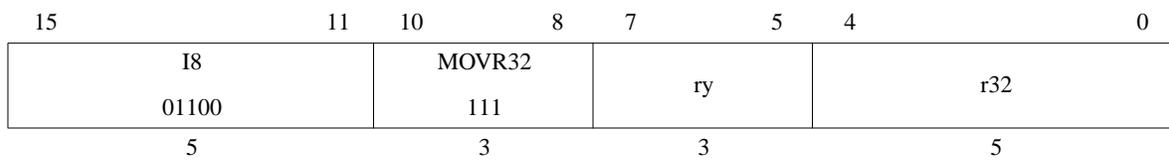
$GPR[r32] \leftarrow GPR[xlat(rz)]$

Exceptions:

None

Programming Notes:

move \$0, \$0, expressed as NOP, is the assembly idiom used to denote no operation.



Format: MOVE *ry*, *r32*

MIPS16e

Purpose:

To move the contents of a GPR to a GPR.

Description: $ry \leftarrow r32$

The contents of GPR *r32* are moved into GPR *ry*, and *r32* can specify any one of the 32 GPRs.

Restrictions:

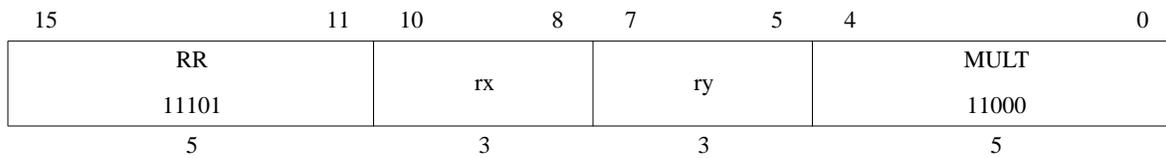
None

Operation:

$GPR[Xlat(ry)] \leftarrow GPR[r32]$

Exceptions:

None



Format: MULT *rx*, *ry*

MIPS16e

Purpose:

To multiply 32-bit signed integers.

Description: (LO, HI) $\leftarrow rx \times ry$

The 32-bit word value in GPR *rx* is multiplied by the 32-bit value in GPR *ry*, 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   $\leftarrow$  GPR[Xlat(rx)] * GPR[Xlat(ry)]
LO     $\leftarrow$  sign_extend(prod31..0)
HI     $\leftarrow$  sign_extend(prod63..32)

```

Exceptions:

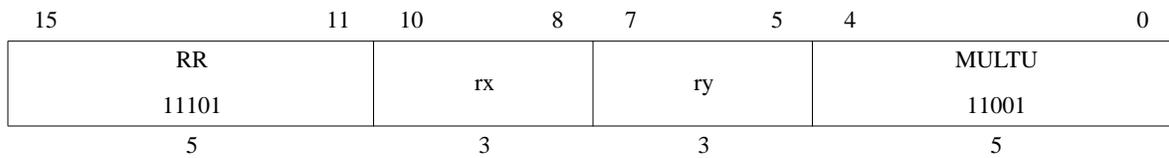
None

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.

Multiply Unsigned Word**MULTU****Format:** MULTU *rx*, *ry***MIPS16e****Purpose:**

To multiply 32-bit unsigned integers.

Description: $(LO, HI) \leftarrow rx \times ry$

The 32-bit word value in GPR *rx* is multiplied by the 32-bit value in GPR *ry*, 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[Xlat(rx)]) * (0 || GPR[Xlat(ry)])
LO ← sign_extend(prod31..0)
HI ← sign_extend(prod63..32)

```

Exceptions:

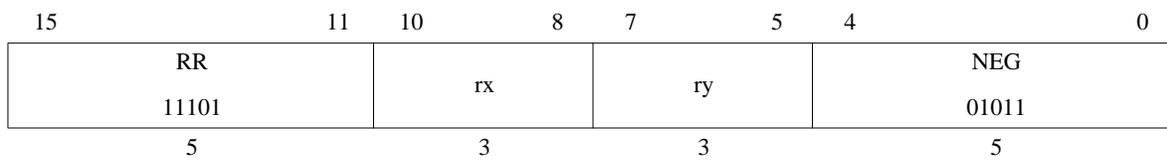
None

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.



Format: NEG *rx*, *ry*

MIPS16e

Purpose:

To negate an integer value.

Description: $rx \leftarrow 0 - ry$

The contents of GPR *ry* are subtracted from zero to form a 32-bit result. The result is placed in GPR *rx*.

Restrictions:

None

Operation:

```
temp ← 0 - GPR[Xlat(ry)]
GPR[Xlat(rx)] ← sign_extend(temp31..0)
```

Exceptions:

None

No Operation**NOP**

15		11	10		8	7		5	4	3	2		0
	I8			MOV32R			0		0		0		
	01100			101			000		00		000		
	5			3			3		2		3		

Format: NOP**MIPS16e Assembly Idiom****Purpose:**

To perform no operation.

Description:

NOP is the assembly idiom used to denote no operation. The actual instruction is interpreted by the hardware as MOVE \$0,\$16.

Restrictions:

None

Operation:

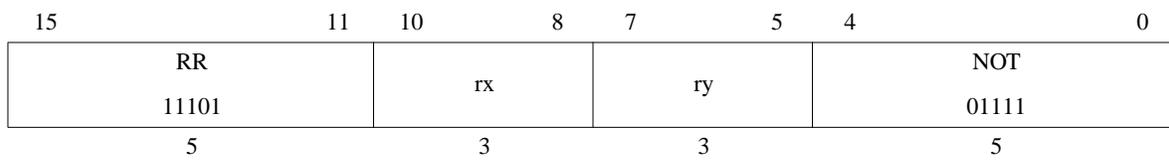
None

Exceptions:

None

Programming Notes:

The 0x6500 instruction word, which represents MOVE \$0,\$16, is the preferred NOP for software to use to fill jump delay slots and to pad out alignment sequences.



Format: NOT *rx*, *ry*

MIPS16e

Purpose:

To complement an integer valu

Description: $rx \leftarrow (\text{NOT } ry)$

The contents of GPR *ry* are bitwise-inverted and placed in GPR *rx*.

Restrictions:

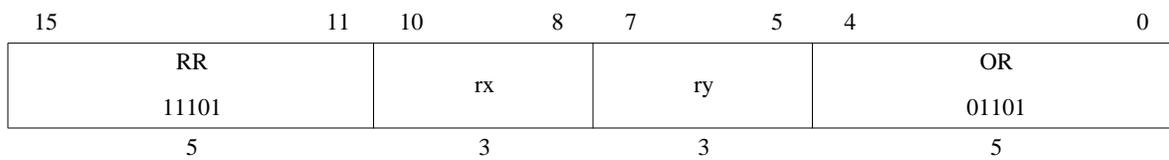
None

Operation:

$GPR[Xlat(rx)] \leftarrow (\text{not } GPR[Xlat(ry)])$

Exceptions:

None

Or**OR**

Format: OR *rx*, *ry*

MIPS16e

Purpose:

To do a bitwise logical OR.

Description: $rx \leftarrow rx \text{ OR } ry$

The contents of GPR *ry* are combined with the contents of GPR *rx* in a bitwise logical OR operation. The result is placed in GPR *rx*.

