MIPS® Architecture for Programmers Volume IV-e: MIPS® DSP Module for MIPS32™ Architecture

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Chapter 1

About This Book

The MIPS® DSP Module for MIPS32™ Architecture comes as part of a multi-volume set.

- Volume I-A describes conventions used throughout the document set, and provides an introduction to the MIPS32® Architecture
- Volume I-B describes conventions used throughout the document set, and provides an introduction to the microMIPS™ Architecture
- Volume II-A provides detailed descriptions of each instruction in the MIPS32® instruction set
- Volume II-B provides detailed descriptions of each instruction in the microMIPS32™ instruction set
- Volume III describes the MIPS32® and microMIPS32™ Privileged Resource Architecture which defines and governs the behavior of the privileged resources included in a MIPS® processor implementation
- Volume IV-a describes the MIPS16e™ Application-Specific Extension to the MIPS32® Architecture. Beginning with Release 3 of the Architecture, microMIPS is the preferred solution for smaller code size. Release 6 removes MIPS16e: MIPS16e cannot be implemented with Release 6.
- Volume IV-b describes the MDMX™ Application-Specific Extension to the MIPS64® Architecture and microMIPS64™. With Release 5 of the Architecture, MDMX is deprecated. MDMX and MSA can not be implemented at the same time. Release 6 removes MDMX: MDMX cannot be implemented with Release 6.
- Volume IV-c describes the MIPS-3D® Application-Specific Extension to the MIPS® Architecture. Release 6 removes MIPS-3D: MIPS-3D cannot be implemented with Release 6.
- Volume IV-d describes the SmartMIPS®Application-Specific Extension to the MIPS32® Architecture and the microMIPS32™ Architecture . Release 6 removes SmartMIPS: SmartMIPS cannot be implemented with Release 6, neither MIPS32 Release 6 nor MIPS64 Release 6.
- Volume IV-e describes the MIPS® DSP Module to the MIPS® Architecture.
- Volume IV-f describes the MIPS® MT Module to the MIPS® Architecture
- Volume IV-h describes the MIPS® MCU Application-Specific Extension to the MIPS® Architecture
- Volume IV-i describes the MIPS® Virtualization Module to the MIPS® Architecture
- Volume IV-j describes the MIPS® SIMD Architecture Module to the MIPS® Architecture

1.1 Typographical Conventions

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

1.1.1 Italic Text

- is used for *emphasis*
- is used for *bits*, *fields*, and *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* and *D*
- is used for the memory access types, such as *cached* and *uncached*

1.1.2 Bold Text

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

1.1.3 Courier Text

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

1.2 UNPREDICTABLE and UNDEFINED

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

1.2.1 UNPREDICTABLE

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

UNPREDICTABLE results or operations have several implementation restrictions:

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

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

1.2.2 UNDEFINED

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

UNDEFINED operations or behavior has one implementation restriction:

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

1.2.3 UNSTABLE

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

UNSTABLE values have one implementation restriction:

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

1.3 Special Symbols in Pseudocode Notation

In this book, algorithmic descriptions of an operation are described using a high-level language pseudocode 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
♦	Assignment
=, …	Tests for equality and inequality
||	Bit string concatenation
x^y	A *y*-bit string formed by *y* copies of the single-bit value *x*
b#n	A constant value *n* in base *b*. For instance 10#100 represents the decimal value 100, 2#100 represents the binary value 100 (decimal 4), and 16#100 represents the hexadecimal value 100 (decimal 256). If the "b#" prefix is omitted, the default base is 10.
0bn	A constant value *n* in base *2*. For instance 0b100 represents the binary value 100 (decimal 4).
0xn	A constant value *n* in base *16*. For instance 0x100 represents the hexadecimal value 100 (decimal 256).
$x_{y\ z}$	Selection of bits *y* through *z* of bit string *x*. Little-endian bit notation (rightmost bit is 0) is used. If *y* is less than *z*, this expression is an empty (zero length) bit string.
x.bit[y]	Bit *y* of bitstring *x*. Alternative to the traditional MIPS notation x_y.
x.bits[y..z]	Selection of bits *y* through *z* of bit string *x*. Alternative to the traditional MIPS notation $x_{y\ z}$.

Table 1.1 Symbols Used in Instruction Operation Statements (Continued)

Symbol	Meaning
x.byte[y]	Byte *y* of bitstring *x*. Equivalent to the traditional MIPS notation $x_{8*y+7\ 8*y}$.
x.bytes[y..z]	Selection of bytes *y* through *z* of bit string *x*. Alternative to the traditional MIPS notation $x_{8*y+7\ 8*z}$
x halfword[y] x.word[i] x.doubleword[i]	Similar extraction of particular bitfields (used in e.g., MSA packed SIMD vectors).
x.bit31, x.byte0, etc.	Examples of abbreviated form of x.bit[y], etc. notation, when y is a constant.
x fieldy	Selection of a named subfield of bitstring *x*, typically a register or instruction encoding. More formally described as “Field y of register x”. For example, FIR.D = “the D bit of the Coprocessor 1 Floating-point Implementation Register (FIR)”.
+, −	2’s complement or floating point arithmetic: addition, subtraction
*, ∞	2’s complement or floating point multiplication (both used for either)
div	2’s complement integer division
mod	2’s complement modulo
/	Floating point division
<	2’s complement less-than comparison
>	2’s complement greater-than comparison
≤	2’s complement less-than or equal comparison
	2’s complement greater-than or equal comparison
nor	Bitwise logical NOR
xor	Bitwise logical XOR
and	Bitwise logical AND
or	Bitwise logical OR
not	Bitwise inversion
&&	Logical (non-Bitwise) AND
<<	Logical Shift left (shift in zeros at right-hand-side)
>>	Logical Shift right (shift in zeros at left-hand-side)
GPRLEN	The length in bits (32 or 64) of the CPU general-purpose registers
GPR[x]	CPU general-purpose register *x*. The content of *GPR[0]* is always zero. In Release 2 of the Architecture, GPR[x] is a short-hand notation for $SGPR[\ SRSCtl_{CSS},\ x]$.
SGPR[s,x]	In Release 2 of the Architecture and subsequent releases, multiple copies of the CPU general-purpose registers may be implemented. *SGPR[s,x]* refers to GPR set *s*, register *x*.
FPR[x]	Floating Point operand register *x*
FCC[CC]	Floating Point condition code CC. *FCC[0]* has the same value as *COC[1]*. Release 6 removes the floating point condition codes.
FPR[x]	Floating Point (Coprocessor unit 1), general register *x*
CPR[z,x,s]	Coprocessor unit *z*, general register *x*, select *s*
CP2CPR[x]	Coprocessor unit 2, general register *x*
CCR[z,x]	Coprocessor unit *z*, control register *x*
CP2CCR[x]	Coprocessor unit 2, control register *x*

Table 1.1 Symbols Used in Instruction Operation Statements (Continued)

Symbol	Meaning
COC[z]	Coprocessor unit *z* condition signal
Xlat[x]	Translation of the MIPS16e GPR number *x* into the corresponding 32-bit GPR number
BigEndianMem	Endian mode as configured at chip reset (0 → Little-Endian, 1 → Big-Endian). Specifies the endianness of the memory interface (see LoadMemory and StoreMemory pseudocode function descriptions) and the endianness of Kernel and Supervisor mode execution.
BigEndianCPU	The endianness for load and store instructions (0 → Little-Endian, 1 → Big-Endian). In User mode, this endianness may be switched by setting the *RE* bit in the *Status* register. Thus, BigEndianCPU may be computed as (BigEndianMem XOR ReverseEndian).
ReverseEndian	Signal to reverse the endianness of load and store instructions. This feature is available in User mode only, and is implemented by setting the *RE* bit of the *Status* register. Thus, ReverseEndian may be computed as (SR_{RE} and User mode).
LLbit	Bit of **virtual** state used to specify operation for instructions that provide atomic read-modify-write. *LLbit* is set when a linked load occurs and is tested by the conditional store. It is cleared, during other CPU operation, when a store to the location would no longer be atomic. In particular, it is cleared by exception return instructions.
I:, **I+n**:, **I-n**:	This occurs as a prefix to *Operation* 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**. The effect of pseudocode statements for the current instruction labeled **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.
PC	The *Program Counter* value. During the instruction time of an instruction, this is the address of the instruction word. The address of the instruction that occurs during the next instruction time is determined by assigning a value to *PC* during an instruction time. If no value is assigned to *PC* during 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 *PC* during the instruction time of the instruction in the branch delay slot. In the MIPS Architecture, the PC value is only visible indirectly, such as when the processor stores the restart address into a GPR on a jump-and-link or branch-and-link instruction, or into a Coprocessor 0 register on an exception. Release 6 adds PC-relative address computation and load instructions. The PC value contains a full -bit address, all of which are significant during a memory reference.

Table 1.1 Symbols Used in Instruction Operation Statements (Continued)

Symbol	Meaning
ISA Mode	In processors that implement the MIPS16e Application Specific Extension or the microMIPS base architectures, the *ISA Mode* is a single-bit register that determines in which mode the processor is executing, as follows: **Encoding** / **Meaning** 0 — The processor is executing 32-bit MIPS instructions 1 — The processor is executing MIIPS16e or microMIPS instructions In the MIPS Architecture, the *ISA Mode* value is only visible indirectly, such as when the processor stores a combined value of the upper bits of PC and the *ISA Mode* into a GPR on a jump-and-link or branch-and-link instruction, or into a Coprocessor 0 register on an exception.
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 $2^{PABITS} = 2^{36}$ bytes.
FP32RegistersMode	Indicates whether the FPU has 32-bit or 64-bit floating point registers (FPRs). In MIPS32 Release 1, the FPU has 32, 32-bit FPRs, in which 64-bit data types are stored in even-odd pairs of FPRs. In MIPS64, (and optionally in MIPS32 Release2 and Release 3) the FPU has 32 64-bit FPRs in which 64-bit data types are stored in any FPR. In MIPS32 Release 1 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 **FP32RegisterMode** is computed from the FR bit in the *Status* register. If this bit is a 0, the processor operates as if it had 32, 32-bit FPRs. If this bit is a 1, the processor operates with 32 64-bit FPRs. The value of **FP32RegistersMode** is computed from the FR bit in the *Status* register.
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 *dynamic* state of the instruction, not the *static* 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 Notation for Register Field Accessibility

In this document, the read/write properties of register fields use the notations shown in Table 1.1.

Table 1.2 Read/Write Register Field Notation

Read/Write Notation	Hardware Interpretation	Software Interpretation
R/W	A field in which all bits are readable and writable by software and, potentially, by hardware. Hardware updates of this field are visible by software read. Software updates of this field are visible by hardware read. If the Reset State of this field is ‘‘Undefined’’, either software or hardware must initialize the value before the first read will return a predictable value. This should not be confused with the formal definition of **UNDEFINED** behavior.	

Table 1.2 Read/Write Register Field Notation (Continued)

Read/Write Notation	Hardware Interpretation	Software Interpretation
R	A field which is either static or is updated only by hardware. If the Reset State of this field is either ‘‘0’’, ‘‘Preset’’, or ‘‘Externally Set’’, hardware initializes this field to zero or to the appropriate state, respectively, on powerup. The term ‘‘Preset’’ is used to suggest that the processor establishes the appropriate state, whereas the term ‘‘Externally Set’’ is used to suggest that the state is established via an external source (e.g., personality pins or initialization bit stream). These terms are suggestions only, and are not intended to act as a requirement on the implementation. If the Reset State of this field is ‘‘Undefined’’, hardware updates this field only under those conditions specified in the description of the field.	A field to which the value written by software is ignored by hardware. Software may write any value to this field without affecting hardware behavior. Software reads of this field return the last value updated by hardware. If the Reset State of this field is ‘‘Undefined’’, software reads of this field result in an **UNPREDICTABLE** value except after a hardware update done under the conditions specified in the description of the field.
R0	R0 = reserved, read as zero, ignore writes by software. Hardware ignores software writes to an R0 field. Neither the occurrence of such writes, nor the values written, affects hardware behavior. Hardware always returns 0 to software reads of R0 fields. The Reset State of an R0 field must always be 0. If software performs an mtc0 instruction which writes a non-zero value to an R0 field, the write to the R0 field will be ignored, but permitted writes to other fields in the register will not be affected.	**Architectural Compatibility:** R0 fields are reserved, and may be used for not-yet-defined purposes in future revisions of the architecture. When writing an R0 field, current software should only write either all 0s, or, preferably, write back the same value that was read from the field. Current software should not assume that the value read from R0 fields is zero, because this may not be true on future hardware. Future revisions of the architecture may redefine an R0 field, but must do so in such a way that software which is unaware of the new definition and either writes zeros or writes back the value it has read from the field will continue to work correctly. Writing back the same value that was read is guaranteed to have no unexpected effects on current or future hardware behavior. (Except for non-atomicity of such read-writes.) Writing zeros to an R0 field may not be preferred because in the future this may interfere with the operation of other software which has been updated for the new field definition.

Table 1.2 Read/Write Register Field Notation (Continued)

Read/Write Notation	Hardware Interpretation	Software Interpretation
0	**Release 6** Release 6 legacy “0” behaves like R0 - read as zero, nonzero writes ignored. Legacy “0” should not be defined for any new control register fields; R0 should be used instead.	
	HW returns 0 when read. HW ignores writes.	Only zero should be written, or, value read from register.
	pre-Release 6 pre-Release 6 legacy “0” - read as zero, nonzero writes UNDEFINED	
	A field which hardware does not update, and for which hardware can assume a zero value.	A field to which the value written by software must be zero. Software writes of non-zero values to this field may result in **UNDEFINED** behavior of the hardware. Software reads of this field return zero as long as all previous software writes are zero. If the Reset State of this field is ‘‘Undefined’’, software must write this field with zero before it is guaranteed to read as zero.
R/W0	Like R/W, except that writes of non-zero to a R/W0 field are ignored. E.g. Status.NMI	
	Hardware may set or clear an R/W0 bit. Hardware ignores software writes of nonzero to an R/W0 field. Neither the occurrence of such writes, nor the values written, affects hardware behavior. Software writes of 0 to an R/W0 field may have an effect. Hardware may return 0 or nonzero to software reads of an R/W0 bit. If software performs an mtc0 instruction which writes a non-zero value to an R/W0 field, the write to the R/W0 field will be ignored, but permitted writes to other fields in the register will not be affected.	Software can only clear an R/W0 bit. Software writes 0 to an R/W0 field to clear the field. Software writes nonzero to an R/W0 bit in order to guarantee that the bit is not affected by the write.

1.5 For More Information

MIPS processor manuals and additional information about MIPS products can be found at http://www.mips.com..

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Chapter 2

Guide to the Instruction Set

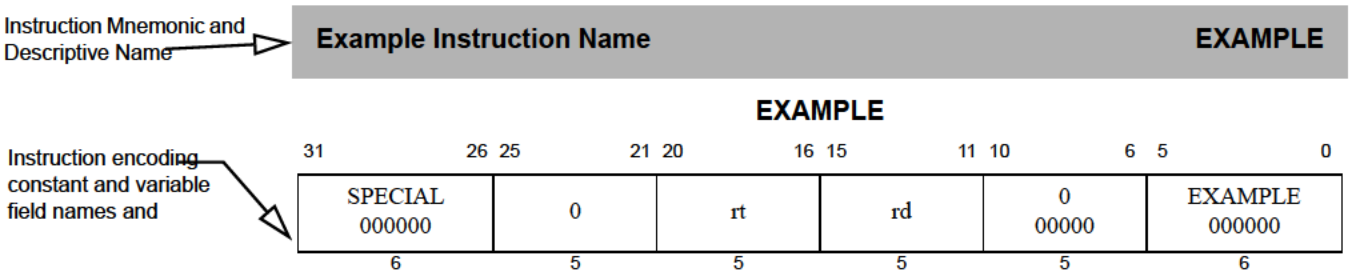
This chapter provides a detailed guide to understanding the instruction descriptions, which are listed in alphabetical order in the tables at the beginning of the next chapter.

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 16
- "Instruction Descriptive Name and Mnemonic" on page 17
- "Format Field" on page 17
- "Purpose Field" on page 18
- "Description Field" on page 18
- "Restrictions Field" on page 18
- "Operation Field" on page 19
- "Exceptions Field" on page 20
- "Programming Notes and Implementation Notes Fields" on page 20

Figure 2.1 Example of Instruction Description



Architecture level at which instruction was defined/ **MIPS32**

Assembler format(s) for each definition — **Format:** `EXAMPLE fd,rs,rt`

Short — **Purpose:** Example Instruction Name

To execute an EXAMPLE op.

Symbolic — **Description:** `GPR[rd] ♦ GPR[r]s exampleop GPR[rt]`

Full description of instruction — This section describes the operation of the instruction in text, tables, and illustrations. It includes information that would be difficult to encode in the Operation section.

Restrictions on instruction and — **Restrictions:**

This section lists any restrictions for the instruction. This can include values of the instruction encoding fields such as register specifiers, operand values, operand formats, address alignment, instruction scheduling hazards, and type of memory access for addressed locations.

High-level language description of instruction operation — **Operation:**

```
/* This section describes the operation of an instruction in */
/* a high-level pseudo-language. It is precise in ways that  */
/* the Description section is not, but is also missing       */
/* information that is hard to express in pseudocode.        */
temp     ♦ GPR[rs] exampleop GPR[rt]
GPR[rd]  ♦ temp
```

Exceptions that instruction can — **Exceptions:**

A list of exceptions taken by the instruction

Notes for — **Programming Notes:**

Information useful to programmers, but not necessary to describe the operation of the instruction

Notes for — **Implementation Notes:**

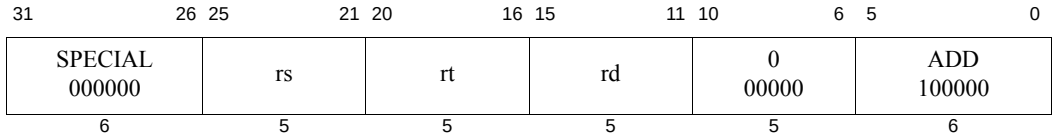
Like *Programming Notes*, except for processor implementors

2.1.1 Instruction Fields

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

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

Figure 2.2 Example of Instruction Fields



2.1.2 Instruction Descriptive Name and Mnemonic

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

Figure 2.3 Example of Instruction Descriptive Name and Mnemonic

Add Word **ADD**

2.1.3 Format Field

The assembler formats for the instruction and the architecture level at which the instruction was originally defined are given in the *Format* field. If the instruction definition was later extended, the architecture levels at which it was extended and the assembler formats for the extended definition are shown in their order of extension (for an example, see C.cond fmt). The MIPS architecture levels are inclusive; higher architecture levels include all instructions in previous levels. Extensions to instructions are backwards compatible. The original assembler formats are valid for the extended architecture.

Figure 2.4 Example of Instruction Format

Format: `ADD fd,rs,rt` **MIPS32**

The assembler format is shown with literal parts of the assembler instruction printed in uppercase characters. The variable parts, the operands, are shown as the lowercase names of the appropriate fields.

The architectural level at which the instruction was first defined, for example “MIPS32” is shown at the right side of the page. Instructions introduced at different times by different ISA family members, are indicated by markings such as “MIPS64, MIPS32 Release 2”. Instructions removed by particular architecture release are indicated in the Availability section.

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.

Figure 2.5 Example of Instruction Purpose

Purpose: Add Word

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

2.1.5 Description Field

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

Figure 2.6 Example of Instruction Description

Description: `GPR[rd] ♦ GPR[rs] + GPR[rt]`

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

- If the addition results in 32-bit 2's complement arithmetic overflow, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR *rd*.

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

This section uses acronyms for register descriptions. "GPR *rt*" is CPU general-purpose register specified by the instruction field *rt*. "FPR *fs*" is the floating point operand register specified by the instruction field *fs*. "CP1 register *fd*" is the coprocessor 1 general register specified by the instruction field *fd*. "*FCSR*" is the floating point *Control / Status* register.

2.1.6 Restrictions Field

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

- Valid values for instruction fields (for example, see floating point ADD.fmt)
- ALIGNMENT requirements for memory addresses (for example, see LW)
- Valid values of operands (for example, see)

- Valid operand formats (for example, see floating point ADD.fmt)
- Order of instructions necessary to guarantee correct execution. These ordering constraints avoid pipeline hazards for which some processors do not have hardware interlocks (for example, see MUL).
- Valid memory access types (for example, see LL/SC)

Figure 2.7 Example of Instruction Restrictions

Restrictions:

2.1.7 Availability and Compatibility Fields

The *Availability* and *Compatibility* sections are not provided for all instructions. These sections list considerations relevant to whether and how an implementation may implement some instructions, when software may use such instructions, and how software can determine if an instruction or feature is present. Such considerations include:

- Some instructions are not present on all architecture releases. Sometimes the implementation is required to signal a Reserved Instruction exception, but sometimes executing such an instruction encoding is architecturally defined to give UNPREDICTABLE results.
- Some instructions are available for implementations of a particular architecture release, but may be provided only if an optional feature is implemented. Control register bits typically allow software to determine if the feature is present.
- Some instructions may not behave the same way on all implementations. Typically this involves behavior that was UNPREDICTABLE in some implementations, but which is made architectural and guaranteed consistent so that software can rely on it in subsequent architecture releases.
- Some instructions are prohibited for certain architecture releases and/or optional feature combinations.
- Some instructions may be removed for certain architecture releases. Implementations may then be required to signal a Reserved Instruction exception for the removed instruction encoding; but sometimes the instruction encoding is reused for other instructions.

All of these considerations may apply to the same instruction. If such considerations applicable to an instruction are simple, the architecture level in which an instruction was defined or redefined in the *Format* field, and/or the *Restrictions* section, may be sufficient; but if the set of such considerations applicable to an instruction is complicated, the *Availability* and *Compatibility* sections may be provided.

2.1.8 Operation Field

The *Operation* field describes the operation of the instruction as pseudocode in a high-level language notation resembling Pascal. This formal description complements the *Description* section; it is not complete in itself because many of the restrictions are either difficult to include in the pseudocode or are omitted for legibility.

Figure 2.8 Example of Instruction Operation

Operation:

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

See 2.2 “Operation Section Notation and Functions” on page 20 for more information on the formal notation used here.

2.1.9 Exceptions Field

The *Exceptions* field lists the exceptions that can be caused by *Operation* of the instruction. It omits exceptions that can be caused by the instruction fetch, for instance, TLB Refill, and also omits exceptions that can be caused by asynchronous external events such as an Interrupt. Although a Bus Error exception may be caused by the operation of a load or store instruction, this section does not list Bus Error for load and store instructions because the relationship between load and store instructions and external error indications, like Bus Error, are dependent upon the implementation.

Figure 2.9 Example of Instruction Exception

Exceptions:

Integer Overflow

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

2.1.10 Programming Notes and Implementation Notes Fields

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

Figure 2.10 Example of Instruction Programming Notes

Programming Notes:

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

2.2 Operation Section Notation and Functions

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

This section presents information about the following topics:

- “Instruction Execution Ordering” on page 21

- "Pseudocode Functions" on page 21

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 21
- "Memory Operation Functions" on page 23
- "Floating Point Functions" on page 26
- "Miscellaneous Functions" on page 30

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.

2.2.2.1.1 COP_LW

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

Figure 2.11 COP_LW Pseudocode Function

```
COP_LW (z, rt, memword)
   z: The coprocessor unit number
   rt: Coprocessor general register specifier
   memword: A 32-bit word value supplied to the coprocessor

   /* Coprocessor-dependent action */

endfunction COP_LW
```

2.2.2.1.2 COP_LD

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

Figure 2.12 COP_LD Pseudocode Function

```
COP_LD (z, rt, memdouble)
```

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

    /* Coprocessor-dependent action */

endfunction COP_LD
```

2.2.2.1.3 COP_SW

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

Figure 2.13 COP_SW Pseudocode Function

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

    /* Coprocessor-dependent action */

endfunction COP_SW
```

2.2.2.1.4 COP_SD

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

Figure 2.14 COP_SD Pseudocode Function

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

    /* Coprocessor-dependent action */

endfunction COP_SD
```

2.2.2.1.5 CoprocessorOperation

The CoprocessorOperation function performs the specified Coprocessor operation.

Figure 2.15 CoprocessorOperation Pseudocode Function

```
CoprocessorOperation (z, cop_fun)

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

    /* Transmit the cop_fun value to coprocessor z */

endfunction CoprocessorOperation
```

2.2.2.2 Memory Operation Functions

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

In the *Operation* pseudocode for load and store operations, the following functions summarize the handling of virtual addresses and the access of physical memory. The size of the data item to be loaded or stored is passed in the *AccessLength* field. The valid constant names and values are shown in Table 2.1. The bytes within the addressed unit of memory (word for 32-bit processors or doubleword for 64-bit processors) that are used can be determined directly from the *AccessLength* and the two or three low-order bits of the address.

2.2.2.2.1 Misaligned Support

MIPS processors originally required all memory accesses to be naturally aligned. MSA (the MIPS SIMD Architecture) supported misaligned memory accesses for its 128 bit packed SIMD vector loads and stores, from its introduction in MIPS Release 5. Release 6 requires systems to provide support for misaligned memory accesses for all ordinary memory reference instructions: the system must provide a mechanism to complete a misaligned memory reference for this instruction, ranging from full execution in hardware to trap-and-emulate.

The pseudocode function MisalignedSupport encapsulates the version number check to determine if mislaignment is supported for an ordinary memory access.

Figure 2.16 MisalignedSupport Pseudocode Function

```
predicate ← MisalignedSupport ()
   return Config.AR □ 2 // Architecture Revision 2 corresponds to MIPS Release 6.
end function
```

See Appendix B, “Misaligned Memory Accesses” on page 511 for a more detailed discussion of misalignment, including pseudocode functions for the actual misaligned memory access.

2.2.2.2.2 AddressTranslation

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

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

Figure 2.17 AddressTranslation Pseudocode Function

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

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

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

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

endfunction AddressTranslation
```

2.2.2.2.3 LoadMemory

The LoadMemory function loads a value from memory.

This action uses cache and main memory as specified in both the Cacheability and Coherency Attribute (*CCA*) and the access (*IorD*) to find the contents of *AccessLength* memory bytes, starting at physical location *pAddr*. The data is returned in a fixed-width naturally aligned memory element (*MemElem*). The low-order 2 (or 3) bits of the address and the *AccessLength* indicate which of the bytes within *MemElem* need to be passed to the processor. If the memory access type of the reference is *uncached*, only the referenced bytes are read from memory and marked as valid within the memory element. If the access type is *cached* but the data is not present in cache, an implementation-specific *size* and *alignment* block of memory is read and loaded into the cache to satisfy a load reference. At a minimum, this block is the entire memory element.

Figure 2.18 LoadMemory Pseudocode Function

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

    /* MemElem:  Data is returned in a fixed width with a natural alignment. The */
    /*           width is the same size as the CPU general-purpose register, */
    /*           32 or 64 bits, aligned on a 32- or 64-bit boundary, */
    /*           respectively. */
    /* CCA:      Cacheability&CoherencyAttribute=method used to access caches */
    /*           and memory and resolve the reference */

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

endfunction LoadMemory
```

2.2.2.2.4 StoreMemory

The StoreMemory function stores a value to memory.

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

Figure 2.19 StoreMemory Pseudocode Function

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

    /* CCA:      Cacheability&Coherency Attribute, the method used to access */
    /*           caches and memory and resolve the reference. */
    /* AccessLength: Length, in bytes, of access */
    /* MemElem:  Data in the width and alignment of a memory element. */
```

```
    /*            The width is the same size as the CPU general */
    /*            purpose register, either 4 or 8 bytes, */
    /*            aligned on a 4- or 8-byte boundary. For a */
    /*            partial-memory-element store, only the bytes that will be*/
    /*            stored must be valid.*/
    /* pAddr:     physical address */
    /* vAddr:     virtual address */

endfunction StoreMemory
```

2.2.2.2.5 Prefetch

The Prefetch function prefetches data from memory.