Restrictions:

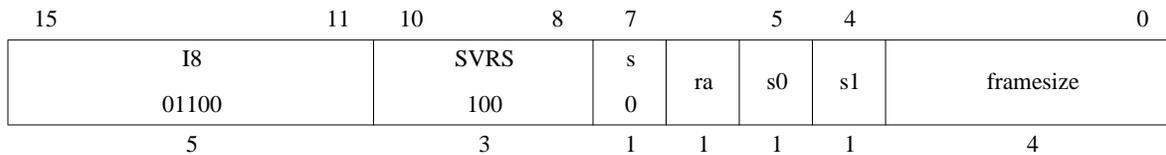
None

Operation:

$GPR[Xlat(rx)] \leftarrow GPR[Xlat(rx)] \text{ or } GPR[Xlat(ry)]$

Exceptions:

None



Format: RESTORE {ra,}{s0/s1/s0-1,}{framesize} (All args are optional)

MIPS16e

Purpose:

To deallocate a stack frame before exit from a subroutine, restoring return address and static registers, and adjusting stack

Description: $ra \leftarrow \text{Stack}$ and/or $GPR[17] \leftarrow \text{Stack}$ and/or $GPR[16] \leftarrow \text{Stack}$,
 $sp \leftarrow sp + (\text{framesize} * 8)$

Restore the ra and/or GPR 16 and/or GPR 17 (s0 and s1 in the MIPS ABI calling convention) registers from the stack if the corresponding ra, s0, or s1 bits of the instruction are set, and adjust the stack pointer by 8 times the framesize value. Registers are loaded from the stack assuming higher numbered registers are stored at higher stack addresses. A framesize value of 0 is interpreted as a stack adjustment of 128.

The opcode and function field describe a general save/restore operation, with the s fields as a variables. The individual instructions, RESTORE and SAVE have specific values for this variable.

Restrictions:

If either of the 2 least-significant bits of the stack pointer are not zero, and any of the ra, s0, or s1 bits are set, then an Address Error exception will occur.

Operation:

```

if framesize = 0 then
    temp ← GPR[29] + 128
else
    temp ← GPR[29] + (0 || (framesize << 3))
endif
temp2 ← temp
if ra = 1 then
    temp ← temp - 4
    GPR[31] ← VirtualMemory[temp]
endif
if s1 = 1 then
    temp ← temp - 4
    GPR[17] ← VirtualMemory[temp]
endif
if s0 = 1 then
    temp ← temp - 4
    GPR[16] ← VirtualMemory[temp]
endif
GPR[29] ← temp2

```

Exceptions:

TLB refill, TLB invalid, Address error, Bus Error

Programming Notes:

This instruction executes for a variable number of cycles and performs a variable number of loads from memory. A full restart of the sequence of operations will be performed on return from any exception taken during execution.

31	27 26	24 23	20 19	16 15	11 10	8 7	6 5	4 3	0	
EXTEND 11110	xsregs	framesize 7:4	aregs	I8 01100	SVRS 100	s 0	ra	s0	s1	framesize 3:0
5	3	4	4	5	3	1	1	1	1	4

Format: RESTORE {ra,}{sregs,}{aregs,}{framesize}(All arguments optional) **MIPS16e**

Purpose:

To deallocate a stack frame before exit from a subroutine, restoring return address and static registers from an extended static register set, and adjusting the stack

Description: ra ← Stack and/or GPR[18-23,30] ← Stack and/or GPR[17] ← Stack
and/or GPR[16] ← Stack and/or GPR[4-7] ← Stack, sp ← sp + (framesize * 8)

Restore the ra register from the stack if the ra bit is set in the instruction. Restore from the stack the number of registers in the set GPR[18-23,30] indicated by the value of the xsregs field. Restore from the stack GPR 16 and/or GPR 17 (s0 and s1 in the MIPS ABI calling convention) from the stack if the corresponding s0 and s1 bits of the instruction are set, restore from the stack the number of registers in the range GPR[4-7] indicated by the aregs field, and adjust the stack pointer by 8 times the 8-bit concatenated framesize value. Registers are loaded from the stack assuming higher numbered registers are stored at higher stack addresses.

Interpretation of the aregs Field

In the standard MIPS ABIs, GPR[4-7] are designated as argument passing registers, a0-a3. When they are so used, they must be saved on the stack at locations allocated by the caller of the routine being entered, but need not be restored on subroutine exit. In other MIPS16e calling sequences, however, it is possible that some of the registers GPR[4-7] need to be saved as static registers on the local stack instead of on the caller stack, and restored before return from the subroutine. The encoding used for the aregs field of an extended RESTORE instruction is the same as that used for the extended SAVE, but since argument registers can be ignored for the purposes of a RESTORE, only the registers treated as static need be handled. The following table shows the RESTORE encoding of the aregs field

<i>aregs</i> Encoding (binary)	Registers Restored as Static Registers
0 0 0 0	None
0 0 0 1	GPR[7]
0 0 1 0	GPR[6], GPR[7]
0 0 1 1	GPR[5], GPR[6], GPR[7]
1 0 1 1	GPR[4], GPR[5], GPR[6], GPR[7]
0 1 0 0	None
0 1 0 1	GPR[7]
0 1 1 0	GPR[6], GPR[7]
0 1 1 1	GPR[5], GPR[6], GPR[7]
1 0 0 0	None
1 0 0 1	GPR[7]
1 0 1 0	GPR[6], GPR[7]
1 1 0 0	None
1 1 0 1	GPR[7]
1 1 1 0	None
1 1 1 1	Reserved

Restrictions:

If either of the 2 least-significant bits of the stack pointer are not zero, and any of the *ra*, *s0*, *s1*, or *xsregs* fields are non-zero or the *aregs* field contains an encoding that implies a register load, then an Address Error exception will occur.


```
if astatic > 0 then
  temp ← temp - 4
  GPR[7] ← VirtualMemory[temp]
  if astatic > 1 then
    temp ← temp - 4
    GPR[6] ← VirtualMemory[temp]
    if astatic > 2 then
      temp ← temp - 4
      GPR[5] ← VirtualMemory[temp]
      if astatic > 3 then
        temp ← temp - 4
        GPR[4] ← VirtualMemory[temp]
      endif
    endif
  endif
endif
endif
GPR[29] ← temp2
```

Exceptions:

TLB refill, TLB invalid, Address error, Bus Error

Programming Notes:

This instruction executes for a variable number of cycles and performs a variable number of loads from memory. A full restart of the sequence of operations will be performed on return from any exception taken during execution.

Behavior of the processor is **UNPREDICTABLE** for Reserved values of *aregs*.

15	11	10	8	7	5	4	0
I8	SVRS		s	ra	s0	s1	framesize
01100	100		1	1	1	1	4
5	3		1	1	1	1	4

Format: SAVE {ra,}{s0/s1/s0-1,}{framesize} (All arguments are optional) **MIPS16e**

Purpose:

To set up a stack frame on entry to a subroutine, saving return address and static registers, and adjusting stack

Description: **stack** ← ra and/or **Stack** ← GPR[17] and/or **Stack** ← GPR[16],
 sp ← sp - (framesize * 8)

Save the *ra* and/or GPR 16 and/or GPR 17 (*s0* and *s1* in the MIPS ABI calling convention) on the stack if the corresponding *ra*, *s0*, and *s1* bits of the instruction are set, and adjust the stack pointer by 8 times the *framesize* value. Registers are stored with higher numbered registers at higher stack addresses. A *framesize* value of 0 is interpreted as a stack adjustment of 128.

The opcode and function field describe a general save/restore operation, with the *s* fields as a variables. The individual instructions, RESTORE and SAVE have specific values for this variable.

Restrictions:

If either of the 2 least-significant bits of the stack pointer are not zero, and any of the *ra*, *s0*, or *s1* bits are set, then an Address Error exception will occur.

Operation:

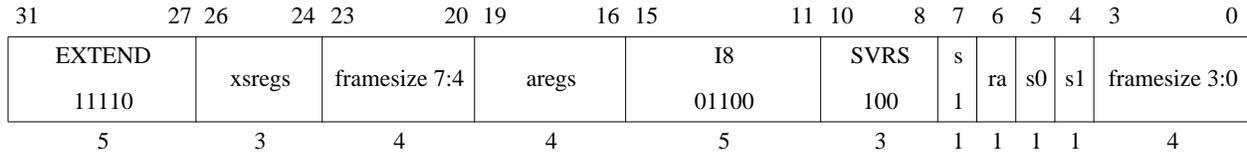
```
temp ← GPR[29]
if ra = 1 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[31]
endif
if s1 = 1 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[17]
endif
if s0 = 1 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[16]
endif
if framesize = 0 then
    temp ← GPR[29] - 128
else
    temp ← GPR[29] - (0 || (framesize << 3))
endif
GPR[29] ← temp
```

Exceptions:

TLB refill, TLB invalid, TLB modified, Address error, Bus Error

Programming Notes:

This instruction executes for a variable number of cycles and performs a variable number of stores to memory. A full restart of the sequence of operations will be performed on return from any exception taken during execution.



Format: SAVE {ra,}{sregs,}{aregs,}{framesize} (All arguments optional) **MIPS16e**

Purpose:

To set up a stack frame on entry to a subroutine, saving return address, static, and argument registers, and adjusting the stack

Description: **stack** ← ra and/or **Stack** ← GPR[18-23,30] and/or **stack** ← GPR[17] and/or **Stack** ← GPR[16] and/or **Stack** ← GPR[4-7], **sp** ← sp - (framesize * 8)

Save registers GPR[4-7] specified to be treated as incoming arguments by the *aregs* field. Save the ra register on the stack if the *ra* bit of the instruction is set. Save the number of registers in the set GPR[18-23, 30] indicated by the value of the *xsregs* field, and/or GPR 16 and/or GPR 17 (s0 and s1 in the MIPS ABI calling convention) on the stack if the corresponding *s0* and *s1* bits of the instruction are set. Save the number of registers in the range GPR[4-7] that are to be treated as static registers as indicated by the *aregs* field, and adjust the stack pointer by 8 times the 8-bit concatenated *framesize* value. Registers are stored with higher numbered registers at higher stack addresses.

Interpretation of the *aregs* Field

In the standard MIPS ABIs, GPR[4-7] are designated as argument passing registers, a0-a3. When they are so used, they must be saved on the stack at locations allocated by the caller of the routine being entered. In other MIPS16e calling sequences, however, it is possible that some of the registers GPR[4-7] will need to be saved as static registers on the local stack instead of on the caller stack. The encoding of the *aregs* field allows for 0-4 arguments, 0-4 statics, and for mixtures of the two. Registers are bound to arguments in ascending order, a0, a1, a2, and a3, and thus assigned to static values in the reverse order, GPR[7], GPR[6], GPR[5], and GPR[4]. The following table shows the encoding of the *aregs* field.

<i>aregs</i> Encoding (binary)	Registers Saved as Arguments	Registers Saved as Static Registers
0 0 0 0	None	None
0 0 0 1	None	GPR[7]
0 0 1 0	None	GPR[6], GPR[7]
0 0 1 1	None	GPR[5], GPR[6], GPR[7]
1 0 1 1	None	GPR[4], GPR[5], GPR[6], GPR[7]
0 1 0 0	a0	None
0 1 0 1	a0	GPR[7]
0 1 1 0	a0	GPR[6], GPR[7]
0 1 1 1	a0	GPR[5], GPR[6], GPR[7]
1 0 0 0	a0, a1	None
1 0 0 1	a0, a1	GPR[7]
1 0 1 0	a0, a1	GPR[6], GPR[7]
1 1 0 0	a0, a1, a2	None
1 1 0 1	a0, a1, a2	GPR[7]
1 1 1 0	a0, a1, a2, a3	None
1 1 1 1	Reserved	Reserved

Restrictions:

If either of the 2 least-significant bits of the stack pointer are not zero, and any of the *ra*, *s0*, *s1*, or *xsregs* fields are non-zero or the *aregs* field contains an value that implies a register store, then an Address Error exception will occur.

Operation:

```

temp ← GPR[29]
temp2 ← GPR[29]
case args of
  2#0000 2#0001 2#0010 2#0011 2#1011: args ← 0
  2#0100 2#0101 2#0110 2#0111: args ← 1
  2#1000 2#1001 2#1010: args ← 2
  2#1100 2#1101: args ← 3
  2#1110: args ← 4
  otherwise: UNPREDICTABLE
endcase
if args > 0 then
  VirtualMemory[temp] ← GPR[4]
  if args > 1 then
    VirtualMemory[temp + 4] ← GPR[5]
    if args > 2 then
      VirtualMemory[temp + 8] ← GPR[6]
      if args > 3 then
        VirtualMemory[temp + 12] ← GPR[7]
      endif
    endif
  endif
endif
if ra = 1 then
  temp ← temp - 4
  VirtualMemory[temp] ← GPR[31]
endif
if xsregs > 0 then
  if xsregs > 1 then
    if xsregs > 2 then
      if xsregs > 3 then
        if xsregs > 4 then
          if xsregs > 5 then
            if xsregs > 6 then
              temp ← temp - 4
              VirtualMemory[temp] ← GPR[30]
            endif
          endif
          temp ← temp - 4
          VirtualMemory[temp] ← GPR[23]
        endif
      endif
      temp ← temp - 4
      VirtualMemory[temp] ← GPR[22]
    endif
  endif
  temp ← temp - 4
  VirtualMemory[temp] ← GPR[21]
endif
temp ← temp - 4
VirtualMemory[temp] ← GPR[20]
endif
temp ← temp - 4
VirtualMemory[temp] ← GPR[19]
endif
temp ← temp - 4
VirtualMemory[temp] ← GPR[18]
endif

```

```

if s1 = 1 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[17]
endif
if s0 = 1 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[16]
endif
case aregs of
    2#0000 2#0100 2#1000 2#1100 2#1110: astatic ← 0
    2#0001 2#0101 2#1001 2#1101: astatic ← 1
    2#0010 2#0110 2#1010: astatic ← 2
    2#0011 2#0111: astatic ← 3
    2#1011: astatic ← 4
    otherwise: UNPREDICTABLE
endcase
if astatic > 0 then
    temp ← temp - 4
    VirtualMemory[temp] ← GPR[7]
    if astatic > 1 then
        temp ← temp - 4
        VirtualMemory[temp] ← GPR[6]
        if astatic > 2 then
            temp ← temp - 4
            VirtualMemory[temp] ← GPR[5]
            if astatic > 3 then
                temp ← temp - 4
                VirtualMemory[temp] ← GPR[4]
            endif
        endif
    endif
endif
temp ← temp2 - (0 || (framesize << 3))
GPR[29] ← temp

```

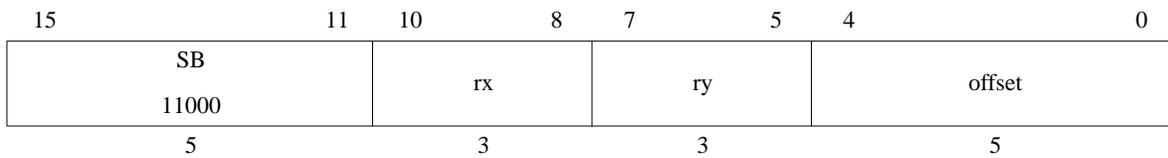
Exceptions:

TLB refill, TLB invalid, TLB modified, Address error, Bus Error

Programming Notes:

This instruction executes for a variable number of cycles and performs a variable number of stores to memory. A full restart of the sequence of operations will be performed on return from any exception taken during execution.