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

Figure 2.20 Prefetch Pseudocode Function

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

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

endfunction Prefetch
```

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

Table 2.1 AccessLength Specifications for Loads/Stores

AccessLength Name	Value	Meaning
DOUBLEWORD	7	8 bytes (64 bits)
SEPTIBYTE	6	7 bytes (56 bits)
SEXTIBYTE	5	6 bytes (48 bits)
QUINTIBYTE	4	5 bytes (40 bits)
WORD	3	4 bytes (32 bits)
TRIPLEBYTE	2	3 bytes (24 bits)
HALFWORD	1	2 bytes (16 bits)
BYTE	0	1 byte (8 bits)

2.2.2.2.6 SyncOperation

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

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

Figure 2.21 SyncOperation Pseudocode Function

```
SyncOperation(stype)

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

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

endfunction SyncOperation
```

2.2.2.3 Floating Point Functions

The pseudocode shown 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).

2.2.2.3.1 ValueFPR

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

Figure 2.22 ValueFPR Pseudocode Function

```
value ← ValueFPR(fpr, fmt)

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

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

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

      D, UNINTERPRETED_DOUBLEWORD:
         if (FP32RegistersMode = 0)
            if (fpr0 ≠ 0) then
               valueFPR ← UNPREDICTABLE
            else
               valueFPR ← FPR[fpr+1]31..0 || FPR[fpr]31..0
            endif
         else
            valueFPR ← FPR[fpr]
         endif

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

```
        DEFAULT:
            valueFPR ← UNPREDICTABLE

    endcase
endfunction ValueFPR
```

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

2.2.2.3.2 StoreFPR

Figure 2.23 StoreFPR Pseudocode Function

```
StoreFPR (fpr, fmt, value)

    /* fpr:   The FPR number */
    /* fmt:   The format of the data, one of: */
    /*        S, D, W, L, PS, */
    /*        OB, QH, */
    /*        UNINTERPRETED_WORD, */
    /*        UNINTERPRETED_DOUBLEWORD */
    /* value: The formattted value to be stored into the FPR */

    /* The UNINTERPRETED values are used to indicate that the datatype */
    /* is not known as, for example, in LWC1 and LDC1 */


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

        D, UNINTERPRETED_DOUBLEWORD:
            if (FP32RegistersMode = 0)
                if (fpr0 ≠ 0) then
                    UNPREDICTABLE
                else
                    FPR[fpr]   ← UNPREDICTABLE^32 || value31..0
                    FPR[fpr+1] ← UNPREDICTABLE^32 || value63..32
                endif
            else
                FPR[fpr] ← value
            endif

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

    endcase

endfunction StoreFPR
```

2.2.2.3.3 CheckFPException

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

Figure 2.24 CheckFPException Pseudocode Function

```
CheckFPException()

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

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

endfunction CheckFPException
```

2.2.2.3.4 FPConditionCode

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

Figure 2.25 FPConditionCode Pseudocode Function

```
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
```

2.2.2.3.5 SetFPConditionCode

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

Figure 2.26 SetFPConditionCode Pseudocode Function

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

endfunction SetFPConditionCode
```

2.2.2.4 Pseudocode Functions Related to Sign and Zero Extension

2.2.2.4.1 Sign extension and zero extension in pseudocode

Much pseudocode uses a generic function `sign_extend` without specifying from what bit position the extension is done, when the intention is obvious. E.g. `sign_extend(immediate16)` or `sign_extend(disp9)`.

However, sometimes it is necessary to specify the bit position. For example, $\texttt{sign\_extend(temp}_{31..0}\texttt{)}$ or the more complicated $\texttt{(offset}_{15}\texttt{)}^{\texttt{GPRLEN-(16+2)}}\ \texttt{||}\ \texttt{offset}\ \texttt{||}\ 0^2$.

The explicit notation `sign_extend.nbits(val)` or `sign_extend(val,nbits)` is suggested as a simplification. They say to sign extend as if an nbits-sized signed integer. The width to be sign extended to is usually apparent by context, and is usually GPRLEN, 32 or 64 bits. The previous examples then become.

$\texttt{sign\_extend(temp}_{31..0}\texttt{)}$
`= sign_extend.32(temp)`

and

$\texttt{(offset}_{15}\texttt{)}^{\texttt{GPRLEN-(16+2)}}\ \texttt{||}\ \texttt{offset}\ \texttt{||}\ 0^2$
`= sign_extend.16(offset)<<2`

Note that sign_extend.N(value) extends from bit position N-1, if the bits are numbered 0..N-1 as is typical.

The explicit notations `sign_extend.nbits(val)` or `sign_extend(val,nbits)` is used as a simplification. These notations say to sign extend as if an nbits-sized signed integer. The width to be sign extended to is usually apparent by context, and is usually GPRLEN, 32 or 64 bits.

Figure 2.27 sign_extend Pseudocode Functions

```
sign_extend.nbits(val) = sign_extend(val,nbits) /* syntactic equivalents */

function sign_extend(val,nbits)
   return (val_nbits-1)^GPRLEN-nbits || val_nbits-1..0
end function
```

The earlier examples can be expressed as

$\texttt{(offset}_{15}\texttt{)}^{\texttt{GPRLEN-(16+2)}}\ \texttt{||}\ \texttt{offset}\ \texttt{||}\ 0^2$
`= sign_extend.16(offset) << 2)`

and

$\texttt{sign\_extend(temp}_{31..0}\texttt{)}$
`= sign_extend.32(temp)`

Similarly for `zero_extension`, although zero extension is less common than sign extension in the MIPS ISA.

Floating point may use notations such as `zero_extend.fmt` corresponding to the format of the FPU instruction. E.g. `zero_extend.S` and `zero_extend.D` are equivalent to `zero_extend.32` and `zero_extend.64`.

Existing pseudocode may use any of these, or other, notations. TBD: rewrite pseudocode.

2.2.2.4.2 memory_address

The pseudocode function `memory_address` performs mode-dependent address space wrapping for compatibility between MIPS32 and MIPS64. It is applied to all memory references. It may be specified explicitly in some places, particularly for new memory reference instructions, but it is also declared to apply implicitly to all memory refer-

ences as defined below. In addition, certain instructions that are used to calculate effective memory addresses but which are not themselves memory accesses specify memory_address explicitly in their pseudocode.

Figure 2.28 memory_address Pseudocode Function

```
function memory_address(ea)
   return ea
end function
```

On a 32-bit CPU, `memory_address` returns its 32-bit effective address argument unaffected.

In addition to the use of `memory_address` for all memory references (including load and store instructions, LL/SC), Release 6 extends this behavior to control transfers (branch and call instructions), and to the PC-relative address calculation instructions (ADDIUPC, AUIPC, ALUIPC). In newer instructions the function is explicit in the pseudocode.

Implicit address space wrapping for all instruction fetches is described by the following pseudocode fragment which should be considered part of instruction fetch:

Figure 2.29 Instruction Fetch Implicit memory_address Wrapping

```
PC ← memory_address( PC )
( instruction_data, length ) ← instruction_fetch( PC )
/* decode and execute instruction */
```

Implicit address space wrapping for all data memory accesses is described by the following pseudocode, which is inserted at the top of the AddressTranslation pseudocode function:

Figure 2.30 AddressTranslation implicit memory_address Wrapping

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

In addition to its use in instruction pseudocode,

2.2.2.5 Miscellaneous Functions

This section lists miscellaneous functions not covered in previous sections.

2.2.2.5.1 SignalException

The SignalException function signals an exception condition.

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

Figure 2.31 SignalException Pseudocode Function

```
SignalException(Exception, argument)

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

endfunction SignalException
```

2.2.2.5.2 SignalDebugBreakpointException

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

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

Figure 2.32 SignalDebugBreakpointException Pseudocode Function

```
SignalDebugBreakpointException()

endfunction SignalDebugBreakpointException
```

2.2.2.5.3 SignalDebugModeBreakpointException

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

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

Figure 2.33 SignalDebugModeBreakpointException Pseudocode Function

```
SignalDebugModeBreakpointException()

endfunction SignalDebugModeBreakpointException
```

2.2.2.5.4 NullifyCurrentInstruction

The NullifyCurrentInstruction function nullifies the current instruction.

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

Figure 2.34 NullifyCurrentInstruction PseudoCode Function

```
NullifyCurrentInstruction()

endfunction NullifyCurrentInstruction
```

2.2.2.5.5 JumpDelaySlot

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

Figure 2.35 JumpDelaySlot Pseudocode Function

```
JumpDelaySlot(vAddr)

   /* vAddr:Virtual address */

endfunction JumpDelaySlot
```

2.2.2.5.6 PolyMult

The PolyMult function multiplies two binary polynomial coefficients.

Figure 2.36 PolyMult Pseudocode Function

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

    PolyMult ← temp

endfunction PolyMult
```

2.3 Op and Function Subfield Notation

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

2.4 FPU Instructions

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

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

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

See “Op and Function Subfield Notation” on page 32 for a description of the *op* and *function* subfields.

Chapter 3

The MIPS® DSP Application Specific Extension to the MIPS® Architecture

3.1 Base Architecture Requirements

The MIPS DSP Module requires the following base architecture support:

- **MIPS32 Release 2 or MIPS64 Release 2 Architecture:** The MIPS DSP Module requires a compliant implementation of the MIPS32 Release 2 or MIPS64 Release 2 Architecture.

The MIPS DSP Module Rev2 requires the following base architecture support:

- **MIPS DSP Module**
- **MIPS32 Release 2 or MIPS64 Release 2 Architecture**

3.2 Software Detection of the Module

Software may determine if the MIPS DSP Module is implemented by checking the state of the DSPP (DSP Present) bit, which is bit 10 in the *Config3* CP0 register.

Software may determine if the MIPS DSP Module Rev2 is implemented by checking the state of the DSP2P (DSP Rev2 Present) bit, which is bit 11 in the *Config3* CP0 register. Compliant MIPS DSP Module Rev2 implementations must set both DSPP and DSP2P bits.

An implementation supports MIPS DSP Module Rev3 if CP0 $\texttt{Config3}_{\texttt{DSPP}}$=1 and $\texttt{Config3}_{\texttt{DSP2P}}$=1 and $\texttt{Config}_{\texttt{AR}}$>=2.

The DSPP and DSP2P bits are fixed by the hardware implementation and are read-only for software.

3.3 Compliance and Subsetting

There are no instruction subsets of the MIPS DSP Module—all DSP Module instructions and state must be implemented.

There are no instruction subsets of the MIPS DSP Module Rev2 — all DSP Module and DSP Module Rev2 instructions and state must be implemented.

3.4 Introduction to the MIPS® DSP Module

This document contains a complete specification of the MIPS® DSP Module to the MIPS®architecture. Statements about MIPS DSP Module include MIPS DSP Module Rev2, except where noted. The table entries in Chapter 4, "MIPS® DSP Module Instruction Summary" on page 50 contain notations which flag the Rev2 instructions; this information is also available in the per instruction pages. The extensions comprises new integer instructions and new state that includes new HI-LO accumulator pairs and a *DSPControl* register. The MIPS DSP Module can be included in either a MIPS32 or MIPS64 architecture implementation. The Module has been designed to benefit a wide range of DSP, multimedia, and DSP-like algorithms. The performance increase from these extensions can be used to integrate DSP-like functionality into MIPS cores used in a SOC (System on Chip), potentially reducing overall system cost. The Module includes many of the typical features found in other integer-based DSP extensions, for example, support for operations on fractional data types and register SIMD (Single Instruction Multiple Data) operations such as add, subtract, multiply, shift, etc. In addition, the extensions includes some key features that efficiently address specific problems often encountered in DSP applications. These include, for example, support for complex multiplication, variable bit insertion and extraction, and the implementation and use of virtual circular buffers.

This chapter contains a basic overview of the principles behind DSP application processing and the data types and structures needed to efficiently process such applications. Chapter 4, "MIPS® DSP Module Instruction Summary" on page 50, contains a list of all the instructions in the MIPS DSP Module arranged by function type. Chapter 5, "Instruction Encoding" on page 70, describes the position of the new instructions in the MIPS instruction opcode map. The rest of the specification contains a complete list of all the instructions that comprise the MIPS DSP Module, and serves as a quick reference guide to all the instructions. Finally, various Appendix chapters describe how to implement and use the DSP Module instructions in some common algorithms and inner loops.

3.5 DSP Applications and their Requirements

The MIPS DSP Module has been designed specifically to improve the performance of a set of DSP and DSP-like applications. Table 3.1 shows these application areas sorted by the size of the data operands typically preferred by that application for internal computations. For example, raw audio data is usually signed 16-bit, but 32-bit internal calculations are often necessary for high quality audio. (Typically, an internal precision of about 28 bits may be all that is required which can be achieved using a fractional data type of the appropriate width.) There is some cross-over in some cases, which are not explicitly listed here. For example, some hand-held consumer devices may use lower precision internal arithmetic for audio processing, that is, 16-bit internal data formats may be sufficient for the quality required for hand-held devices.

Table 3.1 Data Size of DSP Applications

In/Out Data Size	Internal Data Size	Applications
8 bits	8/16 bits	• Printer image processing. • Still JPEG processing. • Moving video processing
16 bits	16 bits	• Voice Processing. For example, G.723.1, G.729, G.726, echo cancellation, noise cancellation, channel equalization, etc. • Soft modem processing. For example V.92. • General DSP processing. For example, filters, correlation, convolution, etc.
16/24 bits	32 bits	• Audio decoding and encoding. For example, MP3, AAC, SRS TruSurround, Dolby Digital Decoder, Pro Logic II, etc.

3.6 Fixed-Point Data Types

Typical implementations of DSP algorithms use fractional fixed-point arithmetic, for reasons of size, cost, and power efficiency. Unlike floating-point arithmetic, fractional fixed-point arithmetic assumes that the position of the decimal point is fixed with respect to the bits representing the fractional value in the operand. To understand this type of arithmetic further, please consult DSP textbooks or other references that are easily available on the internet.

Fractional fixed-point data types are often referred to using Q format notation. The general form for this notation is Q*m.n*, where Q designates that the data is in fractional fixed-point format, *m* is the number of bits used to designate the twos complement integer portion of the number, and *n* is the number of bits used to designate the twos complement fractional part of the number. Because the twos complement number is signed, the number of bits required to express a number is *m*+*n*+1, where the additional bit is required to denote the sign. In typical usage, it is very common for *m* to be zero. That is, only fractional bits are represented. In this case, a Q notation of the form Q0.*n* is abbreviated to Q*n*.

For example, a 32-bit word can be used to represent data in Q31 format, which implies one (left-most) sign bit followed by the binary point and then 31 bits representing the fractional data value. The interpretation of the 32 bits of the Q31 representation is shown in Table 3.2. Negative values are represented using the twos-complement of the equivalent positive value. This format can represent numbers in the range of -1.0 to +0.999999999.... Similarly a 16-bit halfword can be used to represent data in Q15 format, which implies one sign bit followed by 15 fractional bits that represent a value between -1.0 and +0.9999....

Table 3.2 The Value of a Fixed-Point Q31 Number

+ -	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}	2^{-10}	2^{-11}	2^{-12}	2^{-13}	2^{-14}	2^{-15}	2^{-16}	2^{-17}	2^{-18}	2^{-19}	2^{-20}	2^{-21}	2^{-22}	2^{-23}	2^{-24}	2^{-25}	2^{-26}	2^{-27}	2^{-28}	2^{-29}	2^{-30}	2^{-31}

Table 3.3 shows the limits of the Q15 and the Q31 representations. Note that the value -1.0 can be represented exactly, but the value +1.0 cannot. For practical purposes, 0x7FFFFFFF is used to represent 1.0 inexactly. Thus, the multiplication of two values where both are -1 will result in an overflow since there is no representation for +1 in fixed-point format. Saturating instructions must check for this case and prevent the overflow by clamping the result to the maximal representable value. Instructions in the MIPS DSP Module that operate on fractional data types include a "Q" in the instruction mnemonic; the assumed size of the instruction operands is detailed in the instruction description.

Table 3.3 The Limits of Q15 and Q31 Representations

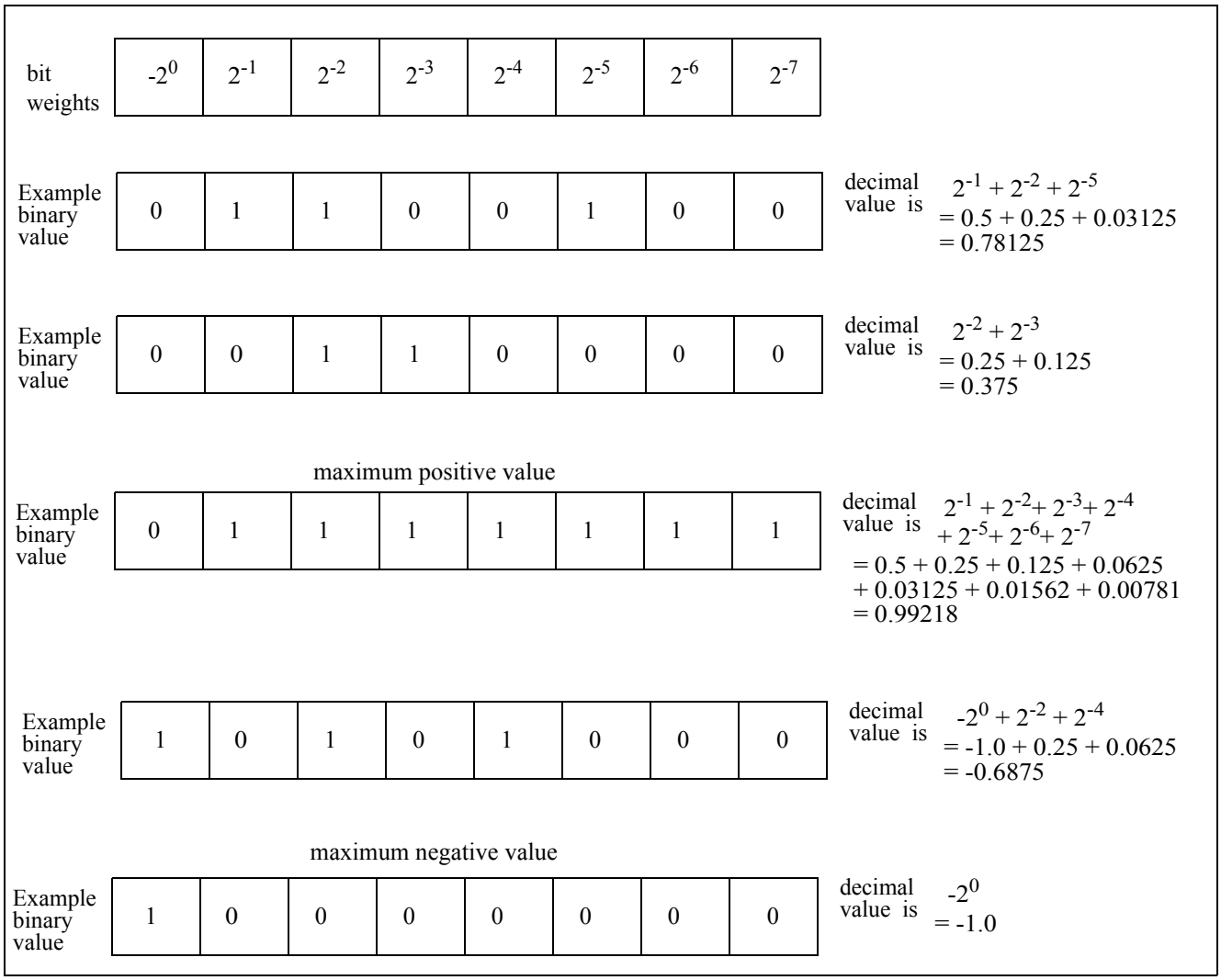
Fixed-Point Representation	Definition	Hexadecimal Representation	Decimal Equivalent
Q15 minimum	$-2^{15}/2^{15}$	0x8000	-1.0
Q15 maximum	$(2^{15}-1)/2^{15}$	0x7FFF	0.999969482421875
Q31 minimum	$-2^{31}/2^{31}$	0x80000000	-1.0
Q31 maximum	$(2^{31}-1)/2^{31}$	0x7FFFFFFF	0.99999999953433871269226074218 75

Given a fixed-point representation, we can compute the corresponding decimal value by using bit weights per position as shown in Figure 3.1 for a hypothetical Q7 format number representation with 8 total bits.

DSP applications often, but not always, prefer to saturate the result after an arithmetic operation that causes an overflow or underflow. For operations on signed values, saturation clamps the result to the smallest negative or largest

positive value in the case of underflow and overflow, respectively. For operations on unsigned values, saturation clamps the result to either zero or the maximum positive value.

Figure 3.1 Computing the Value of a Fixed-Point (Q7) Number



3.7 Saturating Math

Many of the MIPS DSP Module arithmetic instructions provide optional saturation of the results, as detailed in each instructions description.

Saturation of fixed-point addition, subtraction, or shift operations that result in an underflow or overflow requires clamping the result value to the closest available fixed-point value representable in the given number of result bits. For operations on unsigned values, underflow is clamped to zero, and overflow to the largest positive fixed-point value. For operations on signed values, underflow is clamped to the minimum negative fixed-point value and overflow to the maximum positive value.

Saturation of fractional fixed-point multiplication operations clamps the result to the maximum representable fixed-point value when both input multiplicands are equal to the minimum negative value of -1.0, which is independent of the Q format used.

3.8 Conventions Used in the Instruction Mnemonics

MIPS DSP Module instructions with a **Q** in the mnemonic assume the input operands to be in fractional fixed-point format. Multiplication instructions that operate on fractional fixed-point data will not produce correct results when used with integer fixed-point data. However, addition and subtraction instructions will work correctly with either fractional fixed-point or signed integer fixed-point data.

Instructions that use unsigned data are indicated with the letter **U**. This letter appears after the letter **Q** for fractional in the instruction mnemonic. For example, the **ADDQU** instruction performs an unsigned addition of fractional data. In the MIPS base instruction set, the overflow trap distinguishes signed and unsigned arithmetic instructions. In the MIPS DSP Module, the results of saturation distinguish signed and unsigned arithmetic instructions.

Some instructions provide optional rounding up, saturation, or rounding up and saturation of the result(s). These instructions use one of the modifiers **_RS**, **_R**, **_S**, or **_SA** in their mnemonic. For example, **MULQ_RS** is a multiply instruction (**MUL**) where the result is the same size as the input operands (indicated by the absence of **E** for expanded result in the mnemonic) that assumes fractional (**Q**) input data operands, and where the result is rounded up and saturated (**_RS**) before writing the result in the destination register. (For fractional multiplication, saturation clamps the result to the maximum positive representable value if both multiplicands are equal to -1.0.) Several multiply-accumulate (dot product) instructions use a variant of the saturation flag, **_SA**, indicating that the accumulated value is saturated in addition to the regular fractional multiplication saturation check.

The MIPS DSP Module instructions provide support for single-instruction, multiple data (SIMD) operations where a single instruction can invoke multiple operation on multiple data operands. As noted previously, DSP applications typically use data types that are 8, 16, or 32 bits wide. In the MIPS32 architecture a general-purpose register (GPR) is 32 bits wide, and in the MIPS64 architecture, 64 bits wide. Thus, each GPR can be used to hold one or more operands of each size. For example, a 64-bit GPR can store eight 8-bit operands, a 32-bit GPR can store two 16-bit operands, and so on. A GPR containing multiple data operands is referred to as a *vector*.

MIPS implementations of the MIPS DSP Module support three basic formats for data operands: 32 bit, 16 bit, and 8 bit. The latter format is motivated by the fact that video applications typically operate on 8-bit data. The instruction mnemonics indicate the supported data types as follows:

- W = “Word”, 1 × 32-bit
- PH = “Paired Halfword”, 2 × 16-bit. See Figure 3.2.
- QB = “Quad Byte”, 4 × 8-bit. See Figure 3.3.

Figure 3.2 micromicro **A Paired-Half (PH) Representation in a GPR for the MIPS32 Architecture**

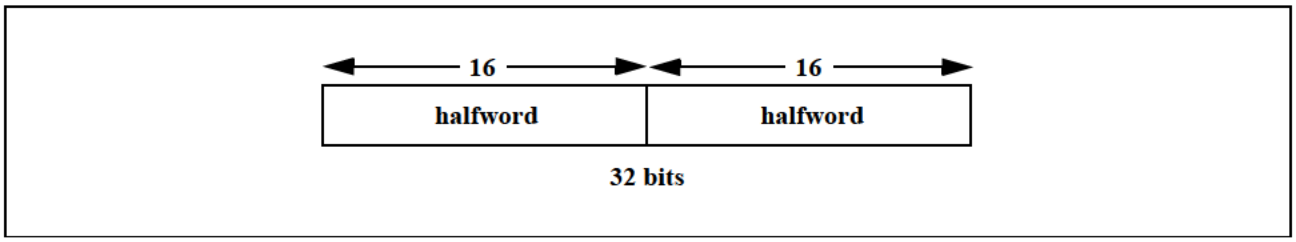
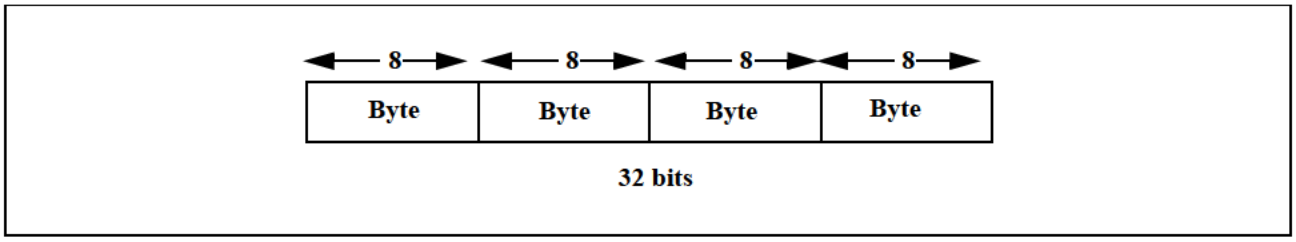


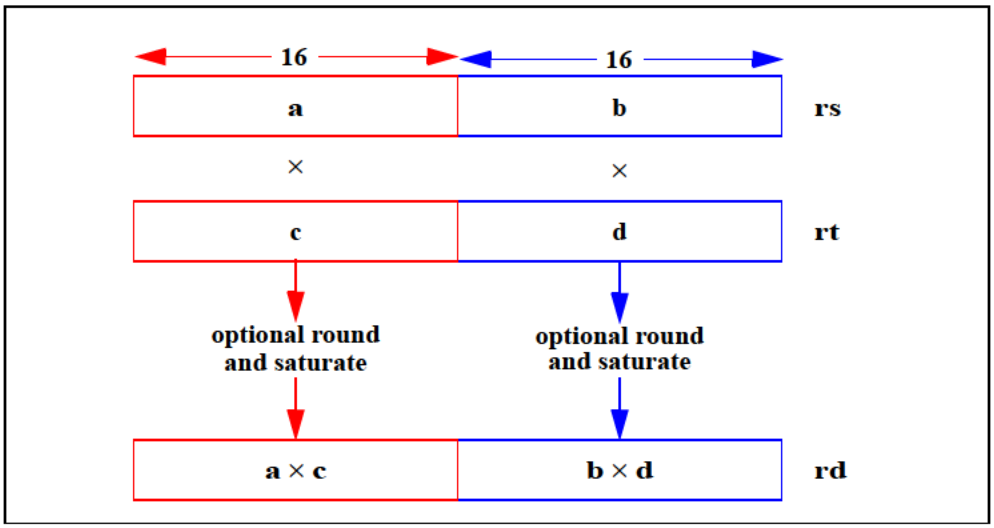
Figure 3.3 A Quad-Byte (QB) Representation in a GPR for the MIPS32 Architecture



For example, **MULQ_RS.PH rd, rs,rt** refers to the multiply instruction (**MUL**) that multiplies two vector elements of type fractional (**Q**) 16 bit (Halfword) data (**PH**) with rounding and saturation (**_RS**). Each source register supplies two data elements and the two results are written into the destination register in the corresponding vector position as shown in Figure 3.4.

When an instruction shows two format types, then the first is the output size and the second is the input size. For example, **PRECRQ.PH.W** is the (fractional) precision reduction instruction that creates a **PH** output format and uses **W** format as input from the two source registers. When the instruction only shows one format then this implies the same source and destination format.

Figure 3.4 Operation of MULQ_RS.PH rd, rs, rt



3.9 Effect of Endian-ness on Register SIMD Data

The order of data in memory and therefore in the register has a direct impact on the algorithm being executed. To reduce the effort required by the programmer and the development tools to take endian-ness into account, many of the instructions operate on pre-defined bits of a given register. The assembler can be used to map the endian-agnostic names to the actual instructions based on the endian-ness of the processor during the compilation and assembling of the instructions.

When a SIMD vector is loaded into a register or stored back to memory from a register, the endian-ness of the processor and memory has an impact on the view of the data. For example, consider a vector of eight byte values aligned in memory on a 64-bit boundary and loaded into a 64-bit register using the load double instruction: the order of the eight byte values within the register depends on the processor endian-ness. In a big-endian processor, the byte value stored

at the lowest memory address is loaded into the left-most (most-significant) 8 bits of the 64-bit register. In a little-endian processor, the same byte value is loaded into the right-most (least-significant) 8 bits of the register.