Behavior of the processor is **UNPREDICTABLE** for Reserved values of *aregs*.

Store Byte**SB****Format:** SB *ry*, offset(*rx*)**MIPS16e****Purpose:**

To store a byte to memory.

Description: memory[*rx* + offset] ← *ry*

The 5-bit *offset* is zero-extended, then added to the contents of GPR *rx* to form the effective address. The least-significant byte of GPR *ry* is stored at the effective address.

Restrictions:

None

Operation:

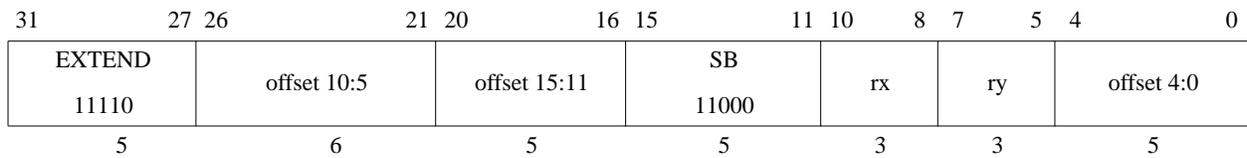
```

vAddr    ← zero_extend(offset) + GPR[Xlat(rx)]
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
pAddr    ← pAddr_PSIZE-1..2 || (pAddr_1..0 xor ReverseEndian2)
bytesel  ← vAddr_1..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

Store Byte (Extended)**SB****Format:** SB *ry*, offset(*rx*)**MIPS16e****Purpose:**

To store a byte to memory.

Description: memory[*rx* + offset] ← *ry*

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The least-significant byte of GPR *ry* is stored at the effective address.

Restrictions:

None

Operation:

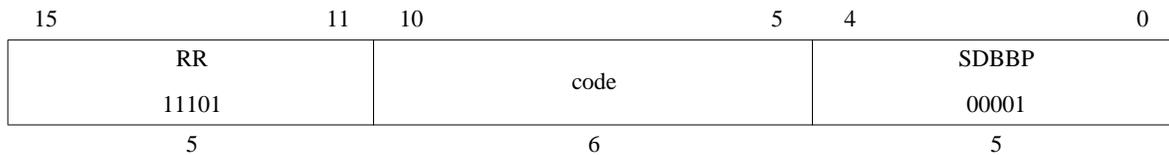
```

vAddr    ← sign_extend(offset) + GPR[Xlat(rx)]
(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



Format: SDBBP code

MIPS16e EJTAG

Purpose:

To cause a debug breakpoint exception

Description:

This instruction causes a debug exception, passing control to the debug exception handler. 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:

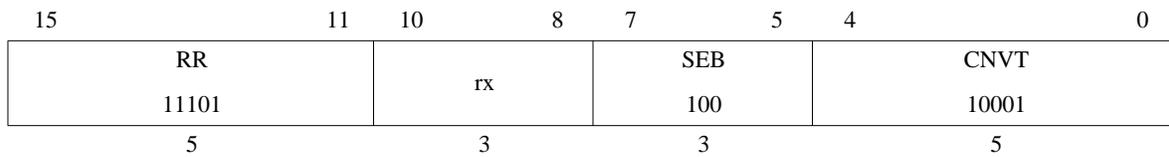
```

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

```

Exceptions:

Debug Breakpoint Exception



Format: SEB rx

MIPS16e

Purpose:

Sign-extend least significant byte in register rx.

Description: $rx \leftarrow \text{sign_extend}(rx_{7..0})$

The least significant byte of rx is sign-extended and the value written back to rx.

Restrictions:

None

Operation:

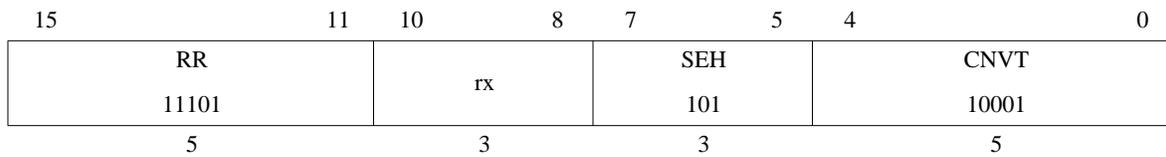
```
temp ← GPR[Xlat(rx)]
GPR[Xlat(rx)] ← sign_extend(temp7..0)
```

Exceptions:

None

Programming Notes:

None.



Format: SEH rx

MIPS16e

Purpose:

Sign-extend least significant word in register rx.

Description: $rx \leftarrow \text{sign_extend}(rx_{15..0})$;

The least significant halfword of rx is sign-extended and the value written back to rx.

Restrictions:

None.

Operation:

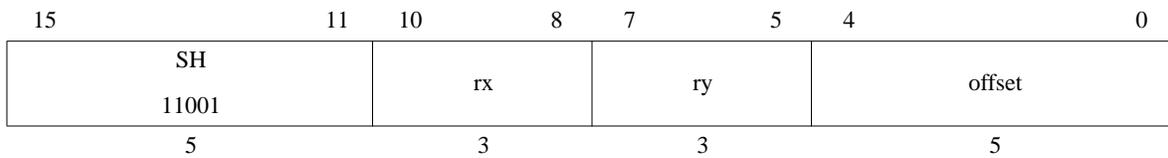
```
temp ← GPR[Xlat(rx)]
GPR[Xlat(rx)] ← sign_extend(temp15..0)
```

Exceptions:

None

Programming Notes:

None.



Format: SH *ry*, offset(*rx*)

MIPS16e

Purpose:

To store a halfword to memory.

Description: $\text{memory}[\text{rx} + \text{offset}] \leftarrow \text{ry}$

The 5-bit *offset* is shifted left 1 bit, zero-extended, and then added to the contents of GPR *rx* to form the effective address. The least-significant halfword of GPR *ry* is stored at 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:

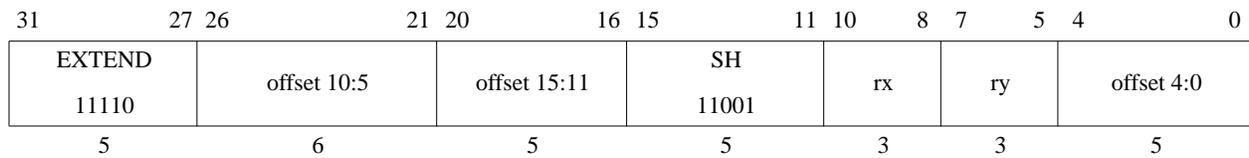
```

vAddr ← zero_extend(offset || 0) + GPR[Xlat(rx)]
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[Xlat(ry)]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, HALFWORD, dataword, pAddr, vAddr, DATA)

```

Exceptions:

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

Store Halfword (Extended)**SH****Format:** SH ry, offset(rx)**MIPS16e****Purpose:**

To store a halfword to memory.

Description: memory[rx + offset] ← ry

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The least-significant halfword of GPR *ry* is stored at 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 ← sign_extend(offset) + GPR[Xlat(rx)]
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[Xlat(ry)]31-8*bytesel..0 || 08*bytesel
StoreMemory (CCA, HALFWORD, dataword, pAddr, vAddr, DATA)

```

Exceptions:

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

15	11	10	8	7	5	4	2	1	0
SHIFT			rx	ry	sa			SLL	
00110								00	
5			3	3	3			2	

Format: SLL *rx*, *ry*, *sa*

MIPS16e

Purpose:

To execute a left-shift of a word by a fixed number of bits—1 to 8 bits.

Description: $rx \leftarrow ry \ll sa$

The 32-bit contents of GPR *ry* are shifted left, and zeros are inserted into the emptied low-order bits. The 3-bit *sa* field specifies the shift amount. A shift amount of 0 is interpreted as a shift amount of 8. The result is placed into GPR *rx*.

Restrictions:

None

Operation:

```

if sa = 03 then
  s ← 8
else
  s ← 02 || sa
endif
temp ← GPR[Xlat(ry)](31-s)..0 || 0s
GPR[Xlat(rx)] ← temp

```

Exceptions:

None

Shift Word Left Logical (Extended)
SLL

31	27 26	22 21	16 15	11 10	8 7	5 4	2 1 0
EXTEND	sa4:0	0	SHIFT	rx	ry	0	SLL
11110		000000	00110			000	00
5	5	6	5	3	3	3	2

Format: SLL *rx*, *ry*, *sa*
MIPS16e
Purpose:

To execute a left-shift of a word by a fixed number of bits—0 to 31 bits.

Description: $rx \leftarrow ry \ll sa$

The 32-bit contents of GPR *ry* are shifted left, and zeros are inserted into the emptied low-order bits. The 5-bit *sa* field specifies the shift amount. The result is placed into GPR *rx*.

Restrictions:

None

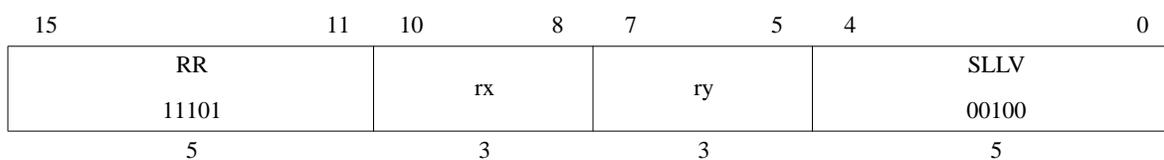
Operation:

$$s \leftarrow sa$$

$$temp \leftarrow GPR[Xlat(ry)]_{(31-s)..0} \parallel 0^s$$

$$GPR[Xlat(rx)] \leftarrow temp$$
Exceptions:

None

Shift Word Left Logical Variable**SLLV****Format:** SLLV *ry*, *rx***MIPS16e****Purpose:**

To execute a left-shift of a word by a variable number of bits.

Description: $ry \leftarrow ry \ll rx$ The 32-bit contents of GPR *ry* are shifted left, and zeros are inserted into the emptied low-order bits; the result word is placed back in GPR *ry*. The 5 low-order bits of GPR *rx* specify the shift amount.**Restrictions:**

None

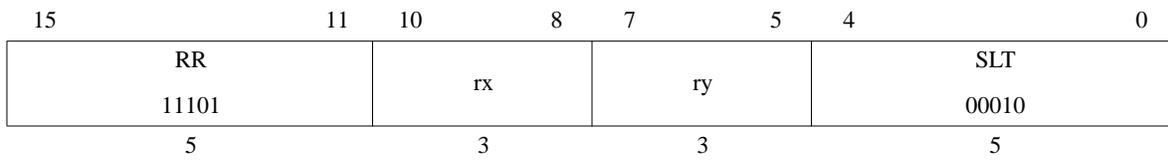
Operation:

$$s \leftarrow \text{GPR}[\text{Xlat}(rx)]_{4..0}$$

$$\text{temp} \leftarrow \text{GPR}[\text{Xlat}(ry)]_{(31-s)..0} \parallel 0^s$$

$$\text{GPR}[\text{Xlat}(ry)] \leftarrow \text{temp}$$
Exceptions:

None



Format: SLT *rx*, *ry*

MIPS16e

Purpose:

To record the result of a less-than comparison.

Description: $T \leftarrow (rx < ry)$

The contents of GPR *ry* are subtracted from the contents of GPR *rx*. Considering both quantities as signed integers, if the contents of GPR *rx* are less than the contents of GPR *ry*, the result is set to 1 (true); otherwise, the result is set to 0 (false). This result is placed into GPR 24.

Restrictions:

None

Operation:

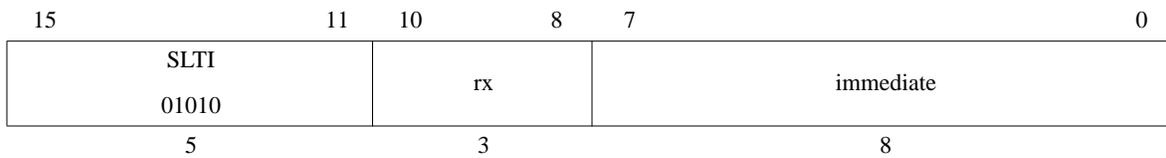
```

if GPR[Xlat(rx)] < GPR[Xlat(ry)] then
  GPR[24] ← 0GPRLEN-1 || 1
else
  GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None



Format: SLTI *rx*, *immediate*

MIPS16e

Purpose:

To record the result of a less-than comparison with a constant.

Description: $T \leftarrow (rx < immediate)$

The 8-bit *immediate* is zero-extended and subtracted from the contents of GPR *rx*. Considering both quantities as signed integers, if GPR *rx* is less than the zero-extended *immediate*, the result is set to 1 (true); otherwise, the result is set to 0 (false). The result is placed into GPR 24.

Restrictions:

None

Operation:

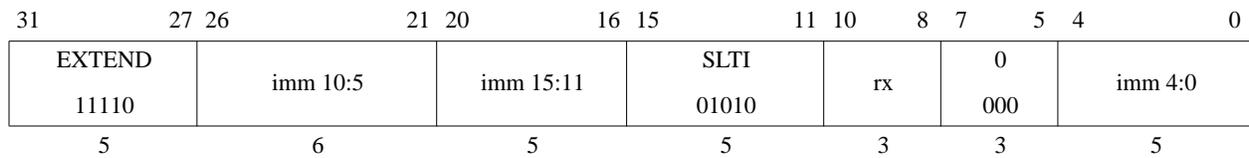
```

if GPR[Xlat(rx)] < zero_extend(immediate) then
  GPR[24] ← 0GPRLEN-1 || 1
else
  GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None

Set on Less Than Immediate (Extended)**SLTI****Format:** SLTI *rx*, *immediate***MIPS16e****Purpose:**

To record the result of a less-than comparison with a constant.

Description: $T \leftarrow (rx < immediate)$

The 16-bit *immediate* is sign-extended and subtracted from the contents of GPR *rx*. Considering both quantities as signed integers, if GPR *rx* is less than the sign-extended *immediate*, the result is set to 1 (true); otherwise, the result is set to 0 (false). The result is placed into GPR 24.

Restrictions:

None

Operation:

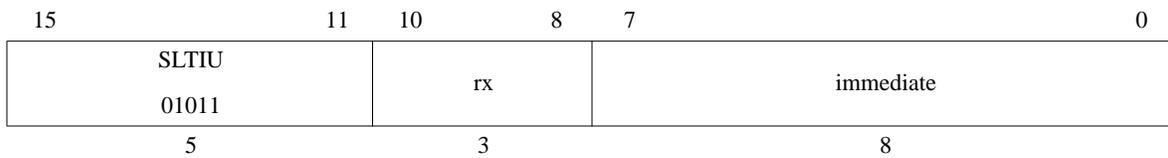
```

if GPR[Xlat(rx)] < sign_extend(immediate) then
  GPR[24] ← 0GPRLEN-1 || 1
else
  GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None

Set on Less Than Immediate Unsigned**SLTIU****Format:** SLTIU *rx*, *immediate***MIPS16e****Purpose:**

To record the result of an unsigned less-than comparison with a constant.