In general, if the byte elements are numbered 0-7 according to their order in memory, in a big-endian configuration, element 0 is at the most-significant end and element 7 is at the least-significant end. In a little-endian configuration, the order is reversed. This effect applies to all the sizes of data when they are in SIMD format.

To avoid dealing with the endian-ness issue directly, the instructions in the DSP Module simply refer to the left and right elements of the register when it is required to specify a subset of the elements. This issue can quite easily be dealt with in the assembler or user code using suitably defined mnemonics that use the appropriate instruction for a given endian-ness of the processor. A description of how to do this is specified in Appendix 7.

3.10 Additional Register State for the DSP Module

The MIPS DSP Module adds four new registers. The operating system is required to recognize the presence of the MIPS DSP Module and to include these additional registers in context save and restore operations.

- Three additional *HI-LO* registers to create a total of four accumulator registers. Many common DSP computations involve accumulation, e.g., convolution. MIPS DSP Module instructions that target the accumulators use two bits to specify the destination accumulator, with the zero value referring to the original accumulator of the MIPS architecture.

  Release 6 of the MIPS Architecture moves the accumulators into the DSP Module for use as a DSP resource exclusively.

- A new control register, *DSPControl*, is used to hold extra state bits needed for efficient support of the new instructions. Figure 3.5 illustrates the bits in this register. Table 3.4 describes the use of the various bits and the instructions that refer to the fields. Table 3.5 lists the instructions that affect the *DSPControl* register *ouflag* field.

Figure 3.5 MIPS® DSP Module Control Register (DSPControl) Format

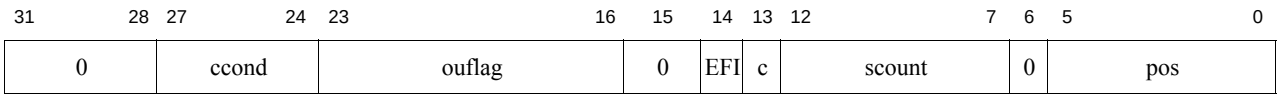


Table 3.4 MIPS® DSP Module Control Register (DSPControl) Field Descriptions

Fields		Description	Read / Write	Reset State	Compliance
Name	Bits				
ccond	27:24	Condition code bits set by vector comparison instructions and used as source selectors by PICK instructions. The vector element size determines the number of bits set by a comparison (1, 2, or 4); bits not set are **UNPREDICTABLE** after the comparison.	R/W	0	Required
ouflag	23:16	Overflow/underflow indication bits set when the result(s) of specific instructions (listed in Table 3.5) caused, or, if optional saturation has been used, would have caused overflow or underflow.	R/W	0	Required

Table 3.4 MIPS® DSP Module Control Register (DSPControl) Field Descriptions

Fields		Description	Read / Write	Reset State	Compliance
Name	Bits				
EFI	14	Extract Fail Indicator. This bit is set to 1 when one of the extraction instructions (EXTP, EXTPV, EXTPDP, or EXTPDP) fails. Failure occurs when there are insufficient bits to extract, i.e., when the value of the *pos* field in the *DSPControl* register is less than the *size* argument specified in the instruction. This bit is not sticky—the bit is set or reset after each extraction operation.	R/W	0	Required
c	13	Carry bit set and used by a special add instruction used to implement a 64-bit addition across two GPRs in a MIPS32 implementation. Instruction ADDSC sets the bit and instruction ADDWC uses this bit.	R/W	0	Required
scount	12:7	This field is used by the INSV instruction to specify the size of the bit field to be inserted.	R/W	0	Required
pos	5:0	This field is used by the variable insert instruction INSV to specify the position to insert bits. It is also used to indicate the extract position for the EXTP, EXTPV, EXTPDP, and EXTPDPVinstructions. The *decrement pos* (DP) variants of these instructions decrement the value of the pos field by the amount *size*+1 after the extraction completes successfully. The MTHLIP instruction increments the value of *pos* by 32 after copying the value of LO to HI.	R/W	0	Required

The bits of the overflow flag (*ouflag*) field in the *DSPControl* register are set by a number of instructions. These bits are sticky and can be reset only by an explicit write to these bits in the register (using the **WRDSP** instruction). The table below shows which bits can be set by which instructions and under what conditions.

Table 3.5 Instructions that set the ouflag bits in DSPControl

Bit Number	Instructions That Set This Bit
16	Instructions that set this bit when the destination is accumulator (*HI-LO* pair) zero and an operation overflow or underflow occurs are: DPAQ_S, DPAQ_SA, DPSQ_S, DPSQ_SA, MAQ_S, MAQ_SA, and MULSAQ_S, DPAQX_S, DPAQX_SA, DPSQX_S, DPSQX_SA.
17	Instructions as above, when the destination is accumulator (*HI-LO* pair) one.
18	Instructions as above, when the destination is accumulator (*HI-LO* pair) two.
19	Instructions as above, when the destination is accumulator (*HI-LO* pair) three.
20	Instructions that on an overflow/underflow will set this bit are: ABSQ_S, ADD, ADD_S, ADDQ, ADDQ_S, ADDU, ADDU_S, ADDWC, SUB, SUB_S, SUBQ, SUBQ_S, SUBU, and SUBU_S.

Table 3.5 Instructions that set the ouflag bits in DSPControl

Bit Number	Instructions That Set This Bit
21	Instructions that on an overflow/underflow will set this bit are: MUL, MUL_S, MULEQ_S, MULEU_S, MULQ_RS, and MULQ_S.
22	Instructions that on an overflow/underflow will set this bit are: PRECRQ_RS, PRECRQU_RS, SHLL, SHLL_S, SHLLV, and SHLLV_S.
23	Instructions that on an overflow/underflow will set this bit are: EXTR, EXTR_S, EXTR_RS, EXTRV, EXTRV_RS

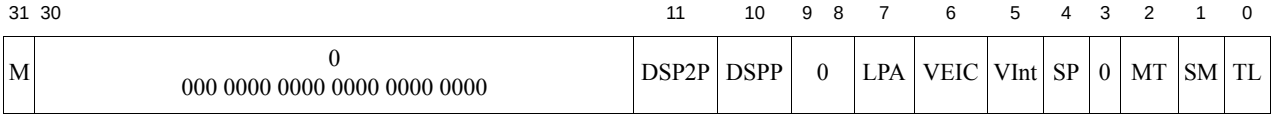
3.11 Software Detection of the DSP Module

Bit 10 in the *config3* CP0 register, "DSP Present" (DSPP), is used to indicate the presence of the MIPS DSP Module, and bit 11, "DSP Rev2 Present," (DSP2P), the presence of the MIPS DSP Module Rev2, as shown in Figure 3.6. Valid MIPS DSP Module Rev2 implementations set both DSPP and DSP2P bits: the condition of DSP2P set and DSPP unset is invalid. Software may read the DSPP, DSP2P bits of the *config3* CP0 register to check whether this processor has implemented the MIPS DSP Module and MIPS DSP Module Rev2.

Release 6 of the MIPS Architecture moves the accumulators into the DSP Module for use as a DSP resource exclusively, and introduces the compact branch BPOSGE32C, for which DSP Module Rev3 is required. An implementation supports Rev3 if CP0 $\texttt{Config3}_{\texttt{DSPP}}$=1 and $\texttt{Config3}_{\texttt{DSP2P}}$=1 and $\texttt{Config}_{\texttt{AR}}$>=2.

Any attempt to execute MIPS DSP Module instructions must cause a Reserved Instruction Exception if DSPP, and DSP2P are not indicating the presence of the appropriate MIPS DSP Module implementation. The DSPP and DSP2P bits are fixed by the hardware implementation and are read-only for software.

Figure 3.6 Config3 Register Format



The "DSP Module Enable" (DSPEn) bit—the MX bit, bit 24 in the CP0 *Status* register as shown in Figure 3.7—is used to enable access to the extra instructions defined by the MIPS DSP Module as well as enabling four modified move instructions (MTLO/HI and MFLO/HI) that provide access to the three additional accumulators *ac1*, *ac2*, and *ac3*. Executing a MIPS DSP Module instruction or one of the four modified move instructions when DSPEn is set to zero causes a DSP State Disabled Exception and results in exception code 26 in the CP0 *Cause* register. This allows the OS to do lazy context-switching. Table 3.6 shows the *Cause* Register exception code fields.

Figure 3.7 CP0 Status Register Format

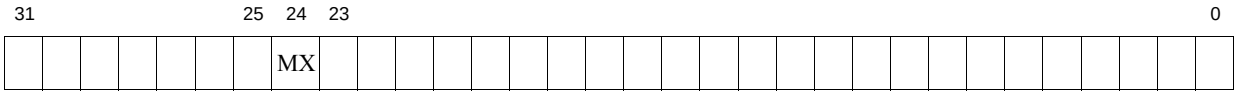


Table 3.6 Cause Register ExcCode Field

Exception Code Value		Mnemonic	Description
Decimal	Hexadecimal		
26	16#1a	DSPDis	DSP Module State Disabled Exception

3.12 Exception Table for the DSP Module

Table 3.7 shows the exceptions caused when a MIPS DSP Module or MIPS DSP Module Rev2 instruction, MTLO/HI or MFLO/HI, or any other instruction such as an CorExtend instruction attempts to access the new DSP Module state, that is, *ac1*, *ac2*, or *ac3*, or the *DSPControl* register, and all other possible exceptions that relate to the DSP Module.

Table 3.7 Exception Table for the DSP Module

$Config3_{DSP2P}$	$Config3_{DSPP}$	$Status_{MX}$	Exception for DSP Module Rev2 Instructions	Exception for DSP Module Instructions
0	0	×	Reserved Instruction	
0	1	0	Reserved Instruction	DSP Module State Disabled
0	1	1	Reserved Instruction	None
1	1	0	DSP Module State Disabled	
1	1	1	None	
1	1	0	DSP Module State Disabled	
1	1	1	None	

3.13 DSP Module Instructions that Read and Write the DSPControl Register

Many MIPS DSP Module instructions read and write the *DSPControl* register, some explicitly and some implicitly. Like other register resource in the architecture, it is the responsibility of the hardware implementation to ensure that appropriate execution dependency barriers are inserted and the pipeline stalled for read-after-write dependencies and

other data dependencies that may occur. Table 3.8 lists the MIPS DSP Module instructions that can read and write the *DSPControl* register and the bits or fields in the register that they read or write.

Table 3.8 Instructions that Read/Write Fields in DSPControl

Instruction	Read/Write	DSPControl Field (Bits)
WRDSP	W	All (31:0)
EXTPDP, EXTPDPV,MTHLIP	W	pos (5:0)
ADDSC	W	c (13)
EXTP, EXTPV, EXTPDP, EXTPDPV	W	EFI (14)
See Table 3.5	W	ouflag (23:16)
CMP, CMPU, and CMPGDU variants	W	ccond (27:24)
RDDSP	R	All (31:0)
BPOSGE32, BPOSGE32C, EXTP, EXTPV, EXTPDP, EXTPDPV, INSV	R	pos (5:0)
INSV	R	scount (12:7)
ADDWC	R	c (13)
PICK variants	R	ccond (27:24)

3.14 Arithmetic Exceptions

Under no circumstances do any of the MIPS DSP Module instructions cause an arithmetic exception. Other exceptions are possible, for example, the indexed load instruction can cause an address exception. The specific exceptions caused by the different instructions are listed in the per-instruction description pages.

Chapter 4

MIPS® DSP Module Instruction Summary

4.1 The MIPS® DSP Module Instruction Summary

The tables in this chapter list all the instructions in the DSP Module. For operation details about each instruction, refer to the per-page descriptions. In each table, the column entitled "Writes GPR / ac / *DSPControl*", indicates the explicit write performed by each instruction. This column indicates the writing of a field in the *DSPControl* register other than the *ouflag* field (which is written by a large number of instructions as a side-effect).

Table 4.1 List of Instructions in MIPS® DSP Module in Arithmetic Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
ADDQ.PH rd,rs,rt ADDQ_S.PH rd,rs,rt	Pair Q15	Pair Q15	GPR	VoIP SoftM	Element-wise addition of two vectors of Q15 fractional values, with optional saturation.
ADDQ_S.W rd,rs,rt	Q31	Q31	GPR	Audio	Add two Q31 fractional values with saturation.
ADDU.QB rd,rs,rt ADDU_S.QB rd,rs,rt	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise addition of unsigned byte values, with optional unsigned saturation.
ADDUH.QB rd,rs,rt ADDUH_R.QB rd,rs,rt **MIPSDSP-R2 Only**	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise addition of vectors of four unsigned byte values, halving each result by right-shifting by one bit position. Results may be optionally rounded up in the least-significant bit.
ADDU.PH rd,rs,rt ADDU_S.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Unsigned Halfword	Pair Unsigned Halfword	GPR	Video	Element-wise addition of vectors of two unsigned halfword values, with optional saturation on overflow.
ADDQH.PH rd,rs,rt ADDQH_R.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Pair Signed Halfword	GPR	Misc	Element-wise addition of vectors of two signed halfword values, halving each result with right-shifting by one bit position. Results may be optionally rounded up in the least-significant bit.
ADDQH.W rd,rs,rt ADDQH_R.W rd,rs,rt **MIPSDSP-R2 Only**	Signed Word	Signed Word	GPR	Misc	Add two signed word values, halving the result with right-shifting by one bit position. Result may be optionally rounded up in the least-significant bit.
SUBQ.PH rd,rs,rt SUBQ_S.PH rd,rs,rt	Pair Q15	Pair Q15	GPR	VoIP	Element-wise subtraction of two vectors of Q15 fractional values, with optional saturation.
SUBQ_S.W rd,rs,rt	Q31	Q31	GPR	Audio	Subtraction with Q31 fractional values, with saturation.

Table 4.1 List of Instructions in MIPS® DSP Module in Arithmetic Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
SUBU.QB rd,rs,rt SUBU_S.QB rd,rs,rt	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise subtraction of unsigned byte values, with optional unsigned saturation.
SUBUH.QB rd,rs,rt SUBUH_R.QB rd,rs,rt **MIPSDSP-R2 Only**	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise subtraction of unsigned byte values, shifting the results right one bit position (halving). The results may be optionally rounded up by adding 1 to each result at the most-significant discarded bit position before shifting.
SUBU.PH rd,rs,rt SUBU_S.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Unsigned Halfword	Pair Unsigned Halfword	GPR	Video	Element-wise subtraction of vectors of two unsigned halfword values, with optional saturation on overflow.
SUBQH.PH rd,rs,rt SUBQH_R.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Pair Signed Halfword	GPR	Misc	Element-wise subtraction of vectors of two signed halfword values, halving each result with right-shifting by one bit position. Results may be optionally rounded up in the least-significant bit.
SUBQH.W rd,rs,rt SUBQH_R.W rd,rs,rt **MIPSDSP-R2 Only**	Signed Word	Signed Word	GPR	Misc	Subtract two signed word values, halving the result with right-shifting by one bit position. Result may be optionally rounded up in the least-significant bit.
ADDSC rd,rs,rt	Signed Word	Signed Word	GPR & *DSPControl*	Audio	Add two signed words and set the carry bit in the *DSPControl* register.
ADDWC rd,rs,rt	Signed Word	Signed Word	GPR	Audio	Add two signed words with the carry bit from the *DSPControl* register.
MODSUB rd,rs,rt	Signed Word	Signed Word	GPR	Misc	Modulo addressing support: update a byte index into a circular buffer by subtracting a specified decrement (in bytes) from the index, resetting the index to a specified value if the subtraction results in underflow.
RADDU.W.QB rd,rs	Quad Unsigned Byte	Unsigned Word	GPR	Misc	Reduce (add together) the 4 unsigned byte values in *rs*, zero-extending the sum to 32 bits before writing to the destination register. For example, if all 4 input values are 0x80 (decimal 128), then the result in *rd* is 0x200 (decimal 512).
ABSQ_S.QB rd,rt **MIPSDSP-R2 Only**	Quad Q7	Quad Q7	GPR	Misc	Find the absolute value of each of four Q7 fractional byte elements in the source register, saturating values of -1.0 to the maximum positive Q7 fractional value.
ABSQ_S.PH rd,rt	Pair Q15	Pair Q15	GPR	Misc	Find the absolute value of each of two Q15 fractional halfword elements in the source register, saturating values of -1.0 to the maximum positive Q15 fractional value.

Table 4.1 List of Instructions in MIPS® DSP Module in Arithmetic Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
ABSQ_S.W rd,rt	Q31	Q31	GPR	Misc	Find the absolute value of the Q31 fractional element in the source register, saturating the value -1.0 to the maximum positive Q31 fractional value.
PRECR.QB.PH rd,rs,rt **MIPSDSP-R2 Only**	Two Pair Integer Halfwords	Four Integer Bytes	GPR	Misc	Reduce the precision of four signed integer halfword input values by discarding the eight most-significant bits from each to create four signed integer byte output values. The two halfword values from register *rs* are used to create the two left-most byte results, allowing an endian-agnostic implementation.
PRECRQ.QB.PH rd,rs,rt	2 Pair Q15	Quad Byte	GPR	Misc	Reduce the precision of four Q15 fractional input values by truncation to create four Q7 fractional output values. The two Q15 values from register *rs* are written to the two left-most byte results, allowing an endian-agnostic implementation.
PRECR_SRA.PH.W rt,rs,sa PRECR_SRA_R.PH.W rt,rs,sa **MIPSDSP-R2 Only**	Two Integer Words	Pair Integer Halfword	GPR	Misc	Reduce the precision of two integer word values to create a pair of integer halfword values. Each word value is first shifted right arithmetically by *sa* bit positions, and optionally rounded up by adding 1 at the most-significant discard bit position. The 16 least-significant bits of each word are then written to the corresponding halfword elements of destination register *rt*.
PRECRQ.PH.W rd,rs,rt PRECRQ_RS.PH.W rd,rs,rt	2 Q31	Pair halfword	GPR	Misc	Reduce the precision of two Q31 fractional input values by truncation to create two Q15 fractional output values. The Q15 value obtained from register *rs* creates the left-most result, allowing an endian-agnostic implementation. Results may be optionally rounded up and saturated before being written to the destination.
PRECRQU_S.QB.PH rd,rs,rt	2 Pair Q15	Quad Unsigned Byte	GPR	Misc	Reduce the precision of four Q15 fractional values by saturating and truncating to create four unsigned byte values.
PRECEQ.W.PHL rd,rt PRECEQ.W.PHR rd,rt	Q15	Q31	GPR	Misc	Expand the precision of a Q15 fractional value to create a Q31 fractional value by adding 16 least-significant bits to the input value.
PRECEQU.PH.QBL rd,rt PRECEQU.PH.QBR rd,rt PRECEQU.PH.QBLA rd,rt PRECEQU.PH.QBRA rd,rt	Unsigned Byte	Q15	GPR	Video	Expand the precision of two unsigned byte values by prepending a sign bit and adding seven least-significant bits to each to create two Q15 fractional values.

Table 4.1 List of Instructions in MIPS® DSP Module in Arithmetic Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
PRECEU.PH.QBL rd,rt PRECEU.PH.QBR rd,rt PRECEU.PH.QBLA rd,rt PRECEU.PH.QBRA rd,rt	Unsigned Byte	Unsigned halfword	GPR	Video	Expand the precision of two unsigned byte values by adding eight least-significant bits to each to create two unsigned halfword values.

Table 4.2 List of Instructions in MIPS® DSP Module in GPR-Based Shift Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
SHLL.QB rd, rt, sa SHLLV.QB rd, rt, rs	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Misc	Element-wise left shift of eight signed bytes. Zeros are inserted into the bits emptied by the shift. The shift amount is specified by the three least-significant bits of sa or *rs*.
SHLL.PH rd, rt, sa SHLLV.PH rd, rt, rs SHLL_S.PH rd, rt, sa SHLLV_S.PH rd, rt, rs	Pair Signed halfword	Pair Signed halfword	GPR	Misc	Element-wise left shift of two signed half-words, with optional saturation on overflow. Zeros are inserted into the bits emptied by the shift. The shift amount is specified by the four least-significant bits of sa or *rs*.
SHLL_S.W rd, rt, sa SHLLV_S.W rd, rt, rs	Signed Word	Signed Word	GPR	Misc	Left shift of a signed word, with saturation on overflow. Zeros are inserted into the bits emptied by the shift. The shift amount is specified by the five least-significant bits of sa or *rs*. Use the MIPS32 instructions SLL or SLLV for non-saturating shift operations.
SHRL.QB rd, rt, sa SHRLV.QB rd, rt, rs	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise logical right shift of four byte values. Zeros are inserted into the bits emptied by the shift. The shift amount is specified by the three least-significant bits of sa or *rs*.
SHRL.PH rd, rt, sa SHRLV.PH rd, rt, rs **MIPSDSP-R2 Only**	Pair Half-words	Pair Half-words	GPR	Video	Element-wise logical right shift of two half-word values. Zeros are inserted into the bits emptied by the shift. The shift amount is specified by the four least-significant bits of *rs* or the *sa* argument.
SHRA.QB rd,rt,sa SHRA_R.QB rd,rt,sa SHRAV.QB rd,rt,rs SHRAV_R.QB rd,rt,rs **MIPSDSP-R2 Only**	Quad Byte	Quad Byte	GPR	Misc	Element-wise arithmetic (sign preserving) right shift of four byte values. Optional rounding may be performed, adding 1 at the most-significant discard bit position. The shift amount is specified by the three least-significant bits of *rs* or by the argument *sa*.

Table 4.2 List of Instructions in MIPS® DSP Module in GPR-Based Shift Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
SHRA.PH rd, rt, sa SHRAV.PH rd, rt, rs SHRA_R.PH rd, rt, sa SHRAV_R.PH rd, rt, rs	Pair Signed halfword	Pair Signed halfword	GPR	Misc	Element-wise arithmetic (sign preserving) right shift of two halfword values. Optionally, rounding may be performed, adding 1 at the most-significant discard bit position. The shift amount is specified by the four least-significant bits of *rs* or by the argument *sa*.
SHRA_R.W rd, rt, sa SHRAV_R.W rd, rt, rs	Signed Word	Signed Word	GPR	Video	Arithmetic (sign preserving) right shift of a word value. Optionally, rounding may be performed, adding 1 at the most-significant discard bit position. The shift amount is specified by the five least-significant bits of *rs* or the argument *sa*.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
MULEU_S.PH.QBL rd,rs,rt MULEU_S.PH.QBR rd,rs,rt	Pair Unsigned Byte, Pair Unsigned Halfword,	Pair Unsigned Halfword	GPR	Still Image	Element-wise multiplication of two unsigned byte values from register *rs* with two unsigned halfword values from register *rt*. Each 24-bit product is truncated to 16 bits, with saturation if the product exceeds 0xFFFF, and written to the corresponding element in the destination register.
MULQ_RS.PH rd,rs,rt	Pair Q15	Pair Q15	GPR	Misc	Element-wise multiplication of two Q15 fractional values to create two Q15 fractional results, with rounding and saturation. After multiplication, each 32-bit product is rounded up by adding 0x00008000, then truncated to create a Q15 fractional value that is written to the destination register. If both multiplicands are -1.0, the result is saturated to the maximum positive Q15 fractional value. To stay compliant with the base architecture, this instruction leaves the base *HI-LO* pair **UNPREDICTABLE** after the operation. The other DSP Module accumulators *ac1-ac3* are untouched.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
MULEQ_S.W.PHL rd,rs,rt MULEQ_S.W.PHR rd,rs,rt	Pair Q15	Q31	GPR	VoIP	Multiplication of two Q15 fractional values, shifting the product left by 1 bit to create a Q31 fractional result. If both multiplicands are -1.0 the result is saturated to the maximum positive Q31 value. To stay compliant with the base architecture, this instruction leaves the base *HI-LO* pair **UNPREDICTABLE** after the operation. The other DSP Module accumulators *ac1-ac3* must be untouched.
DPAU.H.QBL DPAU.H.QBR	Pair Bytes	Halfword	Acc	Image	Dot-product accumulation. Two pairs of corresponding unsigned byte elements from source registers *rt* and *rs* are separately multiplied, and the two 16-bit products are then summed together. The summed products are then added to the accumulator.
DPSU.H.QBL DPSU.H.QBR	Pair Bytes	Halfword	Acc	Image	Dot-product subtraction. Two pairs of corresponding unsigned byte elements from source registers *rt* and *rs* are separately multiplied, and the two 16-bit products are then summed together. The summed products are then subtracted from the accumulator.
DPA.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Pair Signed Halfword	ac	VoIP / SoftM	Dot-product accumulation. The two pairs of corresponding signed integer halfword values from source registers *rt* and *rs* are separately multiplied to create two separate integer word products. The products are then summed and accumulated into the specified accumulator.
DPAX.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Double-word	ac	VoIP	Dot-product with crossed operands and accumulation. The two crossed pairs of signed integer halfword values from source registers *rt* and *rs* are separately multiplied to create two separate integer word products. The products are then summed and accumulated into the specified accumulator.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
DPAQ_S.W.PH ac,rs,rt	Pair Q15	Q32.31	ac	VoIP / SoftM	Dot-product accumulation. Two pairs of corresponding Q15 fractional values from source registers *rt* and *rs* are separately multiplied and left-shifted 1 bit to create two Q31 fractional products. For each product, if both multiplicands are equal to -1.0 the product is clamped to the maximum positive Q31 fractional value. The products are then summed, and the sum is then sign extended to the width of the accumulator and accumulated into the specified accumulator. This instruction may be used to compute the imaginary component of a 16-bit complex multiplication operation after first swapping the operands to place them in the correct order.
DPAQX_S.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Q32.31	ac	VoIP	Dot-product with saturating fractional multiplication and using crossed operands, with a final accumulation. The two crossed pairs of signed fractional halfword values from source registers *rt* and *rs* are separately multiplied to create two separate fractional word products. The products are then summed and accumulated into the specified accumulator.
DPAQX_SA.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Q32.31	ac	VoIP	Dot-product with saturating fractional multiplication and using crossed operands, with a final saturating accumulation. The two crossed pairs of signed fractional halfword values from source registers *rt* and *rs* are separately multiplied to create two separate fractional word products. The products are then summed and accumulated with saturation into the specified accumulator.
DPS.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Double-word	ac	VoIP / SoftM	Dot-product subtraction. The two pairs of corresponding signed integer halfword values from source registers *rt* and *rs* are separately multiplied to create two separate integer word products. The products are then summed and subtracted from the specified accumulator.
DPSX.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Q32.31	ac	VoIP	Dot-product with crossed operands and subtraction. The two crossed pairs of signed integer halfword values from source registers *rt* and *rs* are separately multiplied to create two separate integer word products. The products are then summed and subtracted into the specified accumulator.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
DPSQ_S.W.PH ac,rs,rt	Pair Q15	Q32.31	ac	VoIP / SoftM	Dot-product subtraction. Two pairs of corresponding Q15 fractional values from source registers *rt* and *rs* are separately multiplied and left-shifted 1 bit to create two Q31 fractional products. For each product, if both multiplicands are equal to -1.0 the product is clamped to the maximum positive Q31 fractional value. The products are then summed, and the sum is then sign extended to the width of the accumulator and subtracted from the specified accumulator. This instruction may be used to compute the imaginary component of a 16-bit complex multiplication operation after first swapping the operands to place them in the correct order.
DPSQX_S.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Q32.31	ac	VoIP	Dot-product with saturating fractional multiplication and using crossed operands, with a final subtraction. The two crossed pairs of signed fractional halfword values from source registers *rt* and *rs* are separately multiplied to create two separate fractional word products. The products are then summed and subtracted from the specified accumulator.
DPSQX_SA.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Q32.31	ac	VoIP	Dot-product with saturating fractional multiplication and using crossed operands, with a final saturating subtraction. The two crossed pairs of signed fractional halfword values from source registers *rt* and *rs* are separately multiplied to create two separate fractional word products. The products are then summed and subtracted with saturation into the specified accumulator.
MULSAQ_S.W.PH ac,rs,rt	Pair Q15	Q32.31	ac	SoftM	Complex multiplication step. Performs element-wise fractional multiplication of the two Q15 fractional values from registers *rt* and *rs*, subtracting one product from the other to create a Q31 fractional result that is added to accumulator *ac*. The intermediate products are saturated to the maximum positive Q31 fractional value if both multiplicands are equal to -1.0.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
DPAQ_SA.L.W ac,rs,rt	Q31	Q63	ac	Audio	Fractional multiplication of two Q31 fractional values to produce a Q63 fractional product. If both multiplicands are -1.0 the product is saturated to the maximum positive Q63 fractional value. The product is then added to accumulator *ac*. If the addition results in overflow or underflow, the accumulator is saturated to the maximum positive or minimum negative value.
DPSQ_SA.L.W ac,rs,rt	Q31	Q63	ac	Audio	Fractional multiplication of two Q31 fractional values to produce a Q63 fractional product. If both multiplicands are -1.0 the product is saturated to the maximum positive Q63 fractional value. The product is then subtracted from accumulator *ac*. If the addition results in overflow or underflow, the accumulator is saturated to the maximum positive or minimum negative value.
MAQ_S.W.PHL ac,rs,rt MAQ_S.W.PHR ac,rs,rt	Q15	Q32.31	ac	SoftM	Fractional multiply-accumulate. The product of two Q15 fractional values is sign extended to the width of the accumulator and added to accumulator *ac*. The intermediate product is saturated to the maximum positive Q31 fractional value if both multiplicands are equal to -1.0.
MAQ_SA.W.PHL ac,rs,rt MAQ_SA.W.PHR ac,rs,rt	Q15	Q31	ac	speech	Fractional multiply-accumulate with saturation after accumulation. The product of two Q15 fractional values is sign extended to the width of the accumulator and added to accumulator *ac*. The intermediate product is saturated to the maximum positive Q31 fractional value if both multiplicands are equal to -1.0. If the accumulation results in overflow or underflow, the accumulator value is saturated to the maximum positive or minimumnegative Q31 fractional value.
MUL.PH rd,rs,rt MUL_S.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Pair Signed Halfword	GPR	speech	Element-wise multiplication of two vectors of signed integer halfwords, writing the 16 least-significant bits of each 32-bit product to the corresponding element of the destination register. Optional saturation clamps each 16-bit result to the maximum positive or minimum negative value if the product cannot be accurately represented in 16 bits.

Table 4.3 List of Instructions in MIPS® DSP Module in Multiply Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
MULQ_S.PH rd,rs,rt **MIPSDSP-R2 Only**	Pair Q15	Pair Q15	GPR	speech	Element-wise multiplication of two vectors of Q15 fractional halfwords, writing the 16 most-significant bits of each Q31-format product to the corresponding element of the destination register. Each result is saturated to the maximum positive Q15 value if both multiplicands were equal to -1.0 (0x8000 hexadecimal).
MULQ_S.W rd,rs,rt **MIPSDSP-R2 Only**	Q31	Q31	GPR	speech	Fractional multiplication of two Q31 format words to create a Q63 format result that is truncated by discarding the 32 least-significant bits before being written to the destination register. The result is saturated to the maximum positive Q31 value if both multiplicands were equal to -1.0 (0x80000000 hexadecimal).
MULQ_RS.W rd,rs,rt **MIPSDSP-R2 Only**	Q31	Q31	GPR	speech	Multiplication of two Q31 fractional words to create a Q63-format intermediate product that is rounded up by adding a 1 at bit position 31. The 32 most-significant bits of the rounded result are then written to the destination register. If both multiplicands were equal to -1.0 (0x80000000 hexadecimal), rounding is not performed and the result is clamped to the maximum positive Q31 value before being written to the destination.
MULSA.W.PH ac,rs,rt **MIPSDSP-R2 Only**	Pair Signed Halfword	Double-word	ac	speech	Element-wise multiplication of two vectors of signed integer halfwords to create two 32-bit word intermediate results. The right intermediate result is subtracted from the left intermediate result, and the resulting sum is accumulated into the specified accumulator.

MADD ac,rs,rt
MADDU ac,rs,rt
MSUB ac,rs,rt
MSUBU ac,rs,rt
MULT ac,rs,rt
MULTU ac,rs,rt
	Word	Double-word	ac	Misc	Allows these instructions to target accumulators *ac1*, *ac2*, and *ac3* (in addition to the original *ac0* destination).

Table 4.4 List of Instructions in MIPS® DSP Module in Bit/ Manipulation Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
BITREV rd,rt	Unsigned Word	Unsigned Word	GPR	Audio / FFT	Reverse the order of the 16 least-significant bits of register *rt*, writing the result to register *rd*. The most-significant bits are set to zero.
INSV rt,rs	Unsigned Word	Unsigned Word	GPR	Misc	Like the Release 2 INS instruction, except that the 5 bits for *pos* and *size* values are obtained from the *DSPControl* register. *size* = scount[14:10], and *pos* = pos[20:16].
REPL.QB rd,imm REPLV.QB rd,rt	Byte	Quad Byte	GPR	Video / Misc	Replicate a signed byte value into the four byte elements of register *rd.* The byte value is given by the 8 least-significant bits of the specified 10-bit immediate constant or by the 8 least-significant bits of register *rt*.
REPL.PH rd,imm REPLV.PH rd,rt	Signed halfword	Pair Signed halfword	GPR	Misc	Replicate a signed halfword value into the two halfword elements of register *rd.* The half-word value is given by the 16 least-significant bits of register *rt*, or by the value of the 10-bit immediate constant, sign-extended to 16 bits.

Table 4.5 List of Instructions in MIPS® DSP Module in Compare-Pick Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
CMPU.EQ.QB rs,rt CMPU.LT.QB rs,rt CMPU.LE.QB rs,rt	Quad Unsigned Byte	Quad Unsigned Byte	DSPControl	Video	Element-wise unsigned comparison of the four unsigned byte elements of *rs* and *rt*, recording the boolean comparison results to the four right-most bits in the *ccond* field of the *DSPControl* register.
CMPGDU.EQ.QB rd,rs,rt CMPGDU.LT.QB rd,rs,rt CMPGDU.LE.QB rd,rs,rt **MIPSDSP-R2 Only**	Quad Unsigned Byte	Quad Unsigned Byte	GPR DSPControl	Video	Element-wise unsigned comparison of the four right-most unsigned byte elements of *rs* and *rt*, recording the boolean comparison results to the four least-significant bits of register *rd* and to the four right-most bits in the *ccond* field of the *DSPControl* register.
CMPGU.EQ.QB rd,rs,rt CMPGU.LT.QB rd,rs,rt CMPGU.LE.QB rd,rs,rt	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise unsigned comparison of the four right-most unsigned byte elements of *rs* and *rt*, recording the boolean comparison results to the four least-significant bits of register *rd*.

Table 4.5 List of Instructions in MIPS® DSP Module in Compare-Pick Sub-class (Continued)

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
CMP.EQ.PH rs,rt CMP.LT.PH rs,rt CMP.LE.PH rs,rt	Pair Signed halfword	Pair Signed halfword	DSPControl	Misc	Element-wise signed comparison of the two halfword elements of *rs* and *rt*, recording the boolean comparison results to the two right-most bits in the *ccond* field of the *DSPControl* register.
PICK.QB rd,rs,rt	Quad Unsigned Byte	Quad Unsigned Byte	GPR	Video	Element-wise selection of unsigned bytes from the four bytes of registers *rs* and *rt* into the corresponding elements of register *rd*, based on the value of the four right-most bits of the *ccond* field in the *DSPControl* register. If the corresponding *ccond* bit is 1, the byte value is copied from register *rs*, otherwise it is copied from *rt*.
PICK.PH rd,rs,rt	Pair Signed halfword	Pair Signed halfword	GPR	Misc	Element-wise selection of signed halfwords from the two halfwords in registers *rs* and *rt* into the corresponding elements of register *rd*, based on the value of the two right-most bits of the *ccond* field in the *DSPControl* register. If the corresponding *ccond* bit is 1, the halfword value is copied from register *rs*, otherwise it is copied from *rt*.
APPEND rt,rs,sa **MIPSDSP-R2 Only**	Two Words	Word	GPR	Misc	Shifts the 32-bit word in register *rt* left by *sa* bits, inserting the *sa* least-significant bits from register *rs* into the bit positions emptied by the shift. The 32-bit result is then written to register *rt*.
PREPEND rt,rs,sa **MIPSDSP-R2 Only**	Two Words	Word	GPR	Misc	Shifts the 32-bit word in register *rt* right by *sa* bits, inserting the *sa* least-significant bits from register *rs* into the bit positions emptied by the shift. The 32-bit result is then written to register *rt*.
BALIGN rt,rs,bp **MIPSDSP-R2 Only**	Two Words	Word	GPR	Misc	Packs *bp* bytes from register *rt* and (4-*bp*) bytes from register *rs* into a 32-bit word and writes it to register *rt*.
PACKRL.PH rd,rs,rt	Pair Signed Halfwords	Pair Signed Halfword	GPR	Misc	Pack two halfwords taken from registers *rs* and *rt* into destination register *rd*.

Table 4.6 List of Instructions in MIPS® DSP Module in Accumulator and DSPControl Access Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
EXTR.W rt,ac,shift EXTR_R.W rt,ac,shift EXTR_RS.W rt,ac,shift	Q63	Q31	GPR	Misc	Extract a Q31 fractional value from the 32 least-significant bits of 64-bit accumulator *ac*. The accumulator value may be shifted right logically by *shift* bits prior to the extraction, and the extracted value may be optionally rounded or rounded and saturated before being written to register *rt*. The *shift* argument value ranges from 0 to 31. The optional rounding step adds 1 at the most-significant bit position discarded by the shift. The optional saturation clamps the extracted value to the maximum positive Q31 value if the rounding step results in overflow.
EXTR_S.H rt,ac,shift	Q63	Q15	GPR	Misc	Extract a Q15 fractional value from the 16 least-significant bits of 64-bit accumulator *ac*. The accumulator value may be shifted right logically by *shift* bits prior to the extraction, and the extracted value is saturated before being written to register *rt*. The *shift* argument value ranges from 0 to 31. The saturation clamps the extracted value to the maximum positive or minimum negative Q15 value if the shifted accumulator value cannot be represented accurately as a Q15 format value.
EXTRV_S.H rt,ac,rs	Q63	Q15	GPR	Misc	Extract a Q15 fractional value from the 16 least-significant bits of 64-bit accumulator *ac*. The accumulator value may be shifted right logically by *shift* bits prior to the extraction, and the extracted value is saturated before being written to register *rt*. The *shift* argument ranges from 0 to 31 and is given by the five least-significant bits of register *rs*. The saturation clamps the extracted value to the maximum positive or minimum negative Q15 value if the shifted accumulator value cannot be represented accurately as a Q15 format value.

Table 4.6 List of Instructions in MIPS® DSP Module in Accumulator and DSPControl Access Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
EXTRV.W rt,ac,rs EXTRV_R.W rt,ac,rs EXTRV_RS.W rt,ac,rs	Q63	Q31	GPR	Misc	Extract a Q31 fractional value from the 32 least-significant bits of 64-bit accumulator *ac*. The accumulator value may be shifted right logically by *shift* bits prior to the extraction, and the extracted value may be optionally rounded or rounded and saturated before being written to register *rt*. The *shift* argument value is provided by the five least-significant bits of *rs* and ranges from 0 to 31. The optional rounding step adds 1 at the most-significant bit position discarded by the shift. The optional saturation clamps the extracted value to the maximum positive Q31 value if the rounding step results in overflow.
EXTP rt,ac,size EXTPV rt,ac,rs EXTPDP rt,ac,size EXTPDPV rt,ac,rs	Unsigned DWord	Unsigned Word	GPR / *DSPControl*	Audio / Video	Extract a set of *size*+1 contiguous bits from accumulator *ac*, right-justifying and sign-extending the result to 32 bits before writing the result to register *rt*. The position of the left-most bit to extract is given by the value of the *pos* field in the *DSPControl* register (see Appendix A for details). The number of bits (less one) to extract is provided either by the *size* immediate operand or by the five least-significant bits of *rs*. The EXTPDP and EXTPDPV instructions also decrement the *pos* field by *size*+1 to facilitate sequential bit field extraction operations.
SHILO ac,shift SHILOV ac,rs	Unsigned DWord	Unsigned DWord	ac	Misc	Shift accumulator *ac* left or right by the specified number of bits, writing the shifted value back to the accumulator. The signed shift argument is specified either by the immediate operand *shift* or by the six least-significant bits of register *rs*. A negative shift argument results in a right shift of up to 32 bits, and a positive shift argument results in a left shift of up to 31 bits.
MTHLIP rs, ac	Unsigned Word	Unsigned Word	ac / *DSPControl*	Audio / Video	Copy the *LO* register of the specified accumulator to the *HI* register, copy *rs* to *LO*, and increment the *pos* field in *DSPcontrol* by 32.
MFHI/MFLO/MTHI/MTLO	Unsigned Word	Unsigned Word	GPR/ac	Misc	Copy an unsigned word to or from the specified accumulator *HI* or *LO* register to the specified GPR.

Table 4.6 List of Instructions in MIPS® DSP Module in Accumulator and DSPControl Access Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
WRDSP rt,mask	Unsigned Word	Unsigned Word	*DSPControl*	Misc	Overwrite specific fields in the *DSPControl* register using the corresponding bits from the specified GPR. Bits in the *mask* argument correspond to specific fields in *DSPControl*; a value of 1 causes the corresponding *DSPControl* field to be overwritten using the corresponding bits in *rt*, otherwise the field is unchanged.
RDDSP rt,mask	Unsigned Word	Unsigned Word	GPR	Misc	Copy the values of specific fields in the *DSPControl* register to the specified GPR. Bits in the *mask* argument correspond to specific fields in *DSPControl*; a value of 1 causes the corresponding *DSPControl* field to be copied to the corresponding bits in *rt*, otherwise the bits in *rt* are unchanged.

Table 4.7 List of Instructions in MIPS® DSP Module in Indexed-Load Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
LBUX rd,index(base)	-	Unsigned byte	GPR	Misc	Index byte load from address base+(index). Loads the byte in the low-order bits of the destination register and zero-extends the result.
LHX rd,index(base)	-	Signed halfword	GPR	Misc	Index halfword load from address base+(index). Loads the halfword in the low-order bits of the register and sign-extends the result.
LWX rd, index(base)	-	Signed Word	GPR	Misc	Indexed word load from address base+(index).

Table 4.8 List of Instructions in MIPS® DSP Module in Branch Sub-class

Instruction Mnemonics	Input Data Type	Output Data Type	Writes GPR / ac / DSPControl	App	Description
BPOSGE32 offset BPOSGE32C offset	-	-	-	Audio / Video	Branch if the *pos* value is greater than or equal to integer 32.

Chapter 5

Instruction Encoding

5.1 Instruction Bit Encoding

This chapter describes the bit encoding tables used for the MIPS DSP Module. Table 5.1 describes the meaning of the symbols used in the tables. These tables only list the instruction encoding for the MIPS DSP Module instructions. See Volumes I and II of this multi-volume set for a full encoding of all instructions.

Figure 5.1 shows a sample encoding table and the instruction *opcode* field this table encodes. Bits 31..29 of the *opcode* field are listed in the left-most columns of the table. Bits 28..26 of the *opcode* field are listed along the top-most rows of the table. Both decimal and binary values are given, with the first three bits designating the row, and the last three bits designating the column.

An instruction's encoding is found at the intersection of a row (bits 31..29) and column (bits 28..26) value. For instance, the *opcode* value for the instruction labelled EX1 is 33 (decimal, row and column), or 011011 (binary). Similarly, the *opcode* value for EX2 is 64 (decimal), or 110100 (binary).

Figure 5.1 Sample Bit Encoding Table

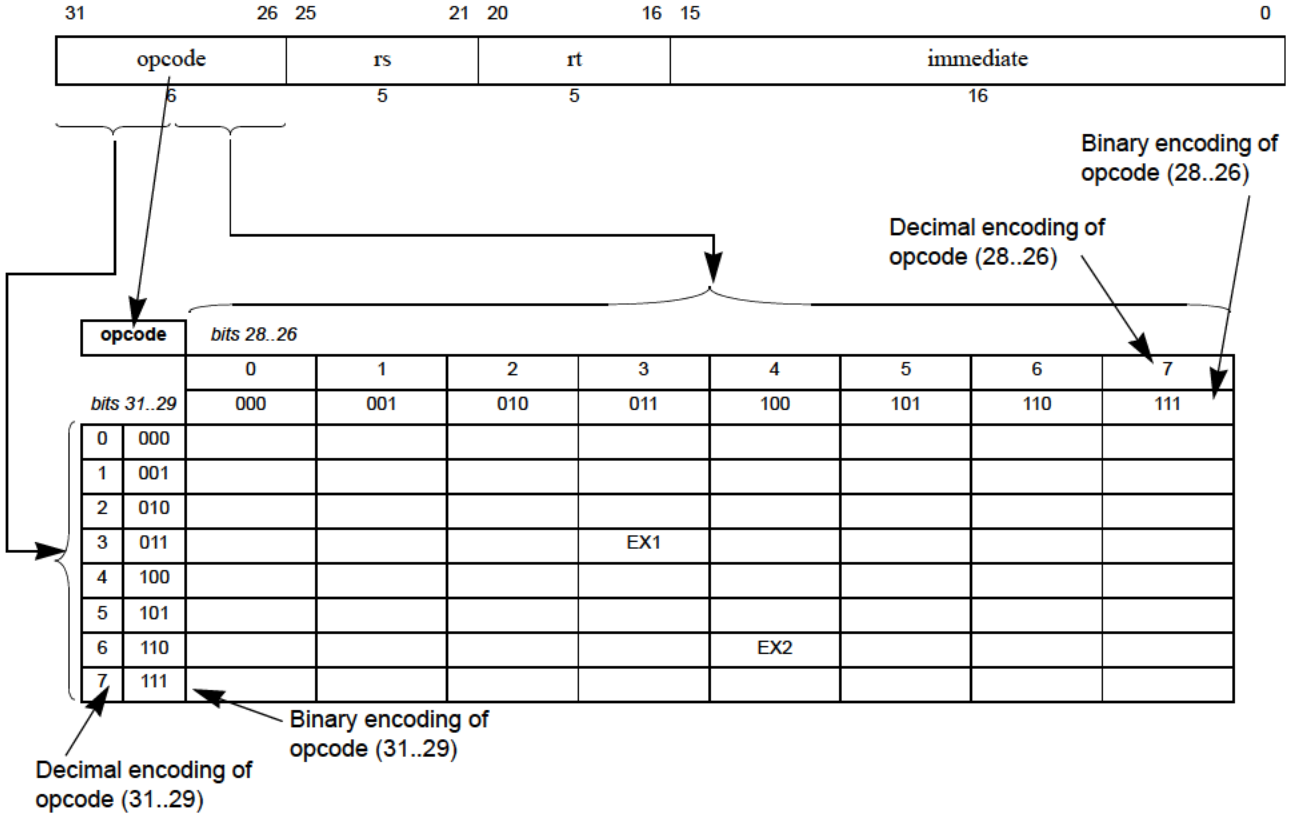


Table 5.1 Symbols Used in the Instruction Encoding Tables

Symbol	Meaning
*	Operation or field codes marked with this symbol are reserved for future use. Executing such an instruction must cause a Reserved Instruction Exception.
δ	(Also *italic* 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.
θ	Operation or field codes marked with this symbol are available to licensed MIPS partners. To avoid multiple conflicting instruction definitions, MIPS Technologies will assist the partner in selecting appropriate encoding if requested by the partner. The partner is not required to consult with MIPS Technologies when one of these encoding is used. If no instruction is encoded with this value, executing such an instruction must cause a Reserved Instruction Exception (*SPECIAL2* encoding or coprocessor instruction encoding for a coprocessor to which access is allowed) or a Coprocessor Unusable Exception (coprocessor instruction encoding 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 Modules/Application Specific Extensions. If the Module/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 MIPS ISA. Software should avoid using these operation or field codes.
⊕	Operation or field codes marked with this symbol are valid for Release 2 implementations of the architecture. Executing such an instruction in a Release 1 implementation must cause a Reserved Instruction Exception.

Table 5.2 MIPS®DSP Module Encoding of Opcode Field

opcode		*bits 28..26*							
		0	1	2	3	4	5	6	7
bits 31..29		000	001	010	011	100	101	110	111
0	000		*REGIMM* δ						
1	001								
2	010								
3	011								*SPECIAL3* δθ
4	100								
5	101								
6	110								
7	111								

The instructions in the MIPS DSP Module are encoded in the *SPECIAL3* space under the *opcode* map as shown in Table 5.2 and Table 5.3. The sub-encoding for individual instructions defined by the MIPS DSP Module are shown in the following tables in this chapter.

Table 5.3 MIPS® SPECIAL3[1] Encoding of Function Field for DSP Module Instructions[2]

function		bits 2..0							
		0	1	2	3	4	5	6	7
bits 5..3		000	001	010	011	100	101	110	111
0	000								
1	001			*LX* δ	*	INSV		*	*
2	010	*ADDU.QB* δ	*CMPU.EQ.QB* δ	*ABSQ_S.PH* δ	*SHLL.QB* δ				
3	011	*ADDUH.QB* δ	*	*	*	*	*	*	*
4	100		*	*	*		*	*	*
5	101	*	*	*	*	*	*	*	*
6	110	*DPA.W.PH* δ	*APPEND* δ	*	*		*	*	*
7	111	*EXTR.W* δ	*	*			*	*	*

1. Release 2 of the Architecture added the *SPECIAL3* opcode. Implementations of Release 1 of the Architecture signaled a Reserved Instruction Exception for this opcode and all function field values shown above.
2. The empty slots in this table are used by Release 2 instructions not shown here, refer to Volume II of this multi-volume specification for these instructions.

Table 5.4 MIPS® REGIMM Encoding of rt Field

rt		bits 18..16							
		0	1	2	3	4	5	6	7
bits 20..19		000	001	010	011	100	101	110	111
0	00					*	*	*	*
1	01						*		*
2	10					*	*	*	*
3	11	*	*	*	*	BPOSGE32		*	

Each MIPS DSP Module instruction sub-class in *SPECIAL3* that needs further decoding, is done via the *op* field as shown in Figure 5.2.

Figure 5.2 SPECIAL3 Encoding of ADDU.QB/CMPU.EQ.QB Instruction Sub-classes

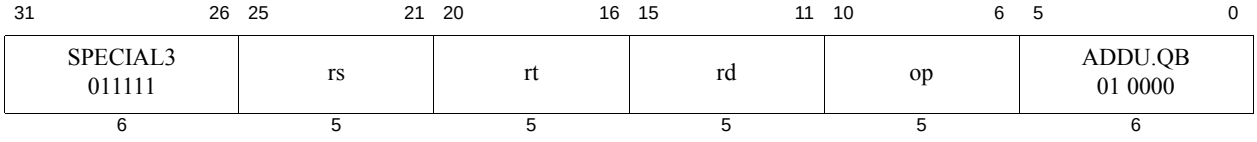


Table 5.5 MIPS® ADDU.QB Encoding of op Field[1]

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	ADDU.QB	SUBU.QB	*	*	ADDU_S.QB	SUBU_S.QB	MULEU_S.PH.QBL	MULEU_S.PH.QBR
1	01	ADDU.PH	SUBU.PH	ADDQ.PH	SUBQ.PH	ADDU_S.PH	SUBU_S.PH	ADDQ_S.PH	SUBQ_S.PH
2	10	ADDSC	ADDWC	MODSUB	*	RADDU.W.QB	*	ADDQ_S.W	SUBQ_S.W
3	11	*	*	*	*	MULEQ_S.W.PHL	MULEQ_S.W.PHR	MULQ_S.PH	MULQ_RS.PH

1. The op field is decoded to identify the final instructions. Entries in this table with no mnemonic are reserved for future use by MIPS Technologies and may or may not cause a Reserved Instruction exception.

Table 5.6 MIPS® CMPU.EQ.QB Encoding of op Field

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	CMPU.EQ.QB	CMPU.LT.QB	CMPU.LE.QB	PICK.QB	CMPGU.EQ.QB	CMPGU.LT.QB	CMPGU.LE.QB	*
1	01	CMP.EQ.PH	CMP.LT.PH	CMP.LE.PH	PICK.PH	PRECRQ.QB.PH	PRECR.QB.PH	PACKRL.PH	PRECRQU_S.QB.PH
2	10	*	*	*	*	PRECRQ.PH.W	PRECRQ_RS.PH.W	*	*
3	11	CMPGDU.EQ.QB	CMPGDU.LT.QB	CMPGDU.LE.QB	*	*	*	PRECR_SRA.PH.W	PRECR_SRA_RPH.W

Figure 5.3 SPECIAL3 Encoding of ABSQ_S.PH Instruction Sub-class without Immediate Field

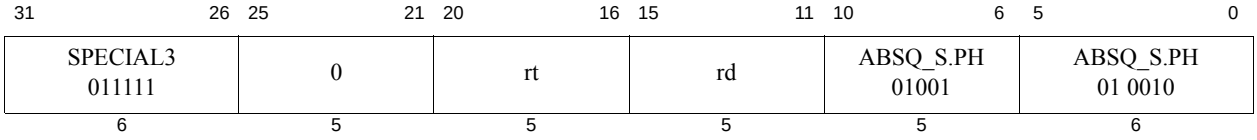


Figure 5.4 SPECIAL3 Encoding of ABSQ_S.PH Instruction Sub-class with Immediate Field

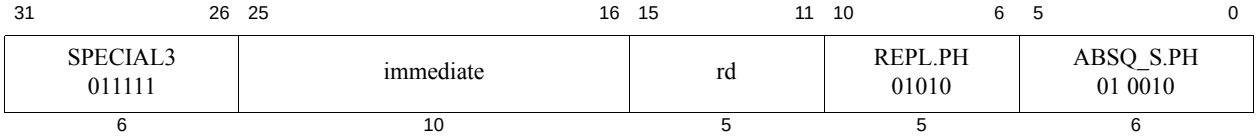


Table 5.7 MIPS® ABSQ_S.PH Encoding of op Field

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	*	ABSQ_S.QB	REPL.QB	REPLV.QB	PRECEQU.PH.QBL	PRECEQU.PH.QBR	PRECEQU.PH.QBLA	PRECEQU.PH.QBRA
1	01	*	ABSQ_S.PH	REPL.PH	REPLV.PH	PRECEQ.W.PHL	PRECEQ.W.PHR	*	*
2	10	*	ABSQ_S.W	*	*	*	*	*	*
3	11	*	*	*	BITREV	PRECEU.PH.QBL	PRECEU.PH.QBR	PRECEU.PH.QBLA	PRECEU.PH.QBRA

Figure 5.5 SPECIAL3 Encoding of SHLL.QB Instruction Sub-class

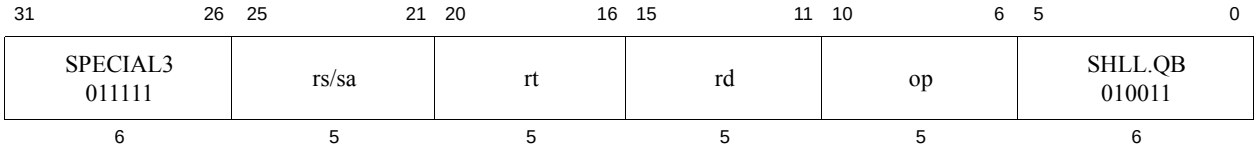


Table 5.8 MIPS® SHLL.QB Encoding of op Field

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	SHLL.QB	SHRL.QB	SHLLV.QB	SHRLV.QB	SHRA.QB	SHRA_R.QB	SHRAV.QB	SHRAV_R.QB
1	01	SHLL.PH	SHRA.PH	SHLLV.PH	SHRAV.PH	SHLL_S.PH	SHRA_R.PH	SHLLV_S.PH	SHRAV_R.PH
2	10	*	*	*	*	SHLL_S.W	SHRA_R.W	SHLLV_S.W	SHRAV_R.W
3	11	*	SHRL.PH	*	SHRLV.PH	*	*	*	*

For the LX sub-class of instructions, the format to interpret the op field is similar to the instructions above, with the exception that the rs and rt fields are named to be the base and index fields respectively for the indexed load operation. The instruction format is shown in Figure 5.6.

Figure 5.6 SPECIAL3 Encoding of LX Instruction Sub-class

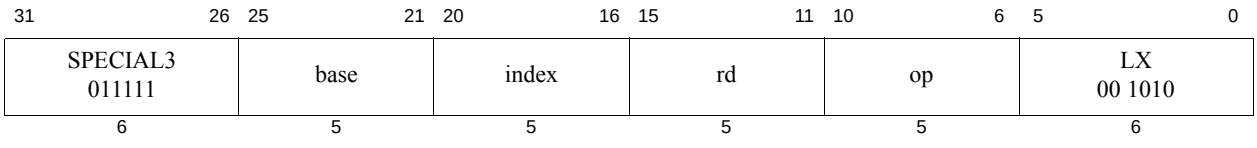


Table 5.9 MIPS® LX Encoding of op Field

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	LWX	*	*	*	LHX	*	LBUX	*
1	01		*	*	*	*	*	*	*
2	10	*	*	*	*	*	*	*	*
3	11	*	*	*	*	*	*	*	*

The sub-class of DPA.W.PH instruction target one of the accumulators for the destination. These instructions use the lower bits of the rd field of the opcode to specify the accumulator number which can range from 0 to 3. This format is shown in Figure 5.7.