Description: $T \leftarrow (rx < immediate)$

The 8-bit *immediate* is zero-extended and subtracted from the contents of GPR *rx*. Considering both quantities as unsigned integers, if GPR *rx* is less than the zero-extended *immediate*, the result is set to 1 (true); otherwise, the result is set to 0 (false). The result is placed into GPR 24.

Restrictions:

None

Operation:

```

if (0 || GPR[Xlat(rx)]) < (0 || zero_extend(immediate)) then
  GPR[24] ← 0GPRLEN-1 || 1
else
  GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None

Set on Less Than Immediate Unsigned (Extended)

SLTIU

31	27 26	21 20	16 15	11 10	8 7	5 4	0
EXTEND 11110	imm 10:5	imm 15:11	SLTIU 01011	rx	0 000	imm 4:0	
5	6	5	5	3	3	5	

Format: SLTIU *rx*, *immediate***MIPS16e****Purpose:**

To record the result of an unsigned less-than comparison with a constant.

Description: $T \leftarrow (rx < immediate)$

The 16-bit *immediate* is sign-extended and subtracted from the contents of GPR *rx*. Considering both quantities as unsigned integers, if GPR *rx* is less than the sign-extended *immediate*, the result is set to 1 (true); otherwise, the result is set to 0 (false). The result is placed into GPR 24.

Restrictions:

None

Operation:

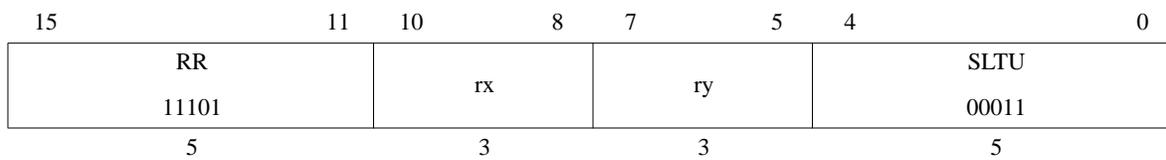
```

if (0 || GPR[Xlat(rx)]) < (0 || sign_extend(immediate)) then
    GPR[24] ← 0GPRLEN-1 || 1
else
    GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None



Format: SLTU *rx*, *ry*

MIPS16e

Purpose:

To record the result of an unsigned less-than comparison.

Description: $T \leftarrow (rx < ry)$

The contents of GPR *ry* are subtracted from the contents of GPR *rx*. Considering both quantities as unsigned integers, if the contents of GPR *rx* are less than the contents of GPR *ry*, set the result to 1 (true); otherwise, set the result to 0 (false). The result is placed into GPR 24.

Restrictions:

None

Operation:

```

if (0 || GPR[Xlat(rx)]) < (0 || GPR[Xlat(ry)]) then
  GPR[24] ← 0GPRLEN-1 || 1
else
  GPR[24] ← 0GPRLEN
endif

```

Exceptions:

None

15	11	10	8	7	5	4	2	1	0
SHIFT			rx	ry	sa			SRA	
00110								11	
5			3	3	3			2	

Format: SRA *rx*, *ry*, *sa*

MIPS16e

Purpose:

To execute an arithmetic right-shift of a word by a fixed number of bits—1 to 8 bits.

Description: $rx \leftarrow ry \gg sa$ (arithmetic)

The 32-bit contents of GPR *ry* are shifted right, and the sign bit is replicated into the emptied high-order bits. The 3-bit *sa* field specifies the shift amount. A shift amount of 0 is interpreted as a shift amount of 8. The result is placed into GPR *rx*.

Restrictions:

None

Operation:

```

s ← 02 || sa
if (s = 0) then
    s ← 8
endif
temp ← (GPR[Xlat(ry)]31)s || GPR[Xlat(ry)]31..s
GPR[Xlat(rx)] ← temp

```

Exceptions:

None

Shift Word Right Arithmetic (Extended)

SRA

31	27 26	22 21	16 15	11 10	8 7	5 4	2 1 0
EXTEND 11110	sa4:0	0 000000	SHIFT 00110	rx	ry	0 000	SRA 11
5	5	6	5	3	3	3	2

Format: SRA *rx*, *ry*, *sa*

MIPS16e

Purpose:

To execute an arithmetic right-shift of a word by a fixed number of bits—0 to 31bits.

Description: $rx \leftarrow ry \gg sa$ (arithmetic)

The 32-bit contents of GPR *ry* are shifted right, and the sign bit is replicated into the emptied high-order bits. The 5-bit *sa* field specifies the shift amount. The result is placed into GPR *rx*.

Restrictions:

None

Operation:

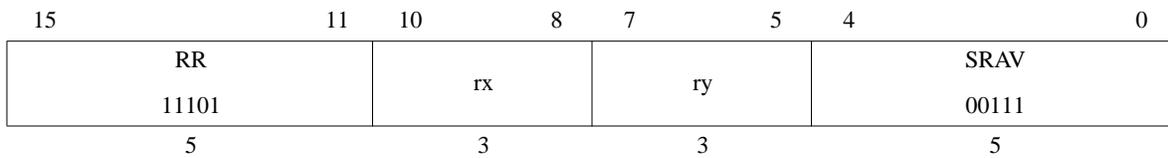
```

s ← sa
temp ← (GPR[Xlat(ry)]31)s || GPR[Xlat(ry)]31..s
GPR[Xlat(rx)] ← sign_extend(temp31..0)

```

Exceptions:

None

Shift Word Right Arithmetic Variable**SRAV****Format:** SRAV *ry*, *rx***MIPS16e****Purpose:**

To execute an arithmetic right-shift of a word by a variable number of bits.

Description: $ry \leftarrow ry \gg rx$ (arithmetic)

The 32-bit contents of GPR *ry* are shifted right, and the sign bit is replicated into the emptied high-order bits; the word result is placed back in GPR *ry*. The 5 low-order bits of GPR *rx* specify the shift amount.

Restrictions:

None

Operation:

$$s \leftarrow \text{GPR}[\text{Xlat}(rx)]_{4..0}$$

$$\text{temp} \leftarrow (\text{GPR}[\text{Xlat}(ry)]_{31})^s \parallel \text{GPR}[\text{Xlat}(ry)]_{31..s}$$

$$\text{GPR}[\text{Xlat}(ry)] \leftarrow \text{temp}$$
Exceptions:

None

15	11	10	8	7	5	4	2	1	0
SHIFT			rx	ry	sa			SRL	
00110								10	
5			3	3	3			2	

Format: SRL *rx*, *ry*, *sa*

MIPS16e

Purpose:

To execute a logical right-shift of a word by a fixed number of bits—1 to 8 bits.

Description: $rx \leftarrow ry \gg sa$ (logical)

The 32-bit contents of GPR *ry* are shifted right, and zeros are inserted into the emptied high-order bits. The 3-bit *sa* field specifies the shift amount. A shift amount of 0 is interpreted as a shift amount of 8. The result is placed into GPR *rx*.

Restrictions:

None

Operation:

```

if sa = 03 then
  s ← 8
else
  s ← 02 || sa
endif
temp ← 0s || GPR[Xlat(ry)]31..s
GPR[Xlat(rx)] ← temp

```

Exceptions:

None

Shift Word Right Logical (Extended)

SRL

31	27 26	22 21	16 15	11 10	8 7	5 4	2 1 0
EXTEND 11110	sa4:0	0 000000	SHIFT 00110	rx	ry	0 000	SRL 10
5	5	6	5	3	3	3	2

Format: SRL *rx*, *ry*, *sa*

MIPS16e

Purpose:

To execute a logical right-shift of a word by a fixed number of bits—0 to 31 bits.

Description: $rx \leftarrow ry \gg sa$ (logical)

The 32-bit contents of GPR *ry* are shifted right, and zeros are inserted into the emptied high-order bits. The 5-bit *sa* field specifies the shift amount. The result is placed into GPR *rx*.

Restrictions:

None

Operation:

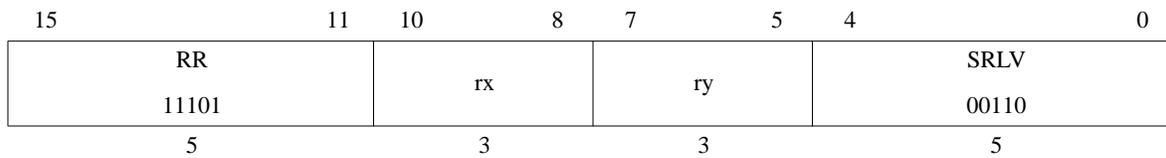
```

s ← sa
temp ← 0s || GPR[Xlat(ry)]31..s
GPR[Xlat(rx)] ← stemp

```

Exceptions:

None

Shift Word Right Logical Variable**SRLV****Format:** SRLV *ry*, *rx***MIPS16e****Purpose:**

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

Description: $ry \leftarrow ry \gg rx$ (logical)The 32-bit contents of GPR *ry* are shifted right, and zeros are inserted into the emptied high-order bits; the word result is placed back in GPR *ry*. The 5 low-order bits of GPR *rx* specify the shift amount.**Restrictions:**

None

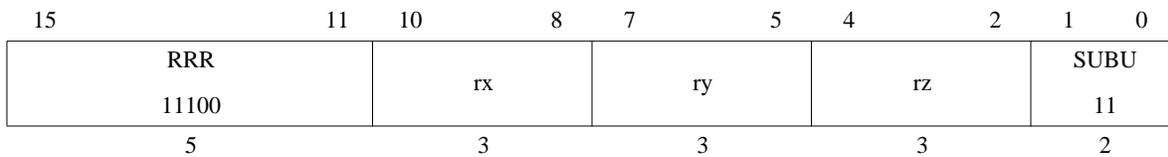
Operation:

$$s \leftarrow \text{GPR}[\text{Xlat}(rx)]_{4..0}$$

$$\text{temp} \leftarrow 0^s \parallel \text{GPR}[\text{Xlat}(ry)]_{31..s}$$

$$\text{GPR}[\text{Xlat}(ry)] \leftarrow \text{temp}$$
Exceptions:

None

Subtract Unsigned Word**SUBU****Format:** SUBU *rz*, *rx*, *ry***MIPS16e****Purpose:**

To subtract 32-bit integers.

Description: $rz \leftarrow rx - ry$ The 32-bit word value in GPR *ry* is subtracted from the 32-bit value in GPR *rx* and the 32-bit arithmetic result is placed into GPR *rz*.

No integer overflow exception occurs under any circumstances.

Restrictions:**None****Operation:**

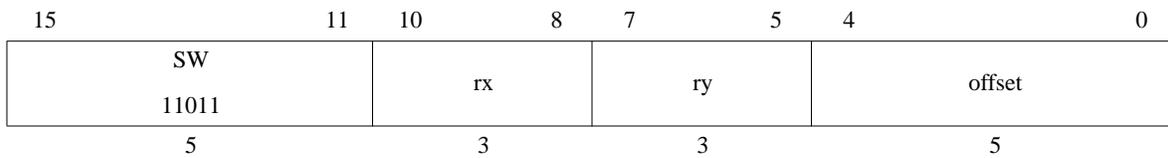
$$\text{temp} \leftarrow \text{GPR}[\text{Xlat}(rx)] - \text{GPR}[\text{Xlat}(ry)]$$

$$\text{GPR}[\text{Xlat}(rz)] \leftarrow \text{sign_extend}(\text{temp}31..0)$$
Exceptions:

None

Programming Notes:

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



Format: `SW ry, offset(rx)`

MIPS16e

Purpose:

To store a word to memory.

Description: `memory[rx + offset] ← ry`

The 5-bit *offset* is shifted left 2 bits, zero-extended, and then added to the contents of GPR *rx* to form the effective address. The contents of GPR *ry* are stored at the effective address.

Restrictions:

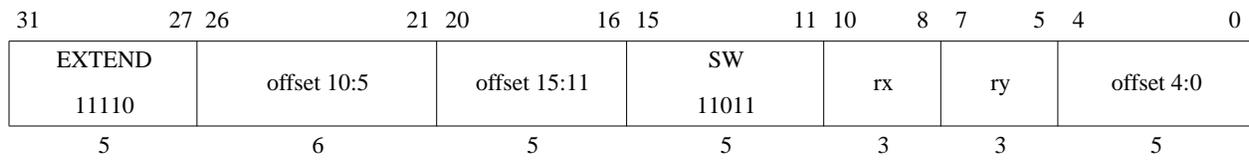
The effective address must be naturally-aligned. If either of the 2 least-significant bits of the address is non-zero, an Address Error exception occurs.

Operation:

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

Exceptions:

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

Store Word (Extended)**SW****Format:** SW ry, offset(rx)**MIPS16e****Purpose:**

To store a word to memory.

Description: memory[rx + offset] ← ry

The 16-bit *offset* is sign-extended and then added to the contents of GPR *rx* to form the effective address. The contents of GPR *ry* are stored at 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:

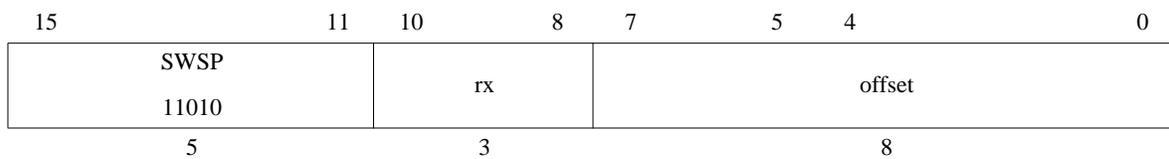
```

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

```

Exceptions:

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

Store Word rx (SP-Relative)**SW****Format:** SW rx, offset(sp)**MIPS16e****Purpose:**

To store an SP-relative word to memory.

Description: $\text{memory}[\text{sp} + \text{offset}] \leftarrow \text{rx}$

The 8-bit *offset* is shifted left 2 bits, zero-extended, and then added to the contents of GPR 29 to form the effective address. The contents of GPR *rx* are stored at 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:

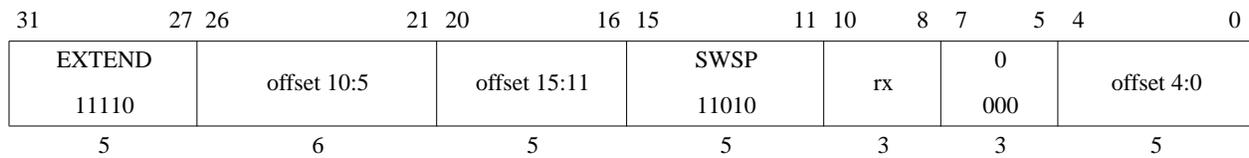
```

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

```

Exceptions:

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

Store Word rx (SP-Relative, Extended)**SW****Format:** SW rx, offset(sp)**MIPS16e****Purpose:**

To store an SP-relative word to memory.