Figure 5.7 SPECIAL3 Encoding of DPA.W.PH Instruction Sub-class

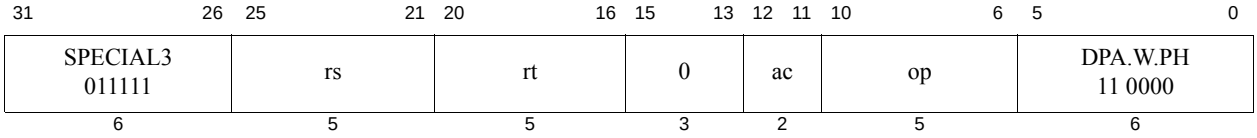


Table 5.10 MIPS® DPA.W.PH Encoding of op Field

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	DPA.W.PH	DPS.W.PH	MULSA.W.PH	DPAU.H.QBL	DPAQ_S.W.PH	DPSQ_S.W.PH	MULSAQ_S.W.PH	DPAU.H.QBR
1	01	DPAX.W.PH	DPSX.W.PH	*	DPSU.H.QBL	DPAQ_SA.L.W	DPSQ_SA.L.W	*	DPSU.H.QBR
2	10	MAQ_SA.W.PHL	*	MAQ_SA.W.PHR	*	MAQ_S.W.PHL	*	MAQ_S.W.PHR	*
3	11	DPAQX_S.W.PH	DPSQX_S.W.PH	DPAQX_SA.W.PH	DPSQX_SA.W.PH	*	*	*	*

The *EXTR.W* sub-class is an assortment that has three types of instructions:

1. In the first one, the destination is a GPR and this is specified by the rt field in the opcode, as shown in Figure 5.8. The source is an accumulator and this comes from the right-most 2 bits of the rd field, again, as shown in the figure. When a second source must be specified, then the rs field is used. The second value could be a 5-bit immediate or a variable from a GPR. The first and the second rows of Table 5.11 show this type of instruction.

2. The RDDSP and WRDSP instructions specify one immediate 6 bit mask field and a GPR that holds both the position and size values, as seen in Figure 5.9.

3. The MTHLIP instruction copies the LO part of the specified accumulator to the HI, the GPR contents to LO. In this case, the source rs field is used and the destination is specified by ac, which is both a source and destination, as shown in Figure 5.10. The SHILO and SHILOV instructions which shift the HI-LO pair and leave the result in the HI-LO register pair is a variant that does not use the source rs register. The shift amount can be specified as an immediate value or in the rs register as a variable value.

Figure 5.8 SPECIAL3 Encoding Example for EXTR.W Instruction Sub-class Type 1

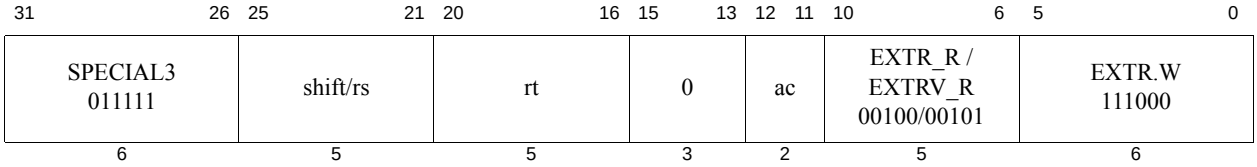


Figure 5.9 SPECIAL3 Encoding Example for EXTR.W Instruction Sub-class Type 2

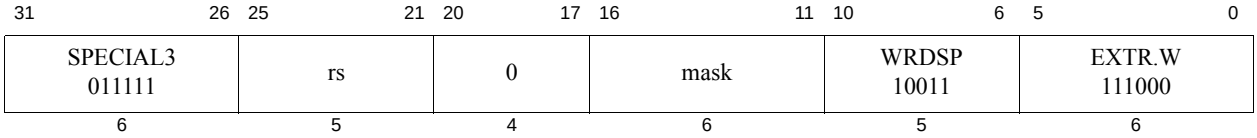


Figure 5.10 SPECIAL3 Encoding Example for EXTR.W Instruction Sub-class Type 3

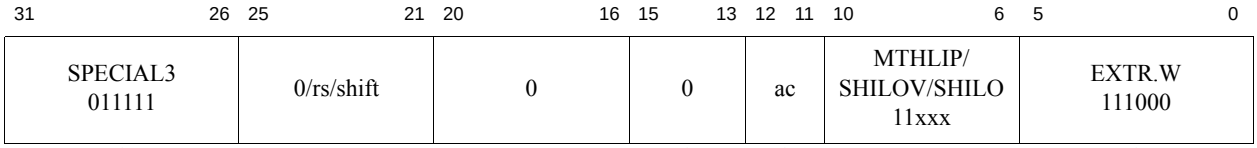


Table 5.11 MIPS® EXTR.W Encoding of op Field

op		*bits 8..6*							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	EXTR.W	EXTRV.W	EXTP	EXTPV	EXTR_R.W	EXTRV_R.W	EXTR_RS.W	EXTRV_RS.W
1	01	*	*	EXTPDP	EXTPDPV	*	*	EXTR_S.H	EXTRV_S.H
2	10	*	*	RDDSP	WRDSP	*	*	*	*
3	11	*	*	SHILO	SHILOV	*	*	*	MTHLIP

Finally, the opcode change for the MFHI and MTLO instructions requires the specification of the accumulator number. For the MTHI and MTLO instructions, the change will use bits 11 and 12 of the opcode to specify the accumulator, where the value of 0 provides backwards compatibility and refers to the original Hi-Lo pair. For the MFHI and MFLO instructions, the change will use bits 21 and 22 to encode the accumulator, and zero is the original pair as before.

Figure 5.11 SPECIAL3 Encoding of ADDUH.QB Instruction Sub-classes

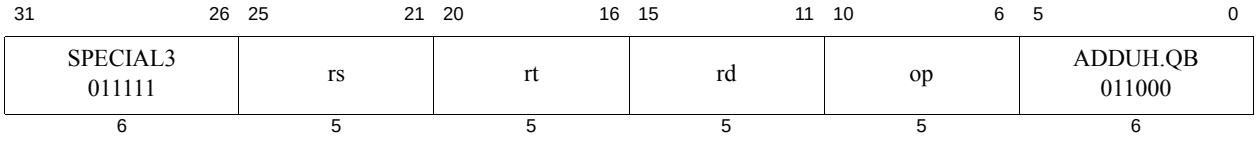


Table 5.12 MIPS® ADDUH.QB Encoding of op Field[1]

op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	ADDUH.QB	SUBUH.QB	ADDUH_R.QB	SUBUH_R.QB	*	*	*	*
1	01	ADDQH.PH	SUBQH.PH	ADDQH_R.PH	SUBQH_R.PH	MUL.PH	*	MUL_S.PH	*
2	10	ADDQH.W	SUBQH.W	ADDQH_R.W	SUBQH_R.W	*	*	MULQ_S.W	MULQ_RS.W
3	11	*	*	*	*	*	*	*	*

1. The op field is decoded to identify the final instructions. Entries in this table with no mnemonic are reserved for future use by MIPS Technologies and may or may not cause a Reserved Instruction exception.

Figure 5.12 SPECIAL3 Encoding of APPEND Instruction Sub-class

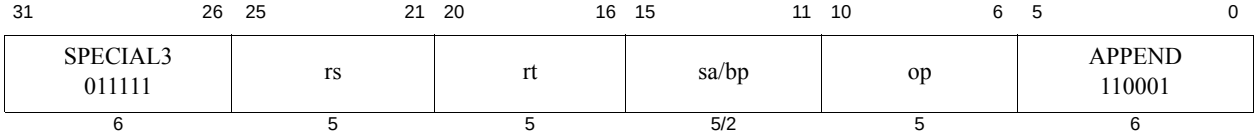


Table 5.13 MIPS® APPEND Encoding of op Field

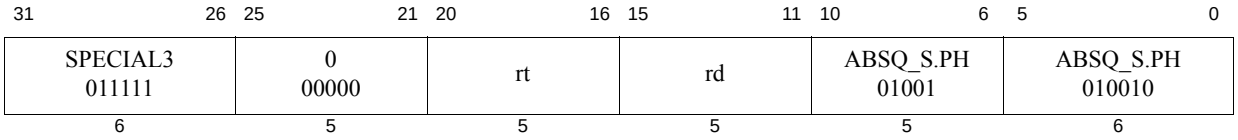
op		bits 8..6							
		0	1	2	3	4	5	6	7
bits 10..9		000	001	010	011	100	101	110	111
0	00	APPEND	PREPEND	*	*	*	*	*	*
1	01	*	*	*	*	*	*	*	*
2	10	BALIGN	*	*	*	*	*	*	*
3	11	*	*	*	*	*	*	*	*

Chapter 6

The MIPS® DSP Module Instruction Set

6.1 Compliance and Subsetting

There are no instruction subsets allowed for the MIPS DSP Module —all instructions must be implemented with all data format types as shown. Instructions are listed in alphabetical order, with a secondary sort on data type format from narrowest to widest, i.e., quad byte, paired halfword, and word.



Format: `ABSQ_S.PH rd, rt` **MIPSDSP**

Purpose: Find Absolute Value of Two Fractional Halfwords

Find the absolute value of each of a pair of Q15 fractional halfword values with 16-bit saturation.

Description: `rd ← sat16(abs(rt31..16)) || sat16(abs(rt15..0))`

For each value in the pair of Q15 fractional halfword values in register *rt*, the absolute value is found and written to the corresponding Q15 halfword in register *rd*. If either input value is the minimum Q15 value (-1.0 in decimal, 0x8000 in hexadecimal), the corresponding result is saturated to 0x7FFF.

This instruction sets bit 20 in the *DSPControl* register in the *ouflag* field if either input value was saturated.

Restrictions:

No data-dependent exceptions are possible.

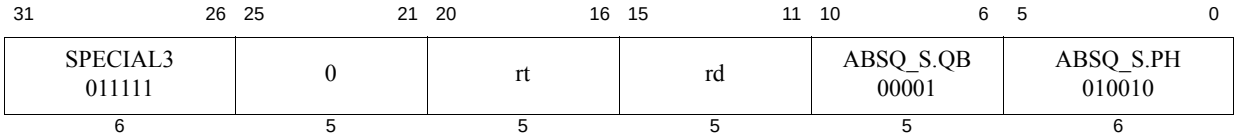
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← satAbs16( GPR[rt]31..16 )
tempA15..0 ← satAbs16( GPR[rt]15..0 )
GPR[rd]..0 ← tempB15..0 || tempA15..0

function satAbs16( a15..0 )
   if ( a15..0 = 0x8000 ) then
      DSPControlouflag:20 ← 1
      temp15..0 ← 0x7FFF
   else
      if ( a15 = 1 ) then
         temp15..0 ← -a15..0
      else
         temp15..0 ← a15..0
      endif
   endif
   return temp15..0
endfunction satAbs16
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `ABSQ_S.QB rd, rt` **MIPSDSP-R2**

Purpose: Find Absolute Value of Four Fractional Byte Values

Find the absolute value of four fractional byte vector elements with saturation.

Description: `rd ← sat8(abs(rt`$_{31..24}$`)) || sat8(abs(rt`$_{23..16}$`)) || sat8(abs(rt`$_{15..8}$`)) || sat8(abs(rt`$_{7..0}$`))`

For each value in the four Q7 fractional byte elements in register *rt*, the absolute value is found and written to the corresponding byte in register *rd*. If either input value is the minimum Q7 value (-1.0 in decimal, 0x80 in hexadecimal), the corresponding result is saturated to 0x7F.t

dThis instruction sets bit 20 in *ouflag* field of the *DSPControl* register if any input value was saturated.

Restrictions:

No data-dependent exceptions are possible.

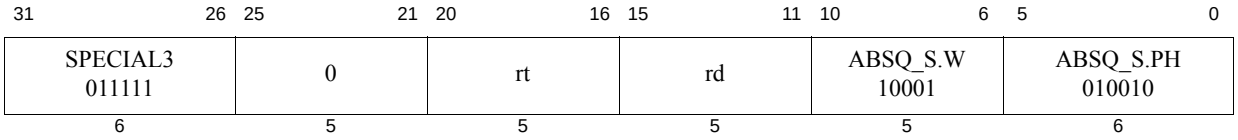
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← abs8( GPR[rt]31..24 )
tempC7..0 ← abs8( GPR[rt]23..16 )
tempB7..0 ← abs8( GPR[rt]15..8 )
tempA7..0 ← abs8( GPR[rt]7..0 )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function abs8( a7..0 )
   if ( a7..0 = 0x80 ) then
      DSPControlouflag:20 ← 1
      temp7..0 ← 0x7F
   else
      if ( a7 = 1 ) then
         temp7..0 ← -a7..0
      else
         temp7..0 ← a7..0
      endif
   endif
   return temp7..0
endfunction abs8
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `ABSQ_S.W rd, rt` **MIPSDSP**

Purpose: Find Absolute Value of Fractional Word

Find the absolute value of a fractional Q31 value with 32-bit saturation.

Description: `rd ← sat32(abs(rt31..0))`

The absolute value of the Q31 fractional value in register *rt* is found and written to destination register *rd*. If the input value is t he minimum Q31 value (-1.0 in decimal, 0x80000000 in hexadecimal), the result is saturated to 0x7FFFFFFF before being sign-extended and written to register `rd`.

This instruction sets bit 20 in the *DSPControl* register in the *ouflag* field if the input value was saturated.

Restrictions:

No data-dependent exceptions are possible.

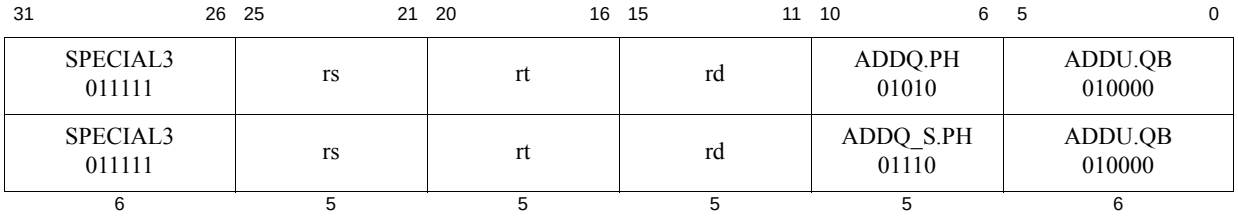
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← satAbs32( GPR[rt]31..0 )
GPR[rd]..0 ← temp31..0

function satAbs32( a31..0 )
   if ( a31..0 = 0x80000000 ) then
      DSPControlouflag:20 ← 1
      temp31..0 ← 0x7FFFFFFF
   else
      if ( a31 = 1 ) then
         temp31..0 ← -a31..0
      else
         temp31..0 ← a31..0
      endif
   endif
   return temp31..0
endfunction satAbs32
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	ADDQ.PH 01010	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	ADDQ_S.PH 01110	ADDU.QB 010000
6	5	5	5	5	6

Format: `ADDQ[_S].PH`

`ADDQ.PH rd, rs, rt` **MIPSDSP**

`ADDQ_S.PH rd, rs, rt` **MIPSDSP**

Purpose: Add Fractional Halfword Vectors

Element-wise addition of two vectors of Q15 fractional values to produce a vector of Q15 fractional results, with optional saturation.

Description: $rd \leftarrow sat16(rs_{31..16} + rt_{31..16}) \ || \ sat16(rs_{15..0} + rt_{15..0})$

Each of the two fractional halfword elements in register *rt* are added to the corresponding fractional halfword elements in register *rs*.

For the non-saturating version of the instruction, the result of each addition is written into the corresponding element in register *rd*. If the addition results in overflow or underflow, the result modulo 2 is written to the corresponding element in register *rd*.

For the saturating version of the instruction, signed saturating arithmetic is performed, where an overflow is clamped to the largest representable value (0x7FFF hexadecimal) and an underflow to the smallest representable value (0x8000 hexadecimal) before being written to the destination register *rd*.

For each instruction, if either of the individual additions result in underflow, overflow, or saturation, a 1 is written to bit 20 in the *DSPControl* register in the ouflag field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

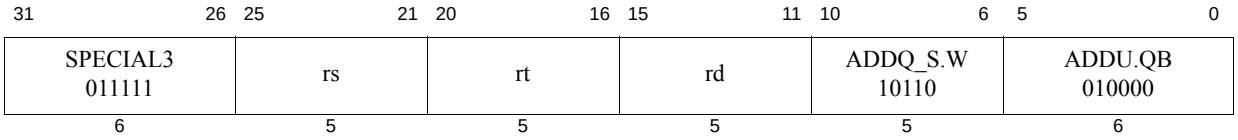
Operation:

```
ADDQ.PH:
    tempB15..0 ← add16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← add16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

ADDQ_S.PH:
    tempB15..0 ← satAdd16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← satAdd16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function add16( a15..0, b15..0 )
    temp16..0 ← ( a15 || a15..0 ) + ( b15 || b15..0 )
    if ( temp16 ≠ temp15 ) then
        DSPControlouflag:20 ← 1
    endif
    return temp15..0
endfunction add16
```

```
function satAdd16( a15..0, b15..0 )
   temp16..0 ← ( a15 || a15..0 ) + ( b15 || b15..0 )
   if ( temp16 ≠ temp15 ) then
      if ( temp16 = 0 ) then
         temp15..0 ← 0x7FFF
      else
         temp15..0 ← 0x8000
      endif
      DSPControlouflag:20 ← 1
   endif
   return temp15..0
endfunction satAdd16
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `ADDQ_S.W rd, rs, rt` **MIPSDSP**

Purpose: Add Fractional Words

Addition of two Q31 fractional values to produce a Q31 fractional result, with saturation.

Description: $rd \leftarrow sat32(rs_{31..0} + rt_{31..0})$

The Q31 fractional word in register *rt* is added to the corresponding fractional word in register *rs*. The result is then written to the destination register *rd*.

Signed saturating arithmetic is used, where an overflow is clamped to the largest representable value (0x7FFFFFFF hexadecimal) and an underflow to the smallest representable value (0x80000000 hexadecimal) before being sign-extended and written to the destination register *rd*.

If the addition results in underflow, overflow, or saturation, a 1 is written to bit 20 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

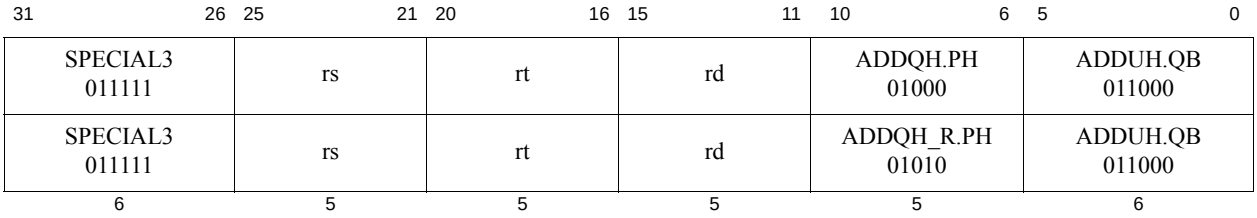
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← satAdd32( GPR[rs]31..0 , GPR[rt]31..0 )
GPR[rd]..0 ← temp31..0

function satAdd32( a31..0, b31..0 )
   temp32..0 ← ( a31 || a31..0 ) + ( b31 || b31..0 )
   if ( temp32 ≠ temp31 ) then
      if ( temp32 = 0 ) then
         temp31..0 ← 0x7FFFFFFF
      else
         temp31..0 ← 0x80000000
      endif
      DSPControlouflag:20 ← 1
   endif
   return temp31..0
endfunction satAdd32
```

Exceptions:

Reserved Instruction, DSP Disabled



31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	ADDQH.PH 01000	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	ADDQH_R.PH 01010	ADDUH.QB 011000
6	5	5	5	5	6

Format: `ADDQH[_R].PH`

`ADDQH.PH rd, rs, rt` **MIPSDSP-R2**

`ADDQH_R.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Add Fractional Halfword Vectors And Shift Right to Halve Results

Element-wise fractional addition of halfword vectors, with a right shift by one bit to halve each result, with optional rounding.

Description: $rd \leftarrow round((rs_{31..16} + rt_{31..16}) >> 1) \,||\, round((rs_{15..0} + rt_{15..0}) >> 1)$

Each element from the two halfword values in register *rs* is added to the corresponding halfword element in register *rt* to create an interim 17-bit result.

In the non-rounding instruction variant, each interim result is then shifted right by one bit before being written to the corresponding halfword element of destination register *rd*.

In the rounding version of the instructi on, a value of 1 is added at the least- significant bit position of each interim result; the interim result is then right-shifted by one bit and written to the destination register.

This instruction does not modify the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
ADDQH.PH
    tempB15..0 ← rightShift1AddQ16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← rightShift1AddQ16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

ADDQH_R.PH
    tempB15..0 ← roundRightShift1AddQ16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← roundRightShift1AddQ16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function rightShift1AddQ16( a15..0 , b15..0 )
    temp16..0 ← (( a15 || a15..0 ) + ( b15 || b15..0 ))
    return temp16..1
endfunction rightShift1AddQ16

function roundRightShift1AddQ16( a15..0 , b15..0 )
    temp16..0 ← (( a15 || a15..0 ) + ( b15 || b15..0 ))
    temp16..0 ← temp16..0 + 1
    return temp16..1
endfunction roundRightShift1AddQ16
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	ADDQH.W 10000	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	ADDQH_R.W 10010	ADDUH.QB 011000
6	5	5	5	5	6

Format: `ADDQH[_R].W`

`ADDQH.W rd, rs, rt` **MIPSDSP-R2**

`ADDQH_R.W rd, rs, rt` **MIPSDSP-R2**

Purpose: Add Fractional Words And Shift Right to Halve Results

Fractional addition of word vectors, with a right shift by one bit to halve the result, with optional rounding.

Description: $rd \leftarrow round((rs_{31..0} + rt_{31..0}) >> 1)$

The word in register *rs* is added to the word in register *rt* to create an interim 33-bit result.

In the non-rounding instruction variant, the interim result is then shifted right by one bit before being written to the destination register *rd*.

In the rounding version of the instruction, a value of 1 is added at the least-significant bit position of the interim result; the interim result is then right-shifted by one bit and written to the destination register.

This instruction does not modify the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

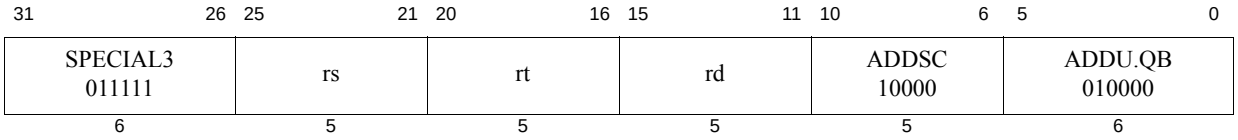
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
ADDQH.W
    tempA31..0 ← rightShift1AddQ32( GPR[rs]31..0 , GPR[rt]31..0 )
    GPR[rd]..0 ← tempA31..0

ADDQH_R.W
    tempA31..0 ← roundRightShift1AddQ32( GPR[rs]31..0 , GPR[rt]31..0 )
    GPR[rd]..0 ← tempA31..0

function rightShift1AddQ32( a31..0 , b31..0 )
    temp32..0 ← (( a31 || a31..0 ) + ( b31 || b31..0 ))
    return temp32..1
endfunction rightShift1AddQ32

function roundRightShift1AddQ32( a31..0 , b31..0 )
    temp32..0 ← (( a31 || a31..0 ) + ( b31 || b31..0 ))
    temp32..0 ← temp32..0 + 1
    return temp32..1
endfunction roundRightShift1AddQ32
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `ADDSC rd, rs, rt` **MIPSDSP**

Purpose: Add Signed Word and Set Carry Bit

Add two signed 32-bit values and set the carry bit in the *DSPControl* register if the addition generates a carry-out bit.

Description: `DSPControl[c],rd ← rs + rt`

The 32-bit signed value in register *rt* is added to the 32-bit signed value in register *rs*. The result is then written into register *rd*. The carry bit result out of the addition operation is written to bit 13 (the c field) of the *DSPControl* register.

This instruction does not modify the ouflag field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

Operation:

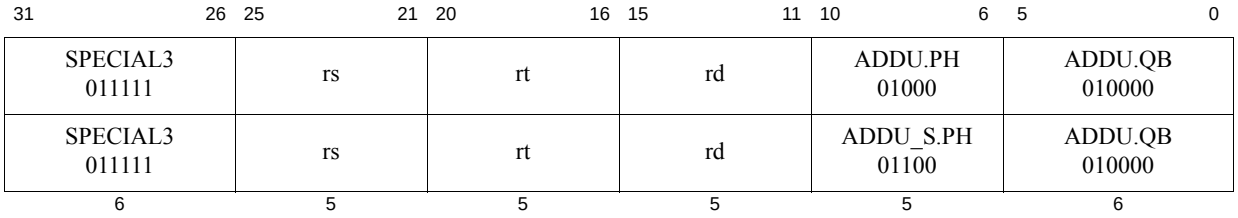
$temp_{32..0} \leftarrow (0 \,||\, GPR[rs]_{31..0}) + (0 \,||\, GPR[rt]_{31..0})$
$DSPControl_{c:13} \leftarrow temp_{32}$
$GPR[rd]_{..0} \leftarrow temp_{31..0}$

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

Note that this is really two's complement (modulo) arithmetic on the two integer values, where the overflow is preserved in architectural state. The ADDWC instruction can be used to do an add using this carry bit. These instructions are provided in the MIPS32 ISA to support 64-bit addition and subtraction using two pairs of 32-bit GPRs to hold each 64-bit value. In the MIPS64 ISA, 64-bit addition and subtraction can be performed directly, without requiring the use of these instructions.



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	ADDU.PH 01000	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	ADDU_S.PH 01100	ADDU.QB 010000
6	5	5	5	5	6

Format: `ADDU[_S].PH`

`ADDU.PH rd, rs, rt` **MIPSDSP-R2**

`ADDU_S.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Unsigned Add Integer Halfwords

Add two pairs of unsigned integer halfwords, with optional saturation.

Description: $rd \leftarrow sat16(rs_{31..16} + rt_{31..16}) \,||\, sat16(rs_{15..0} + rt_{15..0})$

The two unsigned integer halfword elements in register *rt* are added to the corresponding unsigned integer halfword elements in register *rs*.

For the non-saturating version of the instruction, the result modulo 65,536 is written into the corresponding element in register *rd*.

For the saturating version of the instruction, the addition is performed using unsigned saturating arithmetic. Results that overflow are clamped to the largest representable value (65,535 decimal, 0xFFFF hexadecimal) before being written to the destination register *rd*.

For either instruction, if any of the individual additions result in overflow or saturation, a 1 is written to bit 20 in the *DSPControl* register within the ouflag field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
ADDU.PH
    tempB15..0 ← addU16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← addU16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

ADDU_S.PH
    tempB15..0 ← satAddU16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← satAddU16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	ADDU.QB 00000	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	ADDU_S.QB 00100	ADDU.QB 010000
6	5	5	5	5	6

Format: `ADDU[_S].QB`

`ADDU.QB rd, rs, rt` **MIPSDSP**

`ADDU_S.QB rd, rs, rt` **MIPSDSP**

Purpose: Unsigned Add Quad Byte Vectors

Element-wise addition of two vectors of unsigned byte values to produce a vector of unsigned byte results, with optional saturation.

Description: $rd \leftarrow sat8(rs_{31..24} + rt_{31..24}) \,||\, sat8(rs_{23..16} + rt_{23..16}) \,||\, sat8(rs_{15..8} + rt_{15..8}) \,||\, sat8(rs_{7..0} + rt_{7..0})$

The four byte elements in register *rt* are added to the corresponding byte elements in register *rs*.

For the non-saturating version of the instruction, the result modulo 256 is written into the corresponding element in register *rd*.

For the saturating version of the instruction, the addition is performed using unsigned saturating arithmetic. Results that overflow are clamped to the largest representable value (255 decimal, 0xFF hexadecimal) before being written to the destination register *rd*.

For either instruction, if any of the individual additions result in overflow or saturation, a 1 is written to bit 20 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

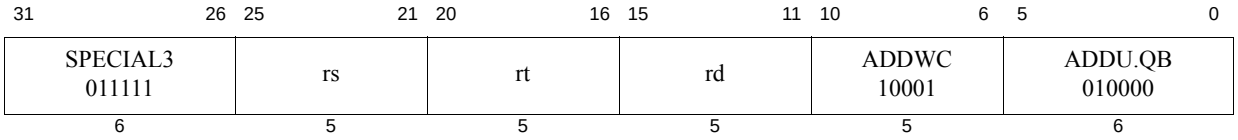
Operation:

```
ADDU.QB:
    tempD7..0 ← addU8( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← addU8( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← addU8( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← addU8( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

ADDU_S.QB:
    tempD7..0 ← satAddU8( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← satAddU8( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← satAddU8( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← satAddU8( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function addU8( a7..0, b7..0 )
    temp8..0 ← ( 0 || a7..0 ) + ( 0 || b7..0 )
    if ( temp8 = 1 ) then
        DSPControlouflag:20 ← 1
```

```
    endif
    return temp7..0
endfunction addU8

function satAddU8( a7..0, b7..0 )
    temp8..0 ← ( 0 || a7..0 ) + ( 0 || b7..0 )
    if ( temp8 = 1 ) then
        temp7..0 ← 0xFF
        DSPControlouflag:20 ← 1
    endif
    return temp7..0
endfunction satAddU8
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `ADDWC rd, rs, rt` **MIPSDSP**

Purpose: Add Word with Carry Bit

Add two signed 32-bit values with the carry bit in the *DSPControl* register.

Description: $rd \leftarrow rs + rt + DSPControl_{c:13}$

The 32-bit value in register *rt* is added to the 32-bit value in register *rs* and the carry bit in the *DSPControl* register. The result is then written to destination register *rd*.

If the addition results in either overflow or underflow, this instruction writes a 1 to bit 20 in the *ouflag* field of the *DSPControl* register.

Restrictions:

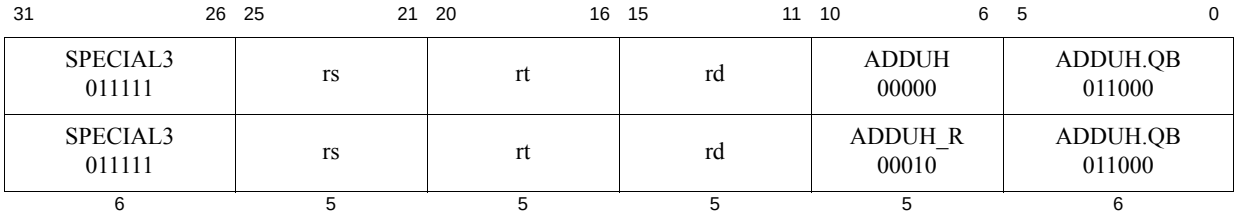
No data-dependent exceptions are possible.

Operation:

```
temp32..0 ← ( GPR[rs]31 || GPR[rs]31..0 ) + ( GPR[rt]31 || GPR[rt]31..0 ) + ( 0^32 ||
DSPControlc:13 )
if ( temp32 ≠ temp31 ) then
    DSPControlouflag:20 ← 1
endif
GPR[rd]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	ADDUH 00000	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	ADDUH_R 00010	ADDUH.QB 011000
6	5	5	5	5	6

Format: `ADDUH[_R].QB`

`ADDUH.QB rd, rs, rt` **MIPSDSP-R2**

`ADDUH_R.QB rd, rs, rt` **MIPSDSP-R2**

Purpose: Unsigned Add Vector Quad-Bytes And Right Shift to Halve Results

Element-wise unsigned addition of unsigned byte vectors, with right shift by one bit to halve each result, with optional rounding.

Description $rd \leftarrow round((rs_{31..24} + rt_{31..24})>>1) \;||\; round((rs_{23..16} + rt_{23..16})>>1) \;||\; round((rs_{15..8} + rt_{15..8})>>1) \;||\; round((rs_{7..0} + rt_{7..0})>>1)$

Each element from the four unsigned byte values in register *rs* is added to the corresponding unsigned byte element in register *rt* to create an unsigned interim result.

In the non-rounding instruction variant, each interim result is then shifted right by one bit before being written to the corresponding unsigned byte element of destination register *rd*.

In the rounding version of the instruction, a value of 1 is added at the least-significant bit position of each interim result before being right-shifted by one bit and written to the destination register.

This instruction does not modify the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

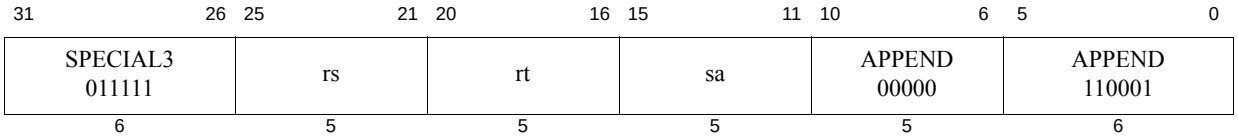
Operation:

```
ADDUH.QB
    tempD7..0 ← rightShift1AddU8( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← rightShift1AddU8( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← rightShift1AddU8( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← rightShift1AddU8( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

ADDUH_R.QB
    tempD7..0 ← roundRightShift1AddU8( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← roundRightShift1AddU8( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← roundRightShift1AddU8( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← roundRightShift1AddU8( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function rightShift1AddU8( a7..0 , b7..0 )
    temp8..0 ← (( 0 || a7..0 ) + ( 0 || b7..0 ))
    return temp8..1
endfunction rightShift1AddU8
```

```
function roundRightShift1AddU8( a7..0 , b7..0 )
   temp8..0 ← (( 0 || a7..0 ) + ( 0 || b7..0 ))
   temp8..0 ← temp8..0 + 1
   return temp8..1
endfunction roundRightShift1AddU8
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `APPEND rt, rs, sa` **MIPSDSP-R2**

Purpose: Left Shift and Append Bits to the LSB

Shift a general-purpose register left, inserting bits from the another GPR into the bit positions emptied by the shift.

Description: $rt \leftarrow (rt_{31..0} << sa_{4..0}) \mid\mid rs_{sa-1..0}$

The 32-bit value in register *rt* is left-shifted by the specified shift amount *sa*, and *sa* bits from the least-significant positions of the *rs* register are inserted into the bit positions in *rt* emptied by the shift. The 32-bit shifted value is written to destination register *rt*.

Restrictions:

No data-dependent exceptions are possible.

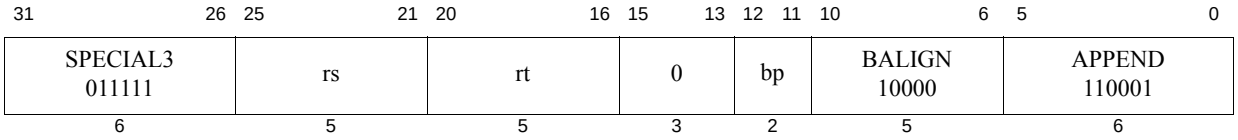
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
if ( sa4..0 = 0 ) then
   temp31..0 ← GPR[rt]31..0
else
   temp31..0 ← ( GPR[rt]31-sa..0 || GPR[rs]sa-1..0 )
endif
GPR[rt]..0 = temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `BALIGN rt, rs, bp` **MIPSDSP-R2**

Purpose: Byte Align Contents from Two Registers

Create a word result by combining a specified number of bytes from each of two source registers.

Description: `rt ← (rt << 8*bp) || (rs >> 8*(4-bp))`

The 32-bit word in register *rt* is left-shifted as a 32-bit value by *bp* byte positions, and the right-most word in register *rs* is right-shifted as a 32-bit value by (4-*bp*) byte positions. The shifted values are then *or*-ed together to create a 32-bit result that is written to destination register *rt*.

The argument *bp* is provided by the instruction, and is interpreted as an unsigned two-bit integer taking values between zero and three.

Restrictions:

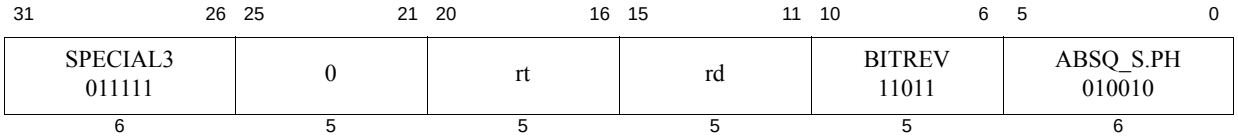
No data-dependent exceptions are possible.

Operation:

```
if (bp1..0 = 0) or (bp1..0 = 2) then
   GPR[rt]..0 ← UNPREDICTABLE
else
   temp31..0 ← ( GPR[rt]31..0 << (8*bp1..0) ) || ( GPR[rs]31..0 >> (8*(4-bp1..0)) )
   GPR[rt]..0 = temp31..0
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `BITREV rd, rt` **MIPSDSP**

Purpose: Bit-Reverse Halfword

To reverse the order of the bits of the least-significant halfword in the specified register.

Description: $rd \leftarrow rt_{0..15}$

The right-most halfword value in register *rt* is bit-reversed into the right-most halfword position in the destination register *rd*. The most-significant bits of the destination register are zero-filled.

Restrictions:

No data-dependent exceptions are possible.

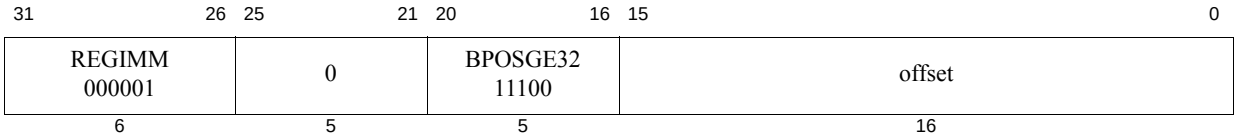
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp15..0 ← GPR[rt]0..15
GPR[rd]..0 ← 0 || temp15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `BPOSGE32 offset` **MIPSDSP**

Purpose: Branch on Greater Than or Equal To Value 32 in *DSPControl* Pos Field

Perform a PC-relative branch if the value of the pos field in the *DSPControl* register is greater than or equal to 32.

Description: `if (DSPControl`$_{pos:..0}$ `>= 32) then goto PC+offset`

First, the *offset* argument is left-shifted by two bits to form an 18-bit signed integer value. This value is added to the address of the instruction immediately following the branch to form a target branch address. Then, if the value of the pos field of the *DSPControl* register is greater than or equal to 32, the branch is taken and execution begins from the target address after the instruction in the branch delay slot has been executed.

Restrictions:

Pre-Release 6: Processor operation is UNPREDICTABLE if a control transfer instruction (CTI), specifically a branch, jump, NAL (Release 6), ERET, ERETNC (Release 5), DERET, WAIT, or PAUSE (Release 2) instruction is placed in the delay slot of a branch or jump.

Release 6: If a control transfer instruction (CTI) is executed in the delay slot of a branch or jump, Release 6 implementations are required to a signal a Reserved Instruction Exception.

Availability:

None.

Operation:

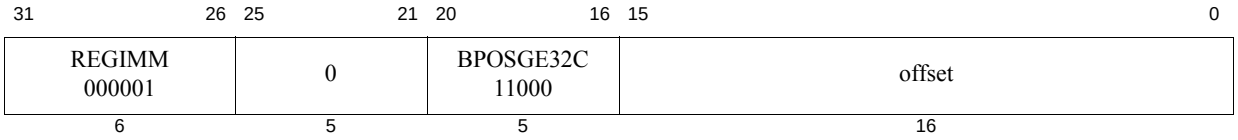
```
I:          se_offset_GPRLEN..0 ← ( offset_15 )^(GPRLEN-18) || offset_15..0 || 0^2
       branch_condition ← ( DSPControl_pos:..0 >= 32 ? 1 : 0 )
I+1:   if ( branch_condition = 1 ) then
          PC_GPRLEN..0 ← PC_GPRLEN..0 + se_offset_GPRLEN..0
       endif
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ±128 Kbytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside of this range.



Format: `BPOSGE32C offset` **MIPSDSP-R3**

Purpose: Branch on Greater Than or Equal To Value 32 in *DSPControl* Pos Field

Perform a PC-relative branch if the value of the pos field in the *DSPControl* register is greater than or equal to 32.

Description: `if (DSPControl`$_{pos:..0}$ `>= 32) then goto PC+offset`

First, the *offset* argument is left-shifted by two bits to form an 18-bit signed integer value. This value is added to the address of the instruction immediately following the branch to form a target branch address. Then, if the value of the pos field of the *DSPControl* register is greater than or equal to 32, the branch is taken and execution begins from the target address.

Restrictions:

If a control transfer instruction (CTI) is executed in the forbidden slot of a branch or jump, Release 6 implementations are required to signal a Reserved Instruction Exception. A CTI is considered to be one of the following instructions: branch, jump, NAL (Release 6), ERET, ERETNC (Release 5), DERET, WAIT, or PAUSE (Release 2). An instruction is in the forbidden slot if it is the instruction following the branch.

Availability:

This instruction is introduced by and required as of Revision 3 of the DSP Module.

Operation:

```
I:          se_offset(GPRLEN..0) ← ( offset15 )^(GPRLEN-18) || offset15..0 || 0^2
       branch_condition ← ( DSPControlpos:..0 >= 32 ? 1 : 0 )
I+1:   if ( branch_condition = 1 ) then
          PC(GPRLEN..0) ← PC(GPRLEN..0) + se_offset(GPRLEN..0)
       endif
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

With the 18-bit signed instruction offset, the conditional branch range is ±128 Kbytes. Use jump (J) or jump register (JR) instructions to branch to addresses outside of this range.

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	0 00000	CMP.EQ.PH 01000	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	0 00000	CMP.LT.PH 01001	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	0 00000	CMP.LEPH 01010	CMPU.EQ.QB 010001
6	5	5	5	5	6

Format: `CMP.cond.PH`

`CMP.EQ.PH rs, rt` **MIPSDSP**

`CMP.LT.PH rs, rt` **MIPSDSP**

`CMP.LE.PH rs, rt` **MIPSDSP**

Purpose: Compare Vectors of Signed Integer Halfword Values

Perform an element-wise comparison of two vectors of two signed integer halfwords, recording the results of the comparison in condition code bits.

Description: $\texttt{DSPControl}_{\texttt{ccond:25..24}} \leftarrow (\texttt{rs}_{\texttt{31..16}}\ \texttt{cond}\ \texttt{rt}_{\texttt{31..16}})\ ||\ (\texttt{rs}_{\texttt{15..0}}\ \texttt{cond}\ \texttt{rt}_{\texttt{15..0}})$

The two signed integer halfword elements in register *rs* are compared with the corresponding signed integer halfword element in register *rt*. The two 1-bit boolean comparison results are written to bits 24 and 25 of the *DSPControl* register's -bit condition code field. The values of the remaining condition code bits (bits 26 through of the *DSPControl* register) are **UNPREDICTABLE**.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
CMP.EQ.PH
    ccB ← GPR[rs]31..16 EQ GPR[rt]31..16
    ccA ← GPR[rs]15..0 EQ GPR[rt]15..0
    DSPControlccond:25..24 ← ccB || ccA
    DSPControlccond:..26 ← UNPREDICTABLE

CMP.LT.PH
    ccB ← GPR[rs]31..16 LT GPR[rt]31..16
    ccA ← GPR[rs]15..0 LT GPR[rt]15..0
    DSPControlccond:25..24 ← ccB || ccA
    DSPControlccond:..26 ← UNPREDICTABLE

CMP.LE.PH
    ccB ← GPR[rs]31..16 LE GPR[rt]31..16
    ccA ← GPR[rs]15..0 LE GPR[rt]15..0
    DSPControlccond:25..24 ← ccB || ccA
    DSPControlccond:..26 ← UNPREDICTABLE
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	CMPGDU.EQ.QB 11000	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	rd	CMPGDU.LT.QB 11001	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	rd	CMPGDU.LE.QB 11010	CMPU.EQ.QB 010001
6	5	5	5	5	6

Format: `CMPGDU.cond.QB`

`CMPGDU.EQ.QB rd, rs, rt` **MIPSDSP-R2**

`CMPGDU.LT.QB rd, rs, rt` **MIPSDSP-R2**

`CMPGDU.LE.QB rd, rs, rt` **MIPSDSP-R2**

Purpose: Compare Unsigned Vector of Four Bytes and Write Result to GPR and DSPControl

Compare two vectors of four unsigned bytes each, recording the comparison results in condition code bits that are written to both the specified destination GPR and the condition code bits in the DSPControl register.

Description: $DSPControl[ccond]_{27..24} \leftarrow (rs_{31..24}\ cond\ rt_{31..24})\ ||\ (rs_{23..16}\ cond\ rt_{23..16})\ ||\ (rs_{15..8}\ cond\ rt_{15..8})\ ||\ (rs_{7..0}\ cond\ rt_{7..0})$;

$rd \leftarrow 0^{(GPRLEN-4)}\ ||\ DSPControl[ccond]_{27..24}$

Each of the unsigned byte elements in register *rs* are compared with the corresponding unsigned byte elements in register *rt*. The four 1-bit boolean comparison results are written to the four least-significant bits of destination register *rd* and to bits 24 through 27 of the *DSPControl* register's -bit condition code field. The remaining bits in destination register *rd* are set to zero.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
CMPGDU.EQ.QB
    ccD ← GPR[rs]31..24 EQ GPR[rt]31..24
    ccC ← GPR[rs]23..16 EQ GPR[rt]23..16
    ccB ← GPR[rs]15..8 EQ GPR[rt]15..8
    ccA ← GPR[rs]7..0 EQ GPR[rt]7..0
    DSPControlcc:27..24 ← ccD || ccC || ccB || ccA
    GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA

CMPGDU.LT.QB
    ccD ← GPR[rs]31..24 LT GPR[rt]31..24
    ccC ← GPR[rs]23..16 LT GPR[rt]23..16
    ccB ← GPR[rs]15..8 LT GPR[rt]15..8
    ccA ← GPR[rs]7..0 LT GPR[rt]7..0
    DSPControlcc:27..24 ← ccD || ccC || ccB || ccA
    GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA

CMPGDU.LE.QB
    ccD ← GPR[rs]31..24 LE GPR[rt]31..24
    ccC ← GPR[rs]23..16 LE GPR[rt]23..16
```

```
ccB ← GPR[rs]15..8 LE GPR[rt]15..8
ccA ← GPR[rs]7..0 LE GPR[rt]7..0
DSPControlcc:27..24 ← ccD || ccC || ccB || ccA
GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	CMPGU.EQ.QB 00100	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	rd	CMPGU.LT.QB 00101	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	rd	CMPGU.LE.QB 00110	CMPU.EQ.QB 010001
6	5	5	5	5	6

Format: `CMPGU.cond.QB`

```
CMPGU.EQ.QB   rd, rs, rt                                   MIPSDSP
CMPGU.LT.QB   rd, rs, rt                                   MIPSDSP
CMPGU.LE.QB   rd, rs, rt                                   MIPSDSP
```

Purpose: Compare Vectors of Unsigned Byte Values and Write Results to a GPR

Perform an element-wise comparison of two vectors of unsigned bytes, recording the results of the comparison in condition code bits that are written to the specified GPR.

Description: $rd \leftarrow (rs_{31..24}\ cond\ rt_{31..24}) \ ||\ (rs_{23..16}\ cond\ rt_{23..16}) \ ||\ (rs_{15..8}\ cond\ rt_{15..8}) \ ||\ (rs_{7..0}\ cond\ rt_{7..0})$

Each of the unsigned byte elements in register *rs* are compared with the corresponding unsigned byte elements in register *rt*. The four 1-bit boolean comparison results are written to the four least-significant bits of destination register *rd*. The remaining bits in *rd* are set to zero.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
CMPGU.EQ.QB
    ccD ← GPR[rs]31..24 EQ GPR[rt]31..24
    ccC ← GPR[rs]23..16 EQ GPR[rt]23..16
    ccB ← GPR[rs]15..8 EQ GPR[rt]15..8
    ccA ← GPR[rs]7..0 EQ GPR[rt]7..0
    GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA

CMPGU.LT.QB
    ccD ← GPR[rs]31..24 LT GPR[rt]31..24
    ccC ← GPR[rs]23..16 LT GPR[rt]23..16
    ccB ← GPR[rs]15..8 LT GPR[rt]15..8
    ccA ← GPR[rs]7..0 LT GPR[rt]7..0
    GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA

CMPGU.LE.QB
    ccD ← GPR[rs]31..24 LE GPR[rt]31..24
    ccC ← GPR[rs]23..16 LE GPR[rt]23..16
    ccB ← GPR[rs]15..8 LE GPR[rt]15..8
    ccA ← GPR[rs]7..0 LE GPR[rt]7..0
    GPR[rd]..0 ← 0(GPRLEN-4) || ccD || ccC || ccB || ccA
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	0 00000	CMPU.EQ.QB 00000	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	0 00000	CMPU.LT.QB 00001	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	0 00000	CMPU.LE.QB 00010	CMPU.EQ.QB 010001
6	5	5	5	5	6

Format: `CMPU.cond.QB`

`CMPU.EQ.QB rs, rt` **MIPSDSP**

`CMPU.LT.QB rs, rt` **MIPSDSP**

`CMPU.LE.QB rs, rt` **MIPSDSP**

Purpose: Compare Vectors of Unsigned Byte Values

Perform an element-wise comparison of two vectors of unsigned bytes, recording the results of the comparison in condition code bits.

Description: $DSPControl_{ccond:27..24} \leftarrow (rs_{31..24}\ cond\ rt_{31..24})\ ||\ (rs_{23..16}\ cond\ rt_{23..16})\ ||\ (rs_{15..8}\ cond\ rt_{15..8})\ ||\ (rs_{7..0}\ cond\ rt_{7..0})$

Each of the unsigned byte elements in register *rs* are compared with the corresponding unsigned byte elements in register *rt*. The four 1-bit boolean comparison results are written to bits 24 through 27 of the *DSPControl* register's -bit condition code field.

Restrictions:

No data-dependent exceptions are possible.

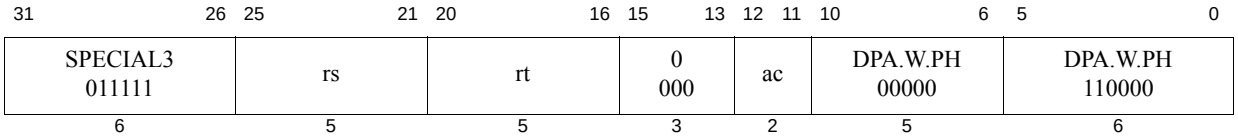
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
CMPU.EQ.QB
    ccD ← GPR[rs]31..24 EQ GPR[rt]31..24
    ccC ← GPR[rs]23..16 EQ GPR[rt]23..16
    ccB ← GPR[rs]15..8 EQ GPR[rt]15..8
    ccA ← GPR[rs]7..0 EQ GPR[rt]7..0
    DSPControlccond:27..24 ← ccD || ccC || ccB || ccA

CMPU.LT.QB
    ccD ← GPR[rs]31..24 LT GPR[rt]31..24
    ccC ← GPR[rs]23..16 LT GPR[rt]23..16
    ccB ← GPR[rs]15..8 LT GPR[rt]15..8
    ccA ← GPR[rs]7..0 LT GPR[rt]7..0
    DSPControlccond:27..24 ← ccD || ccC || ccB || ccA

CMPU.LE.QB
    ccD ← GPR[rs]31..24 LE GPR[rt]31..24
    ccC ← GPR[rs]23..16 LE GPR[rt]23..16
    ccB ← GPR[rs]15..8 LE GPR[rt]15..8
    ccA ← GPR[rs]7..0 LE GPR[rt]7..0
    DSPControlccond:27..24 ← ccD || ccC || ccB || ccA
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPA.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Dot Product with Accumulate on Vector Integer Halfword Elements

Generate the dot-product of two integer halfword vector elements using full-size intermediate products and then accumulate into the specified accumulator register.

Description: $ac \leftarrow ac + ((rs_{31..16} * rt_{31..16}) + (rs_{15..0} * rt_{15..0}))$

Each of the two halfword integer values from register *rt* is multiplied with the corresponding halfword element from register *rs* to create two integer word results. These two products are summed to generate a dot-product result, which is then accumulated into the specified 64-bit *HI*/*LO* accumulator, creating a 64-bit integer result.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits of the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

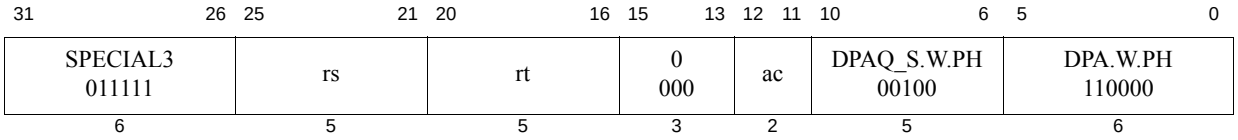
The operands must be a value in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← (GPR[rs]31..16 * GPR[rt]31..16)
tempA31..0 ← (GPR[rs]15..0 * GPR[rt]15..0)
dotp32..0 ← ( tempB31 || tempB31..0 ) + ( tempA31 || tempA31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + ( (dotp32)31 || dotp32..0 )
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 || acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAQ_S.W.PH ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Accumulation on Fractional Halfword Elements

Element-wise multiplication of two vectors of fractional halfword elements and accumulation of the accumulated 32-bit intermediate products into the specified 64-bit accumulator register, with saturation.

Description: $ac \leftarrow ac + (sat32(rs_{31..16} * rt_{31..16}) + sat32(rs_{15..0} * rt_{15..0}))$

Each of the two Q15 fractional word values from registers *rt* and *rs* are multiplied together, and the results left-shifted by one bit position to generate two Q31 fractional format intermediate products. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is accumulated into the specified 64-bit *HI*/*LO* accumulator to produce a final Q32.31 fractional result.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of a halfword multiplication, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the ouflag field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

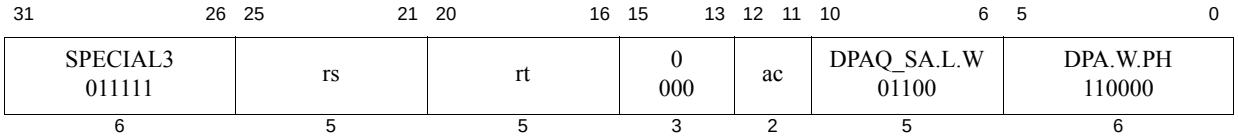
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]31..16 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]15..0 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0

function multiplyQ15Q15( acc1..0, a15..0, b15..0 )
    if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
        temp31..0 ← 0x7FFFFFFF
        DSPControlouflag:16+acc ← 1
    else
        temp31..0 ← ( a15..0 * b15..0 ) << 1
    endif
    return temp31..0
endfunction multiplyQ15Q15
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAQ_SA.L.W ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Accumulate on Fractional Word Element

Multiplication of two fractional word elements, accumulating the product to the specified 64-bit accumulator register, with saturation.

Description: `ac ← sat64(ac + sat32(rs`$_{31..0}$ `* rt`$_{31..0}$`))`

The two right-most Q31 fractional word values from registers *rt* and *rs* are multiplied together and the result left-shifted by one bit position to generate a 64-bit, Q63 fractional format intermediate product. If both multiplicands are equal to -1.0 (0x80000000 hexadecimal), the intermediate product is saturated to the maximum positive Q63 fractional value (0x7FFFFFFFFFFFFFFF hexadecimal).