Description: memory[sp + offset] ← rx

The 16-bit *offset* is sign-extended and then added to the contents of GPR 29 to form the effective address. The contents of GPR *rx* are stored at the effective address.

Restrictions:

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

Operation:

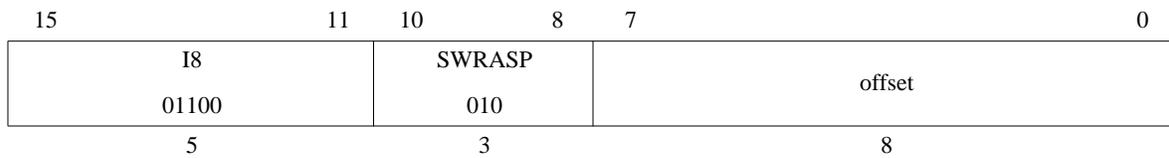
```

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

```

Exceptions:

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



Format: `SW ra, offset(sp)`

MIPS16e

Purpose:

To store register *ra* SP-relative to memory.

Description: `memory[sp + offset] ← ra`

The 8-bit *offset* is shifted left 2 bits, zero-extended, and then added to the contents of GPR 29 to form the effective address. The contents of GPR 31 are stored at 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:

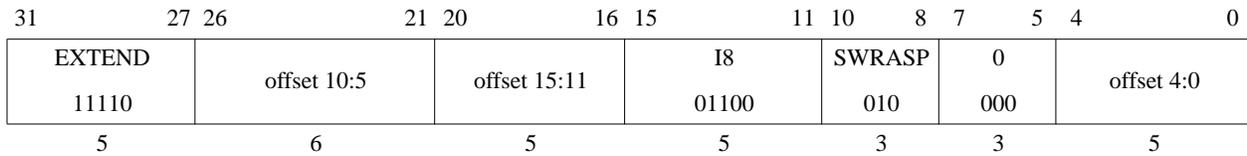
```

vAddr ← zero_extend(offset || 02) + GPR[29]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation(vAddr, DATA, STORE)
dataword ← GPR[31]
StoreMemory(CCA, WORD, dataword, pAddr, vAddr, DATA)

```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error

Store Word ra(SP-Relative, Extended)**SW****Format:** SW ra, offset(sp)**MIPS16e****Purpose:**To store register *ra* SP-relative to memory.**Description:** memory[sp + offset] ← ra

The 16-bit *offset* is sign-extended and then added to the contents of GPR 29 to form the effective address. The contents of GPR 31 are stored at 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:

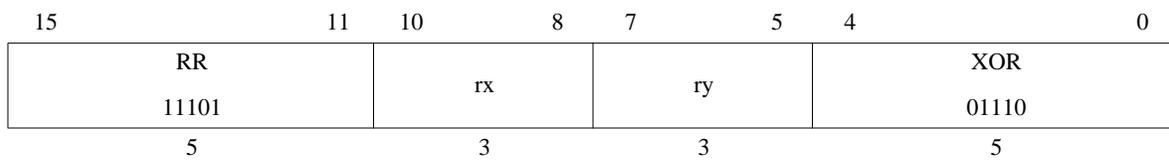
```

vAddr ← sign_extend(offset) + GPR[29]
if vAddr1..0 ≠ 02 then
    SignalException(AddressError)
endif
(pAddr, CCA) ← AddressTranslation (vAddr, DATA, STORE)
dataword ← GPR[31]
StoreMemory (CCA, WORD, dataword, pAddr, vAddr, DATA)

```

Exceptions:

TLB Refill, TLB Invalid, TLB Modified, Address Error

Exclusive OR**XOR****Format:** XOR *rx*, *ry***MIPS16e****Purpose:**

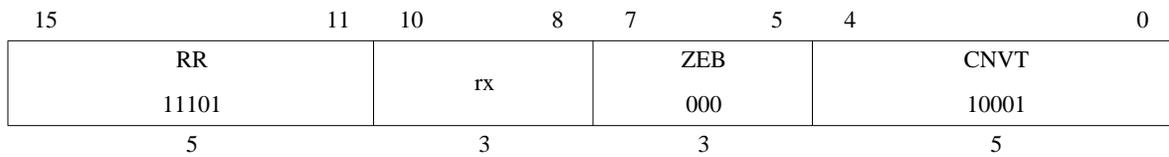
To do a bitwise logical Exclusive OR.

Description: $rx \leftarrow rx \text{ XOR } ry$ The contents of GPR *ry* are combined with the contents of GPR *rx* in a bitwise Exclusive OR operation. The result is placed in GPR *rx*.**Restrictions:**

None

Operation: $GPR[Xlat(rx)] \leftarrow GPR[Xlat(rx)] \text{ xor } GPR[Xlat(ry)]$ **Exceptions:**

None



Format: ZEB rx

MIPS16e

Purpose:

Zero-extend least significant byte in register rx.

Description: $rx \leftarrow \text{zero_extend}(rx_{7..0});$

The least significant byte of rx is zero-extended and the value written back to rx.

Restrictions:

None

Operation:

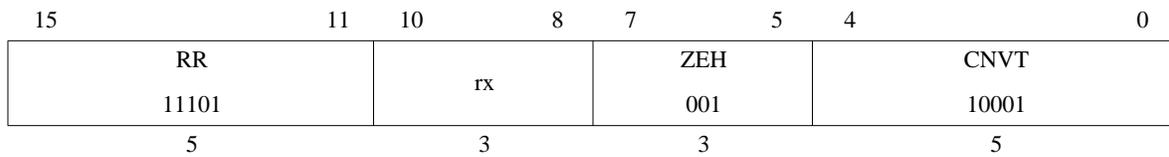
```
temp ← GPR[Xlat(rx)]
GPR[Xlat(rx)] ← 0 || temp7..0
```

Exceptions:

None

Programming Notes:

None.



Format: ZEH rx

MIPS16e

Purpose:

Zero-extend least significant halfword in register rx.

Description: $rx \leftarrow \text{zero_extend}(rx_{15..0});$

The least significant halfword of rx is zero-extended and the value written back to rx.

Restrictions:

None

Operation:

```
temp ← GPR[Xlat(rx)]
GPR[Xlat(rx)] ← 0 || temp15..0
```

Exceptions:

None

Programming Notes:

None.

Revision History

Revision	Date	Description
0.90	November 1, 2000	External review copy of reorganized and updated architecture documentation.
		Changes in this revision:
0.91	November 15, 2000	<ul style="list-style-type: none"> • Correct table 3-10 description of branch instructions (branches really are implemented in the 32-bit architecture and are extensible) • Correct the pseudo code for all MIPS16 branches - the offset value should be added to the address of the instruction following the branch, not the branch itself.
		Changes in this revision:
0.92	December 15, 2000	<ul style="list-style-type: none"> • Add missing I8_MOVER32 instruction format.
		Changes in this revision:
0.93	January 25, 2001	<ul style="list-style-type: none"> • Correct minor typos in the previous version. • Add the 32-bit MIPS version of JALX and update the instruction descriptions of JAL and JALX.
0.95	March 12, 2001	Document cleanup for next external release.
		Changes in this revision:
0.96	November 12, 2001	<ul style="list-style-type: none"> • Declassify the MIPS32 Architecture for Programmers volume. • Fix PDF bookmarks for the MIPS16 instructions. • Fix formatting in instruction translation section. • Correct the description of the shift count for extended SRA and SLL. • Change all uses of “MIPS16” to “MIPS16e”.