The intermediate product is then added to the specified 64-bit *HI*/*LO* accumulator, creating a Q63 fractional result. If the accumulation results in overflow or underflow, the accumulator is saturated to either the maximum positive or minimum negative Q63 fractional value (0x8000000000000000 hexadecimal), respectively.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the ouflag field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

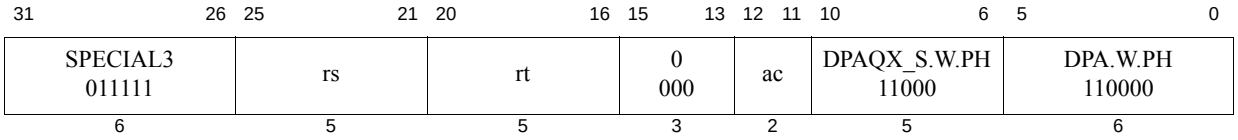
Operation:

```
dotp63..0 ← multiplyQ31Q31( ac, GPR[rs]31..0, GPR[rt]31..0 )
temp64..0 ← HI[ac]31 || HI[ac]31..0 || LO[ac]31..0
temp64..0 ← temp64..0 + dotp63..0
if ( temp64 ≠ temp63 ) then
    if ( temp64 = 1 ) then
        temp63..0 ← 0x8000000000000000
    else
        temp63..0 ← 0x7FFFFFFFFFFFFFFF
    endif
    DSPControlouflag:16+ac ← 1
endif
( HI[ac]..0 || LO[ac]..0 ) ← temp63..32 || temp31..0

function multiplyQ31Q31( acc1..0, a31..0, b31..0 )
    if (( a31..0 = 0x80000000 ) and ( b31..0 = 0x80000000 )) then
        temp63..0 ← 0x7FFFFFFFFFFFFFFF
        DSPControlouflag:16+acc ← 1
    else
        temp63..0 ← ( a31..0 * b31..0 ) << 1
    endif
    return temp63..0
```

```
endfunction multiplyQ31Q31
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAQX_S.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Accumulation on Fractional Halfword Elements

Element-wise cross multiplication of two vectors of fractional halfword elements and accumulation of the 32-bit intermediate products into the specified 64-bit accumulator register, with saturation.

Description: $ac \leftarrow ac + (sat32(rs_{31..16} * rt_{15..0}) + sat32(rs_{15..0} * rt_{31..16}))$

The left Q15 fractional word value from registers *rt* is multiplied with the right halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. Similarly, the right Q15 fractional word value from registers *rt* is multiplied with the left halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is accumulated into the specified 64-bit *HI*/*LO* accumulator to produce a final Q32.31 fractional result.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of a halfword multiplication, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the ouflag field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

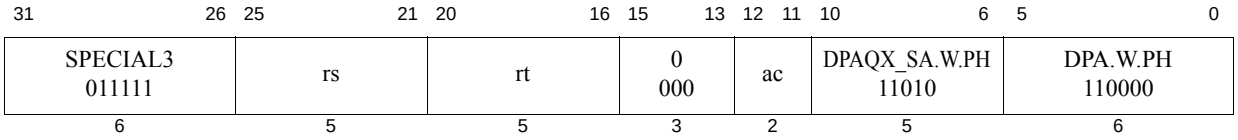
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]15..0 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]31..16 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0

function multiplyQ15Q15( acc1..0, a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:16+acc ← 1
   else
      temp31..0 ← ( a15..0 * b15..0 ) << 1
   endif
   return temp31..0
endfunction multiplyQ15Q15
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAQX_SA.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Accumulation on Fractional Halfword Elements

Element-wise cross multiplication of two vectors of fractional halfword elements and accumulation of the 32-bit intermediate products into the specified 64-bit accumulator register, with saturation of the accumulator.

Description: $ac \leftarrow sat32(ac + (sat32(rs_{31..16} * rt_{15..0}) + sat32(rs_{15..0} * rt_{31..16})))$

The left Q15 fractional word value from registers *rt* is multiplied with the right halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. Similarly, the right Q15 fractional word value from registers *rt* is multiplied with the left halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is accumulated into the specified 64-bit *HI*/*LO* accumulator to produce a Q32.31 fractional result. If this result is larger than or equal to +1.0, or smaller than -1.0, it is saturated to the Q31 range.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of halfword multiplication or accumulation, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the ouflag field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

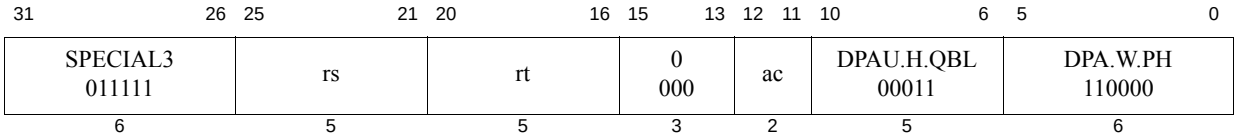
Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]15..0 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]31..16 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
if ( tempC63 = 0 ) and ( tempC62..31 ≠ 0 ) then
   tempC63..0 = 032 || 0x7FFFFFFF
   DSPControlouflag:16+acc ← 1
endif
if ( tempC63 = 1) and ( tempC62..31 ≠ 132) then
   tempC63..0 = 132 || 0x80000000
   DSPControlouflag:16+acc ← 1
endif
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0

function multiplyQ15Q15( acc1..0, a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:16+acc ← 1
```

```
        else
            temp31..0 ← ( a15..0 * b15..0 ) << 1
        endif
        return temp31..0
    endfunction multiplyQ15Q15
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAU.H.QBL ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Accumulate on Vector Unsigned Byte Elements

Element-wise multiplication of the two left-most elements of the four elements of each of two vectors of unsigned bytes, accumulating the sum of the products into the specified 64-bit accumulator register.

Description: $ac \leftarrow ac + zero\_extend((rs_{31..24} * rt_{31..24}) + (rs_{23..16} * rt_{23..16}))$

The two left-most elements of the four unsigned byte elements of each of registers *rt* and *rs* are multiplied together using unsigned arithmetic to generate two 16-bit unsigned intermediate products. The intermediate products are then zero-extended to 64 bits and accumulated into the specified 64-bit *HI*/*LO* accumulator.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits in the ouflag field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

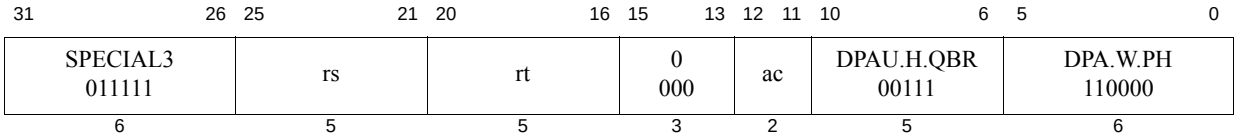
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U8( GPR[rs]31..24, GPR[rt]31..24 )
tempA15..0 ← multiplyU8U8( GPR[rs]23..16, GPR[rt]23..16 )
dotp63..0 ← ( 0^48 || tempB15..0 ) + ( 0^48 || tempA15..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
( HI[ac]..0 || LO[ac]..0 )  ← tempC63..32 || tempC31..0

function multiplyU8U8( a7..0, b7..0 )
   temp17..0 ← ( 0 || a7..0 ) * ( 0 || b7..0 )
   return temp15..0
endfunction multiplyU8U8
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAU.H.QBR ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Accumulate on Vector Unsigned Byte Elements

Element-wise multiplication of the two right-most elements of the four elements of each of two vectors of unsigned bytes, accumulating the sum of the products into the specified 64-bit accumulator register.

Description: $ac \leftarrow ac + zero\_extend((rs_{15..8} * rt_{15..8}) + (rs_{7..0} * rt_{7..0}))$

The two right-most elements of the four unsigned byte elements of each of registers *rt* and *rs* are multiplied together using unsigned arithmetic to generate two 16-bit unsigned intermediate products. The intermediate products are then zero-extended to 64 bits and accumulated into the specified 64-bit *HI*/*LO* accumulator.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits in the ouflag field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

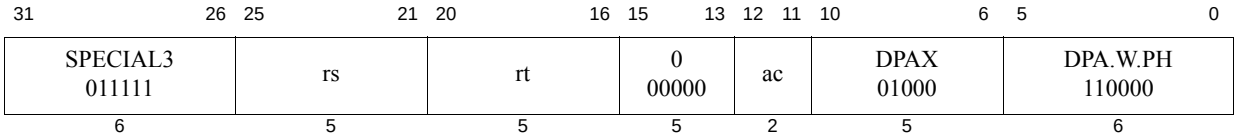
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U8( GPR[rs]15..8, GPR[rs]15..8 )
tempA15..0 ← multiplyU8U8( GPR[rs]7..0, GPR[rs]7..0 )
dotp63..0 ← ( 0^48 || tempB15..0 ) + ( 0^48 || tempA15..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPAX.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Accumulate on Vector Integer Halfword Elements

Generate the cross dot-product of two integer halfword vector elements using full-size intermediate products and then accumulate into the specified accumulator register.

Description: $ac \leftarrow ac + ((rs_{31..16} * rt_{15..0}) + (rs_{15..0} * rt_{31..16}))$

The left halfword integer value from register *rt* is multiplied with the right halfword element from register *rs* to create an integer word result. Similarly, the right halfword integer value from register *rt* is multiplied with the left halfword element from register *rs* to create the second integer word result. These two products are summed to generate the dot-product result, which is then accumulated into the specified 64-bit *HI*/*LO* accumulator, creating a 64-bit integer result.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

This instruction will not set any bits of the ouflag field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

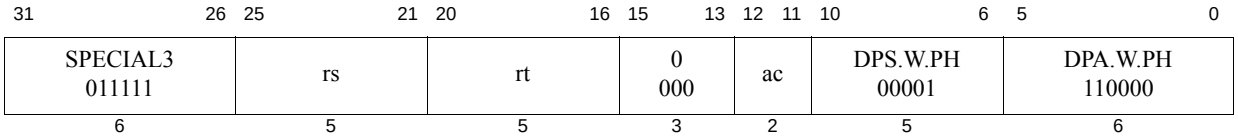
The operands must be a value in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← (GPR[rs]31..16 * GPR[rt]15..0)
tempA31..0 ← (GPR[rs]15..0 * GPR[rt]31..16)
dotp32..0 ← ( (tempB31) || tempB31..0 ) + ( (tempA31) || tempA31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + ( (dotp32)31 || dotp32..0 )
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPS.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Dot Product with Subtract on Vector Integer Half-Word Elements

Generate the dot-product of two integer halfword vector elements using full-size intermediate products and then subtract from the specified accumulator register.

Description: $ac \leftarrow ac - ((rs_{31..16} * rt_{31..16}) + (rs_{15..0} * rt_{15..0}))$

Each of the two halfword integer values from register *rt* is multiplied with the corresponding halfword element from register *rs* to create two integer word results. These two products are summed to generate the dot-product result, which is then subtracted from the specified 64-bit *HI*/*LO* accumulator, creating a 64-bit integer result.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

This instruction will not set any bits of the ouflag field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

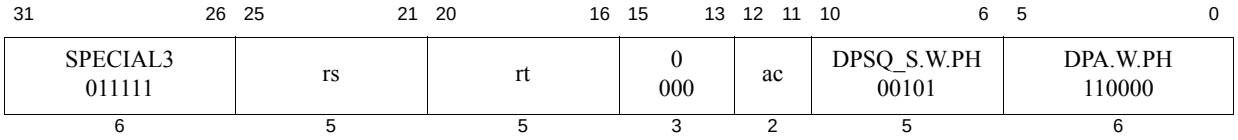
The operands must be a value in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← (GPR[rs]31..16 * GPR[rt]31..16)
tempA31..0 ← (GPR[rs]15..0 * GPR[rt]15..0)
dotp32..0 ← ( (tempB31) || tempB31..0 ) + ( (tempA31) || tempA31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - ( (dotp32)31 || dotp32..0 )
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 || acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSQ_S.W.PH ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Subtraction on Fractional Halfword Elements

Element-wise multiplication of two vectors of fractional halfword elements and subtraction of the accumulated 32-bit intermediate products from the specified 64-bit accumulator register, with saturation.

Description: $ac \leftarrow ac - (sat32(rs_{31..16} * rt_{31..16}) + sat32(rs_{15..0} * rt_{15..0}))$

Each of the two Q15 fractional word values from registers *rt* and *rs* are multiplied together, and the results left-shifted by one bit position to generate two Q31 fractional format intermediate products. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is subtracted from the specified 64-bit *HI*/*LO* accumulator to produce a final Q32.31 fractional result.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of a halfword multiplication, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the ouflag field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

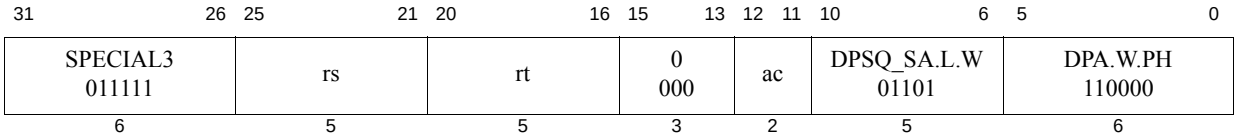
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]31..16 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]15..0 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - dotp63..0
( HI[ac]..0 || LO[ac]..0 )  ← tempC63..32 || tempC31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSQ_SA.L.W ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Subtraction on Fractional Word Element

Multiplication of two fractional word elements, subtracting the accumulated product from the specified 64-bit accumulator register, with saturation.

Description: `ac ← sat64(ac - sat32(rs`$_{31..0}$ `* rt`$_{31..0}$`))`

The two right-most Q31 fractional word values from registers *rt* and *rs* are multiplied together and the result left-shifted by one bit position to generate a 64-bit Q63 fractional format intermediate product. If both multiplicands are equal to -1.0 (0x80000000 hexadecimal), the intermediate product is saturated to the maximum positive Q63 fractional value (0x7FFFFFFFFFFFFFFF hexadecimal).

The intermediate product is then subtracted from the specified 64-bit *HI*/*LO* accumulator, creating a Q63 fractional result. If the accumulation results in overflow or underflow, the accumulator is saturated to either the maximum positive or minimum negative Q63 fractional value (0x8000000000000000 hexadecimal), respectively.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

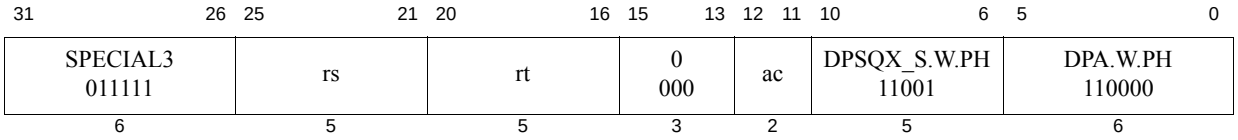
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
dotp63..0 ← multiplyQ31Q31( ac, GPR[rs]31..0, GPR[rt]31..0 )
temp64..0 ← HI[ac]31 || HI[ac]31..0 || LO[ac]31..0
temp64..0 ← temp - dotp63..0
if ( temp64 ≠ temp63 ) then
    if ( temp64 = 1 ) then
        temp63..0 ← 0x8000000000000000
    else
        temp63..0 ← 0x7FFFFFFFFFFFFFFF
    endif
    DSPControlouflag:16+ac ← 1
endif
( HI[ac]..0 || LO[ac]..0 )  ← temp63..32 || temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSQX_S.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Subtraction on Fractional Halfword Elements

Element-wise cross multiplication of two vectors of fractional halfword elements and subtraction of the accumulated 32-bit intermediate products from the specified 64-bit accumulator register, with saturation.

Description: $ac \leftarrow ac - (sat32(rs_{31..16} * rt_{15..0}) + sat32(rs_{15..0} * rt_{31..16}))$

The left Q15 fractional word value from registers *rt* is multiplied with the right halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. Similarly, the right Q15 fractional word value from registers *rt* is multiplied with the left halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is subtracted from the specified 64-bit *HI*/*LO* accumulator to produce a final Q32.31 fractional result.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of a halfword multiplication, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

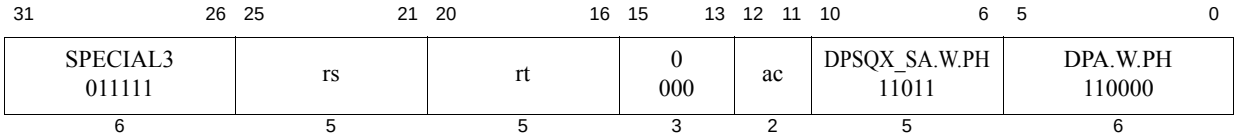
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]15..0 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]31..16 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0

function multiplyQ15Q15( acc1..0, a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:16+acc ← 1
   else
      temp31..0 ← ( a15..0 * b15..0 ) << 1
   endif
   return temp31..0
endfunction multiplyQ15Q15
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSQX_SA.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Subtraction on Fractional Halfword Elements

Element-wise cross multiplication of two vectors of fractional halfword elements and subtraction of the accumulated 32-bit intermediate products from the specified 64-bit accumulator register, with saturation of the accumulator.

Description: $ac \leftarrow sat32(ac - (sat32(rs_{31..16} * rt_{15..0}) + sat32(rs_{15..0} * rt_{31..16})))$

The left Q15 fractional word value from registers *rt* is multiplied with the right halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. Similarly, the right Q15 fractional word value from registers *rt* is multiplied with the left halfword element from register *rs* and the result left-shifted by one bit position to generate a Q31 fractional format intermediate product. If both multiplicands for either of the multiplications are equal to -1.0 (0x8000 hexadecimal), the resulting intermediate product is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal).

The two intermediate products are then sign-extended and summed to generate a 64-bit, Q32.31 fractional format dot-product result that is subtracted from the specified 64-bit *HI*/*LO* accumulator to produce a Q32.31 fractional result. If this result is larger than or equal to +1.0, or smaller than -1.0, it is saturated to the Q31 range.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs as a result of halfword multiplication or accumulation, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

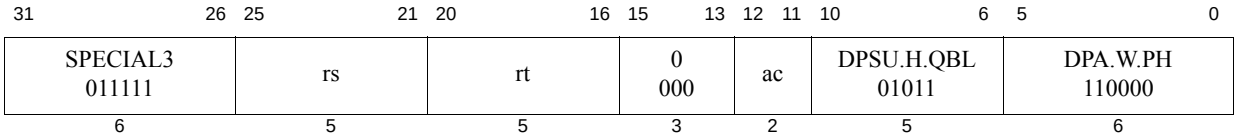
Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]15..0 )
tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]31..16 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) + ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - dotp63..0
if ( tempC63 = 0 ) and ( tempC62..31 ≠ 0 ) then
   tempC63..0 = 032 || 0x7FFFFFFF
   DSPControlouflag:16+acc ← 1
endif
if ( tempC63 = 1) and ( tempC62..31 ≠ 132) then
   tempC63..0 = 132 || 0x80000000
   DSPControlouflag:16+acc ← 1
endif
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0

function multiplyQ15Q15( acc1..0, a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:16+acc ← 1
```

```
        else
            temp31..0 ← ( a15..0 * b15..0 ) << 1
        endif
        return temp31..0
    endfunction multiplyQ15Q15
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSU.H.QBL ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Subtraction on Vector Unsigned Byte Elements

Element-wise multiplication of two left -most elements from the four elements of each of two vectors of unsigned bytes, subtracting the sum of the products from the specified 64-bit accumulator register.

Description: $ac \leftarrow ac - zero\_extend((rs_{31..24} * rt_{31..24}) + (rs_{23..16} * rt_{23..16}))$

The two left-most elements of the four unsigned byte elements of each of registers *rt* and *rs* are multiplied together using unsigned arithmetic to generate two 16-bit unsigned intermediate products. The intermediate products are then zero-extended to 64 bits and subtracted from the specified 64-bit *HI*/*LO* accumulator. The result of the subtraction is written back to the specified 64-bit *HI/LO* accumulator.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits in the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

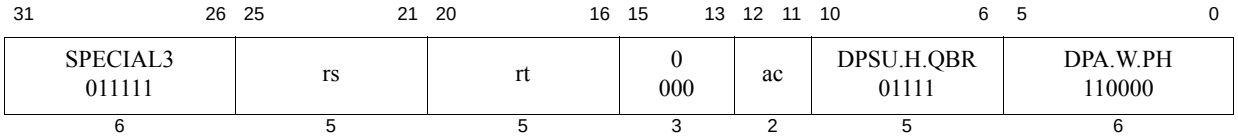
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U8( GPR[rs]31..24, GPR[rt]31..24 )
tempA15..0 ← multiplyU8U8( GPR[rs]23..16, GPR[rt]23..16 )
dotp63..0 ← ( 0^48 || tempB15..0 ) + ( 0^48 || tempA15..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSU.H.QBR ac, rs, rt` **MIPSDSP**

Purpose: Dot Product with Subtraction on Vector Unsigned Byte Elements

Element-wise multiplication of the two right-most elements of the four elements of each of two vectors of unsigned bytes, subtracting the sum of the products from the specified 64-bit accumulator register.

Description: $ac \leftarrow ac - zero\_extend((rs_{15..8} * rt_{15..8}) + (rs_{7..0} * rt_{7..0}))$

The two right-most elements of the four unsigned byte elements of each of registers *rt* and *rs* are multiplied together using unsigned arithmetic to generate two 16-bit unsigned intermediate products. The intermediate products are then zero-extended to 64 bits and subtracted from the specified 64-bit *HI*/*LO* accumulator.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits in the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

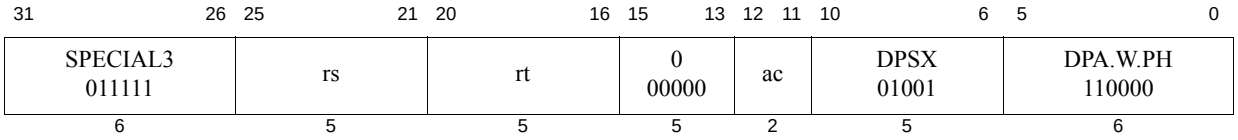
The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U8( GPR[rs]15..8, GPR[rt]15..8 )
tempA15..0 ← multiplyU8U8( GPR[rs]7..0, GPR[rt]7..0 )
dotp63..0 ← ( 0^48 || tempB15..0 ) + ( 0^48 || tempA15..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `DPSX.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Cross Dot Product with Subtract on Vector Integer Halfword Elements

Generate the cross dot-product of two integer halfword vector elements using full-size intermediate products and then subtract from the specified accumulator register.

Description: $ac \leftarrow ac - ((rs_{31..16} * rt_{15..0}) + (rs_{15..0} * rt_{31..16}))$

The left halfword integer value from register *rt* is multiplied with the right halfword element from register *rs* to create an integer word result. Similarly, the right halfword integer value from register *rt* is multiplied with the left halfword element from register *rs* to create the second integer word result. These two products are summed to generate the dot-product result, which is then subtracted from the specified 64-bit *HI*/*LO* accumulator, creating a 64-bit integer result.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

This instruction will not set any bits of the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

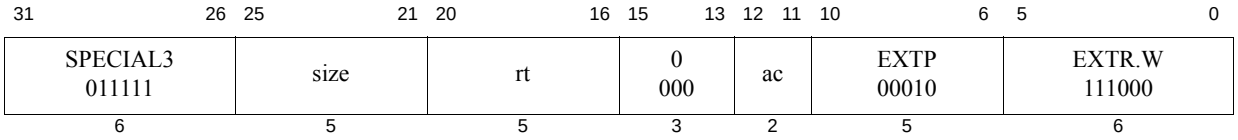
The operands must be a value in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← (GPR[rs]31..16 * GPR[rt]15..0)
tempA31..0 ← (GPR[rs]15..0 * GPR[rt]31..16)
dotp32..0 ← ( (tempB31) || tempB31..0 ) + ( (tempA31) || tempA31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - ( (dotp32)31 || dotp32..0 )
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTP rt, ac, size` **MIPSDSP**

Purpose: Extract Fixed Bitfield From Arbitrary Position in Accumulator to GPR

Extract *size*+1 contiguous bits from a 64-bit accumulator from a position specified in the *DSPControl* register, writing the bits to a GPR with zero-extension.

Description: $rt \leftarrow zero\_extend(ac_{pos..pos-size})$

A set of *size*+1 contiguous bits are extracted from an arbitrary position in accumulator *ac*, zero-extended to bits, and then written to register *rt*.

The bit position, *start_pos*, of the first bit of the contiguous set to extract is specified by the pos field in bits 0 through 5 of the *DSPControl* register. The last bit in the set is *start_pos* - *size*, where *size* is specified in the instruction.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, accumulator *ac* remains unmodified.

If $start\_pos - (size + 1) \geq -1$, the extraction is valid, otherwise the extraction is invalid and is said to have failed. The value of the destination register is **UNPREDICTABLE** when the extraction is invalid. Upon an invalid extraction this instruction writes a 1 to bit 14, the Extract Failed Indicator (EFI) bit of the *DSPControl* register, and 0 otherwise.

The values of bits 0 to in the pos field of the *DSPControl* register are unchanged by this instruction.

Restrictions:

No data-dependent exceptions are possible.

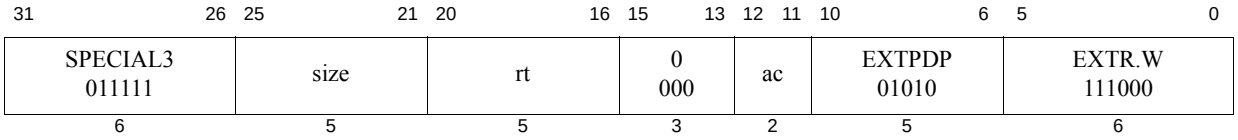
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
start_pos5..0 ← DSPControlpos:5..0
if ( start_pos - (size+1) >= -1 ) then
   tempsize..0 ← ( HI[ac]31..0 || LO[ac]31..0 )start_pos..start_pos-size
   temp31..0 ← 0(32-(size+1)) || tempsize..0
   GPR[rt]..0 ← temp31..0
   DSPControlEFI:14 ← 0
else
   DSPControlEFI:14 ← 1
   GPR[rt] ← UNPREDICTABLE
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTPDP rt, ac, size` **MIPSDSP**

Purpose: Extract Fixed Bitfield From Arbitrary Position in Accumulator to GPR and Decrement Pos

Extract *size*+1 contiguous bits from a 64-bit accumulator from a position specified in the *DSPControl* register, writing the bits to a GPR with zero-extension and modifying the extraction position.

Description: `rt ← zero_extend(ac`$_{pos..pos-size}$`) ; DSPControl`$_{pos:..0}$ `-= (size+1)`

A set of *size*+1 contiguous bits are extracted from an arbitrary position in accumulator *ac*, zero-extended to bits, then written to register *rt*.

The bit position, *start_pos*, of the first bit of the contiguous set to extract is specified by the *pos* field in bits 0 through 5 of the *DSPControl* register. The position of the last bit in the extracted set is *start_pos* - *size*, where the *size* argument is specified in the instruction.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, accumulator *ac* remains unmodified.

If $start\_pos - (size + 1) \geq -1$, the extraction is valid and the value of the pos field in the *DSPControl* register is decremented by *size*+1. Otherwise, the extraction is invalid and is said to have failed. The value of the destination register is **UNPREDICTABLE** when the extraction is invalid, and the value of the pos field in the *DSPControl* register (bits 0 through) is not modified.

Upon an invalid extraction this instruction writes a 1 to bit 14, the Extract Failed Indicator (EFI) bit of the *DSPControl* register, and 0 otherwise.

Restrictions:

No data-dependent exceptions are possible.

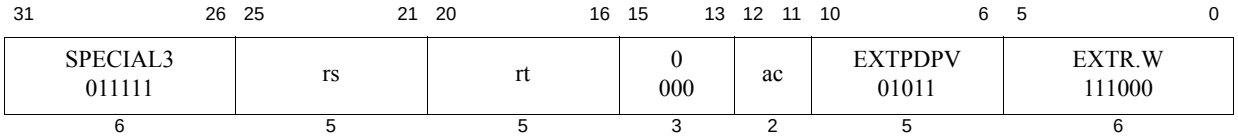
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
start_pos5..0 ← DSPControlpos:5..0
if ( start_pos - (size+1) >= -1 ) then
   tempsize..0 ← ( HI[ac]31..0 || LO[ac]31..0 )start_pos..start_pos-size
   GPR[rt] ← 0(GPRLEN-(size+1)) || tempsize..0
   DSPControlpos:..0 ← DSPControlpos:..0 - (size + 1)
   DSPControlEFI:14 ← 0
else
   DSPControlEFI:14 ← 1
   GPR[rt] ← UNPREDICTABLE
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTPDPV rt, ac, rs` **MIPSDSP**

Purpose: Extract Variable Bitfield From Arbitrary Position in Accumulator to GPR and Decrement Pos

Extract a fixed number of contiguous bits from a 64-bit accumulator from a position specified in the *DSPControl* register, writing the bits to a GPR with zero-extension and modifying the extraction position.

Description: $rt \leftarrow zero\_extend(ac_{pos..pos-GPR[rs][4:0]})$; $DSPControl_{pos:..0} -= (GPR[rs]_{4..0}+1)$

A fixed number of contiguous bits are extracted from an arbitrary position in accumulator *ac*, zero-extended to bits, then written to destination register *rt*. The number of bits extracted is *size*+1, where *size* is specified by the five least-significant bits in register *rs*, interpreted as a five-bit unsigned integer. The remaining bits in register *rs* are ignored.

The bit position, *start_pos*, of the first bit of the contiguous set to extract is specified by the pos field in bits 0 through 5 of the *DSPControl* register. The position of the last bit in the extracted set is *start_pos* - *size*.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, accumulator *ac* remains unmodified.

If $start\_pos - (size + 1) \geq -1$, the extraction is valid and the value of the pos field in the *DSPControl* register is decremented by *size*+1. Otherwise, the extraction is invalid and is said to have failed. The value of the destination register is **UNPREDICTABLE** when the extraction is invalid, and the value of the pos field in the *DSPControl* register (bits 0 through) is not modified.

Upon an invalid extraction this instruction writes a 1 to bit 14, the Extract Failed Indicator (EFI) bit of the *DSPControl* register, and 0 otherwise.

Restrictions:

No data-dependent exceptions are possible.

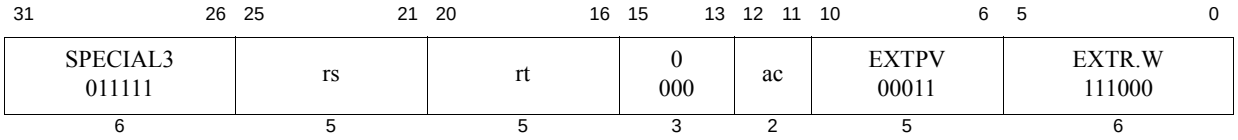
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
start_pos5..0 ← DSPControlpos:5..0
size4..0 ← GPR[rs]4..0
if ( start_pos - (size+1) >= -1 ) then
   tempsize..0 ← ( HI[ac]31..0 || LO[ac]31..0 )start_pos..start_pos-size
   GPR[rt] ← 0(GPRLEN-(size+1)) || tempsize..0
   DSPControlpos:..0 ← DSPControlpos:..0 - (size + 1)
   DSPControlEFI:14 ← 0
else
   DSPControlEFI:14 ← 1
   GPR[rt] ← UNPREDICTABLE
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTPV rt, ac, rs` **MIPSDSP**

Purpose: Extract Variable Bitfield From Arbitrary Position in Accumulator to GPR

Extract a variable number of contiguous bits from a 64-bit accumulator from a position specified in the *DSPControl* register, writing the bits to a GPR with zero-extension.

Description: `rt ← zero_extend(ac`$_{pos..pos-rs[4:0]}$`)`

A variable number of contiguous bits are extracted from an arbitrary position in accumulator *ac*, zero-extended to bits, then written to register *rt*. The number of bits extracted is *size*+1, where *size* is specified by the five least-significant bits in register *rs*, interpreted as a five-bit unsigned integer. The remaining bits in register *rs* are ignored.

The position of the first bit of the contiguous set to extract, *start_pos*, is specified by the pos field in bits 0 through of the *DSPControl* register. The position of the last bit in the contiguous set is *start_pos* - *size*.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, accumulator *ac* remains unmodified.

An extraction is valid if $start\_pos - (size + 1) \geq -1$; otherwise, the extraction is invalid and is said to have failed. The value of the destination register is **UNPREDICTABLE** when the extraction is invalid. Upon an invalid extraction this instruction writes a 1 to bit 14, the Extract Failed Indicator (EFI) bit of the *DSPControl* register, and 0 otherwise.

The values of bits 0 to in the pos field of the *DSPControl* register are unchanged by this instruction.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
start_pos5..0 ← DSPControlpos:5..0
size4..0 ← GPR[rs]4..0
if ( start_pos - (size+1) >= -1 ) then
   tempsize..0 ← ( HI[ac]31..0 || LO[ac]31..0 )start_pos..start_pos-size
   GPR[rt] ← 0(GPRLEN-(size+1)) || tempsize..0
   DSPControlEFI:14 ← 0
else
   DSPControlEFI:14 ← 1
   GPR[rt] ← UNPREDICTABLE
endif
```

Exceptions:

Reserved Instruction, DSP Disabled

31–26	25–21	20–16	15–13	12–11	10–6	5–0
SPECIAL3 011111	shift	rt	0 000	ac	EXTR.W 00000	EXTR.W 111000
SPECIAL3 011111	shift	rt	0 000	ac	EXTR_R.W 00100	EXTR.W 111000
SPECIAL3 011111	shift	rt	0 000	ac	EXTR_RS.W 00110	EXTR.W 111000
6	5	5	3	2	5	6

Format: `EXTR[_RS].W`

```
EXTR.W    rt, ac, shift                                  MIPSDSP
EXTR_R.W  rt, ac, shift                                  MIPSDSP
EXTR_RS.W rt, ac, shift                                  MIPSDSP
```

Purpose: Extract Word Value With Right Shift From Accumulator to GPR

Extract a word value from a 64-bit accumulator to a GPR with right shift, and with optional rounding or rounding and saturation.

Description: `rt ← sat32(round(ac >> shift))`

The value in accumulator *ac* is shifted right by *shift* bits with sign extension (arithmetic shift right). The 32 least-significant bits of the shifted value are then written to the destination register *rt*.

The rounding variant of the instruction adds a 1 at the most-significant discarded bit position. The 32 least-significant bits of the rounded result are then written to the destination register.

The rounding and saturating variant of the instruction adds a 1 at the most-significant discarded bit position. If the rounding operation results in an overflow, the shifted value is clamped to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal). The rounded and saturated result is then written to the destination register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, *ac* remains unmodified.

For all variants of the instruction, including EXTR.W, bit 23 of the *DSPControl* register is set to 1 if either of the rounded or non-rounded calculation results in overflow or saturation.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

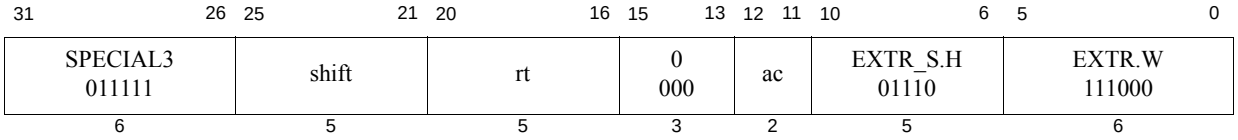
Operation:

```
EXTR.Wtemp64..0 ← _shiftShortAccRightArithmetic( ac, shift )
   if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF ) ) then
      DSPControlouflag:23 ← 1
   endif
   GPR[rt]..0 ← temp32..1
   temp64..0 ← temp + 1
   if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
      DSPControlouflag:23 ← 1
   endif


EXTR_R.W
```

```
        temp64..0 ← _shiftShortAccRightArithmetic( ac, shift )
        if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
            DSPControlouflag:23 ← 1
        endif
        temp64..0 ← temp + 1
        if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
            DSPControlouflag:23 ← 1
        endif
        GPR[rt]..0 ← temp32..1

    EXTR_RS.W
        temp64..0 ← _shiftShortAccRightArithmetic( ac, shift )
        if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
            DSPControlouflag:23 ← 1
        endif
        temp64..0 ← temp + 1
        if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
            if ( temp64 = 0 ) then
                temp32..1 ← 0x7FFFFFFF
            else
                temp32..1 ← 0x80000000
            endif
            DSPControlouflag:23 ← 1
        endif
        GPR[rt]..0 ← temp32..1

    function _shiftShortAccRightArithmetic( ac1..0, shift4..0 )
        if ( shift4..0 = 0 ) then
            temp64..0 ← ( HI[ac]31..0 || LO[ac]31..0 || 0 )
        else
            temp64..0 ← ( (HI[ac]31)shift || HI[ac]31..0 || LO[ac]31..shift-1 )
        endif
        return temp64..0
    endfunction _shiftShortAccRightArithmetic
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTR_S.H rt, ac, shift` **MIPSDSP**

Purpose: Extract Halfword Value From Accumulator to GPR With Right Shift and Saturate

Extract a halfword value from a 64-bit accumulator to a GPR with right shift and saturation.

Description: `rt ← sat16(ac >> shift)`

The value in the 64-bit accumulator *ac* is shifted right by *shift* bits with sign extension (arithmetic shift right). The 64-bit value is then saturated to 16-bits, sign extended to bits, and written to the destination register *rt*. The shift argument is provided in the instruction.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, *ac* remains unmodified.

This instruction sets bit 23 of the *DSPControl* register in the *ouflag* field if the operation results in saturation.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp63..0 ← shiftShortAccRightArithmetic( ac, shift )
if ( temp63..0 > 0x0000000000007FFF ) then
   temp31..0 ← 0x00007FFF
   DSPControlouflag:23 ← 1
else if ( temp63..0 < 0xFFFFFFFFFFFF8000 ) then
   temp31..0 ← 0xFFFF8000
   DSPControlouflag:23 ← 1
endif
GPR[rt]..0 ← temp31..0

function shiftShortAccRightArithmetic( ac1..0, shift4..0 )
   sign ← HI[ac]31
   if ( shift = 0 ) then
      temp63..0 ← HI[ac]31..0 || LO[ac]31..0
   else
      temp63..0 ← sign^shift || (( HI[ac]31..0 || LO[ac]31..0 ) >> shift )
   endif
   if ( sign ≠ temp31 ) then
      DSPControlouflag:23 ← 1
   endif
   return temp63..0
endfunction shiftShortAccRightArithmetic
```

Exceptions:

Reserved Instruction, DSP Disabled

31–26	25–21	20–16	15–13	12–11	10–6	5–0
SPECIAL3 011111	rs	rt	0 000	ac	EXTRV.W 00001	EXTR.W 111000
SPECIAL3 011111	rs	rt	0 000	ac	EXTRV_R.W 00101	EXTR.W 111000
SPECIAL3 011111	rs	rt	0 000	ac	EXTRV_RS.W 00111	EXTR.W 111000
6	5	5	3	2	5	6

Format: `EXTRV[_RS].W`

```
EXTRV.W    rt, ac, rs                                   MIPSDSP
EXTRV_R.W  rt, ac, rs                                   MIPSDSP
EXTRV_RS.W rt, ac, rs                                   MIPSDSP
```

Purpose: Extract Word Value With Variable Right Shift From Accumulator to GPR

Extract a word value from a 64-bit accumulator to a GPR with variable right shift, and with optional rounding or rounding and saturation.

Description: $rt \leftarrow sat32(round(ac >> rs_{5..0}))$

The value in accumulator *ac* is shifted right by *shift* bits with sign extension (arithmetic shift right). The lower 32 bits of the shifted value are then written to the destination register *rt*. The number of bits to shift is given by the five least-significant bits of register `rs`; the remaining bits of *rs* are ignored.

The rounding variant of the instruction adds a 1 at the most-significant discarded bit position. The 32 least-significant bits of the rounded result are then written to the destination register.

The rounding and saturating variant of the instruction adds a 1 at the most-significant discarded bit position. If the rounding operation results in an overflow, the shifted value is clamped to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal). The rounded and saturated result is then written to the destination register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, *ac* remains unmodified.

For all variants of the instruction, including EXTRV.W, bit 23 of the *DSPControl* register is set to 1 if either of the rounded or non-rounded calculation results in overflow or saturation.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

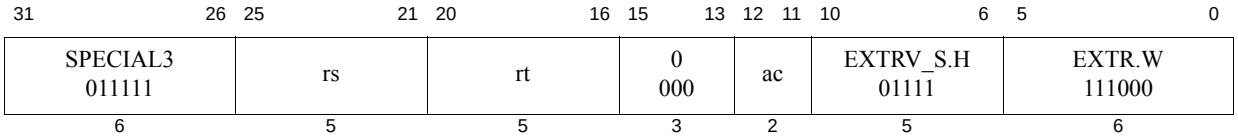
Operation:

```
EXTRV.W
    temp64..0 ← _shiftShortAccRightArithmetic( ac, GPR[rs]4..0 )
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        DSPControlouflag:23 ← 1
    endif
    GPR[rt]..0 ← temp32..1
    temp64..0 ← temp + 1
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        DSPControlouflag:23 ← 1
    endif
```

```
EXTRV_R.W
    temp64..0 ← _shiftShortAccRightArithmetic( ac, GPR[rs]4..0 )
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        DSPControlouflag:23 ← 1
    endif
    temp64..0 ← temp + 1
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        DSPControlouflag:23 ← 1
    endif
    GPR[rt]..0 ← temp32..1

EXTRV_RS.W
    temp64..0 ← _shiftShortAccRightArithmetic( ac, GPR[rs]4..0 )
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        DSPControlouflag:23 ← 1
    endif
    temp64..0 ← temp + 1
    if (( temp64..32 ≠ 0 ) and ( temp64..32 ≠ 0x1FFFFFFFF )) then
        if ( temp64 = 0 ) then
            temp32..1 ← 0x7FFFFFFF
        else
            temp32..1 ← 0x80000000
        endif
        DSPControlouflag:23 ← 1
    endif
    GPR[rt]..0 ← temp32..1
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `EXTRV_S.H rt, ac, rs` **MIPSDSP**

Purpose: Extract Halfword Value Variable From Accumulator to GPR With Right Shift and Saturate

Extract a halfword value from a 64-bit accumulator to a GPR with right shift and saturation.

Description: $rt \leftarrow sat16(ac >> rs_{4..0})$

The value in the 64-bit accumulator *ac* is shifted right by *shift* bits with sign extension (arithmetic shift right). The 64-bit value is then saturated to 16-bits and sign-extended to bits before being written to the destination register *rt*. The five least-significant bits of register *rs* provide the shift argument, interpreted as a five-bit unsigned integer; the remaining bits in *rs* are ignored.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture. After the execution of this instruction, *ac* remains unmodified.

This instruction sets bit 23 of the *DSPControl* register in the *ouflag* field if the operation results in saturation.

Restrictions:

No data-dependent exceptions are possible.

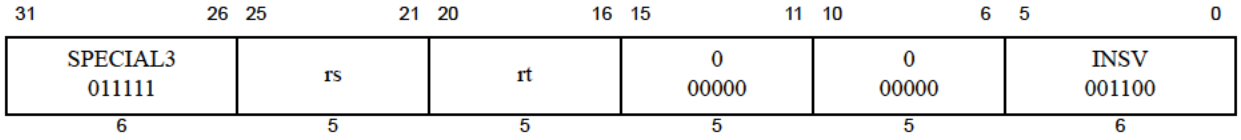
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
shift4..0 ← GPR[rs]4..0
temp31..0 ← shiftShortAccRightArithmetic( ac, shift )
if ( temp63..0 > 0x0000000000007FFF ) then
   temp31..0 ← 0x00007FFF
   DSPControl23 ← 1
else if ( temp63..0 < 0xFFFFFFFFFFFF8000 ) then
   temp31..0 ← 0xFFFF8000
   DSPControl23 ← 1
endif
GPR[rt]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `INSV rt, rs` **MIPSDSP**

Purpose: Insert Bit Field Variable

To merge a right-justified bit field from register *rs* into a specified field in register *rt*.

Description: `rt ← InsertFieldVar(rt, rs, Scount, Pos)`

The *DSPControl* register provides the *size* value from the *Scount* field, and the *pos* value from the *pos* field. The right-most *size* bits from register *rs* are merged into the value from register *rt* starting at bit position *pos*. The result is put back in register *rt*. These *pos* and *size* values are converted by the instruction into the fields *msb* (the most significant bit of the field), and *lsb* (least significant bit of the field), as follows:

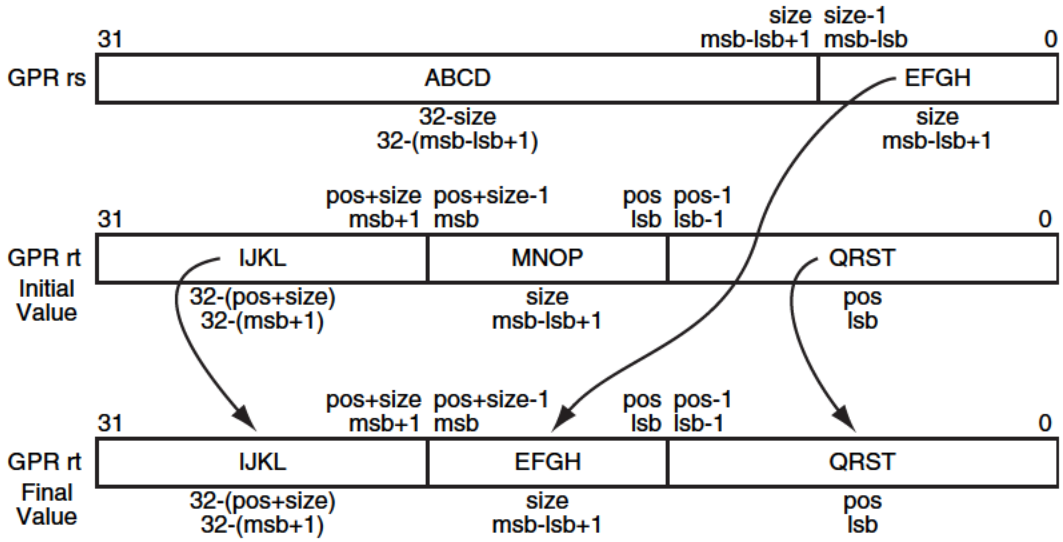
```
pos  ← DSPControl5..0
size ← DSPControl12..7
msb  ← pos+size-1
lsb  ← pos
```

The values of *pos* and *size* must satisfy all of the following relations, or the instruction results in UNPREDICTABLE results:

```
0 ≤ pos < 32
0 < size ≤ 32
0 < pos+size ≤ 32
```

Figure 6.1 shows the symbolic operation of the instruction.

Figure 6.1 Operation of the INSV Instruction



Restrictions:

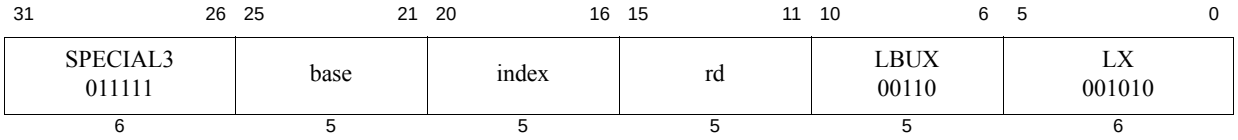
The operation is **UNPREDICTABLE** if lsb > msb.

Operation:

```
if (lsb > msb) then
   UNPREDICTABLE
endif
GPR[rt]..0 ← GPR[rt]31..msb+1 || GPR[rs]msb-lsb..0 || GPR[rt]lsb-1..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `LBUX rd, index(base)` **MIPSDSP**

Purpose: Load Unsigned Byte Indexed

To load a byte from memory as an unsigned value, using indexed addressing.

Description: `rd ← memory[base+index]`

The contents of GPR *index* is added to the contents of GPR *base* to form an effective address. The contents of the 8-bit byte at the memory location specified by the aligned effective address are fetched, zero-extended to the GPR register length and placed in GPR *rd*.

Restrictions:

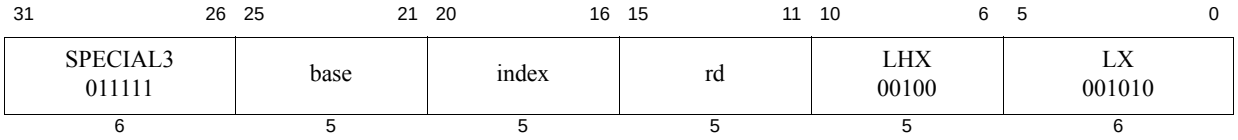
None.

Operation:

```
vAddr31..0 ← GPR[index]31..0 + GPR[base]31..0
( pAddr, CCA ) ← AddressTranslation( vAddr, DATA, LOAD )
pAddr ← pAddrPSIZE-1..2 || ( pAddr1..0 xor ReverseEndian2 )
memwordGPRLEN..0 ← LoadMemory ( CCA, BYTE, pAddr, vAddr, DATA )
GPR[rd]..0 ← zero_extend( memword7..0 )
```

Exceptions:

Reserved Instruction, DSP Disabled, TLB Refill, TLB Invalid, Bus Error, Address Error, Watch



Format: `LHX rd, index(base)` **MIPSDSP**

Purpose: Load Halfword Indexed

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

Description: `rd ← memory[base+index]`

The contents of GPR *index* is added to the contents of GPR *base* to form an effective address. The contents of the 16-bit halfword at the memory location specified by the aligned effective address are fetched, sign-extended to the length of the destination GPR, and placed in GPR *rd*.

Restrictions:

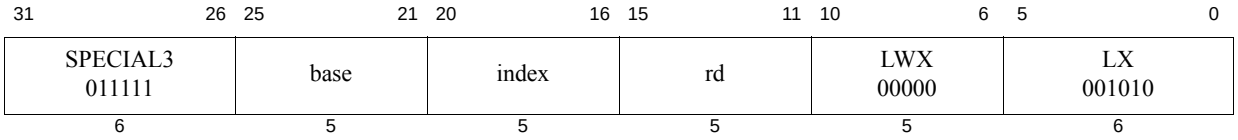
The effective address must be naturally-aligned. If the least-significant bit of the effective address is non-zero, an Address Error exception occurs.

Operation:

```
vAddr31..0 ← GPR[index]31..0 + GPR[base]31..0
if ( vAddr0 ≠ 0 ) then
   SignalException( AddressError )
endif
( pAddr, CCA ) ← AddressTranslation( vAddr, DATA, LOAD )
halfwordGPRLEN..0 ← LoadMemory( CCA, HALFWORD, pAddr, vAddr, DATA )
GPR[rd]..0 ← sign_extend( halfword15..0 )
```

Exceptions:

Reserved Instruction, DSP Disabled, TLB Refill, TLB Invalid, Bus Error, Address Error, Watch



Format: `LWX rd, index(base)` **MIPSDSP**

Purpose: Load Word Indexed

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

Description: `rd ← memory[base+index]`

The contents of GPR *index* is added to the contents of GPR *base* to form an effective address. The contents of the 32-bit word at the memory location specified by the aligned effective address are fetched and placed in GPR *rd*.

Restrictions:

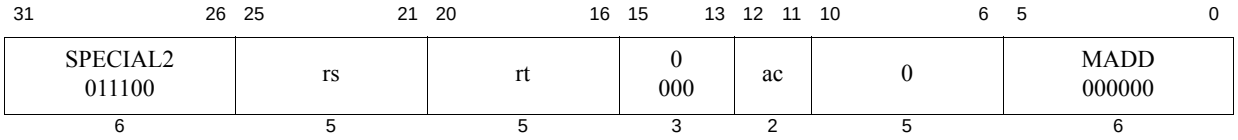
The effective address must be naturally-aligned. If either of the two least-significant bits of the address are non-zero, an Address Error exception occurs.

Operation:

```
vAddr31..0 ← GPR[index]31..0 + GPR[base]31..0
if ( vAddr1..0 ≠ 0^2 ) then
   SignalException( AddressError )
endif
( pAddr, CCA ) ← AddressTranslation( vAddr, DATA, LOAD )
memwordGPRLEN..0 ← LoadMemory( CCA, WORD, pAddr, vAddr, DATA )
GPR[rd]..0 ← memword31..0
```

Exceptions:

Reserved Instruction, DSP Disabled, TLB Refill, TLB Invalid, Bus Error, Address Error, Watch



Format: `MADD ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Word and Add to Accumulator

To multiply two 32-bit integer words and add the 64-bit result to the specified accumulator.

Description: `(HI[ac]||LO[ac]) ← (HI[ac]||LO[ac]) + (rs31..0 * rt31..0)`

The 32-bit signed integer word in register *rs* is multiplied by the corresponding 32-bit signed integer word in register *rt* to produce a 64-bit result. The 64-bit product is added to the specified 64-bit accumulator.

These special registers *HI* and *LO* are specified by the value of *ac*. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

This instruction does not provide the capability of writing directly to a target GPR.

Operation:

```
temp63..0 ← ((GPR[rs]31)32 || GPR[rs]31..0) * ((GPR[rt]31)32 || GPR[rt]31..0)
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + temp63..0
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 || acc31..0
```

Exceptions:

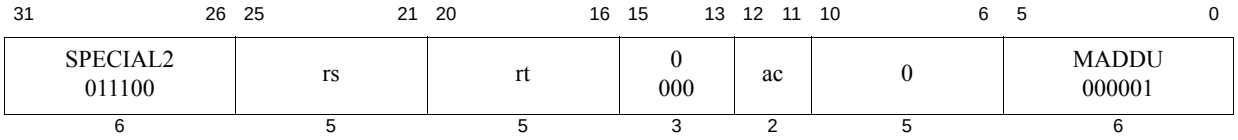
Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



Format: `MADDU ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Unsigned Word and Add to Accumulator

To multiply two 32-bit unsigned integer words and add the 64-bit result to the specified accumulator.

Description: `(HI[ac]||LO[ac]) ← (HI[ac]||LO[ac]) + (rs31..0 * rt31..0)`

The 32-bit unsigned integer word in register *rs* is multiplied by the corresponding 32-bit unsigned integer word in register *rt* to produce a 64-bit result. The 64-bit product is added to the specified 64-bit accumulator.

These special registers *HI* and *LO* are specified by the value of *ac*. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

This instruction does not provide the capability of writing directly to a target GPR.

Operation:

```
temp64..0 ← (0^32 || GPR[rs]31..0 ) * ( 0^32 || GPR[rt]31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + temp63..0
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 || acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.

31 26	25 21	20 16	15 13	12 11	10 6	5 0
SPECIAL3 011111	rs	rt	0 000	ac	MAQ_S.W.PHL 10100	DPA.W.PH 110000
SPECIAL3 011111	rs	rt	0 000	ac	MAQ_SA.W.PHL 10000	DPA.W.PH 110000
6	5	5	3	2	5	6

Format: `MAQ_S[A].W.PHL`

`MAQ_S.W.PHL ac, rs, rt` **MIPSDSP**

`MAQ_SA.W.PHL ac, rs, rt` **MIPSDSP**

Purpose: Multiply with Accumulate Single Vector Fractional Halfword Element

To multiply one pair of elements from two vectors of fractional halfword values using full-sized intermediate products and accumulate the result into the specified 64-bit accumulator, with optional saturating accumulation.

Description: $ac \leftarrow sat32(ac + sat32(rs_{31..16} * rt_{31..16}))$

The left-most Q15 fractional halfword values from the paired halfword vectors in each of registers *rt* and *rs* are multiplied together, and the product left-shifted by one bit position to generate a Q31 fractional format intermediate result. If both multiplicands are equal to -1.0 in Q15 fractional format (0x8000 hexadecimal), the intermediate result is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal). The intermediate result is then sign-extended and accumulated into accumulator *ac* to generate a 64-bit Q32.31 fractional format result.

In the saturating accumulation variant of this instruction, if the accumulation of the intermediate product with the accumulator results in a value that cannot be represented as a Q31 fractional format value, the accumulator is saturated to either the maximum positive Q31 fractional format value (0x7FFFFFFF hexadecimal) or the minimum negative Q31 fractional format value (0x80000000), sign-extended to 64 bits.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If overflow or saturation occurs, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
MAQ_S.W.PHL
    tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]31..16 )
    tempB63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + ( (tempA31)32 || tempA31..0 )
    ( HI[ac]..0 || LO[ac]..0 )  ← tempB63..32 || tempB31..0

MAQ_SA.W.PHL
    tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]31..16, GPR[rt]31..16 )
    tempA31..0 ← sat32AccumulateQ31( ac, temp )
    tempB63..0 ← (tempA31)32 || tempA31..0
    ( HI[ac]..0 || LO[ac]..0 )  ← tempB63..32 || tempB31..0

function sat32AccumulateQ31( acc1..0, a31..0 )
    signA ← a31
    temp..0 ← HI[acc]..0 || LO[acc]..0
```

```
    temp_..0 ← temp + ( (sign_A) || a_31..0 )
    if ( temp_32 ≠ temp_31 ) then
        if ( temp_32 = 0 ) then
            temp_31..0 ← 0x80000000
        else
            temp_31..0 ← 0x7FFFFFFF
        endif
        DSPControl_ouflag:16+acc ← 1
    endif
    return temp_31..0
endfunction sat32AccumulateQ31
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The MAQ_SA version of the instruction is useful for compliance with some ITU speech processing codecs that require a 32-bit saturation after every multiply-accumulate operation.

31 26	25 21	20 16	15 13	12 11	10 6	5 0
SPECIAL3 011111	rs	rt	0 000	ac	MAQ_S.W.PHR 10110	DPA.W.PH 110000
SPECIAL3 011111	rs	rt	0 000	ac	MAQ_SA.W.PHR 10010	DPA.W.PH 110000
6	5	5	3	2	5	6

Format: `MAQ_S[A].W.PHR`

`MAQ_S.W.PHR ac, rs, rt` **MIPSDSP**

`MAQ_SA.W.PHR ac, rs, rt` **MIPSDSP**

Purpose: Multiply with Accumulate Single Vector Fractional Halfword Element

To multiply one pair of elements from two vectors of fractional halfword values using full-sized intermediate products and accumulate the result into the specified 64-bit accumulator, with optional saturating accumulation.

Description: $ac \leftarrow sat32(ac + sat32(rs_{15..0} * rt_{15..0}))$

The right-most Q15 fractional halfword values from each of the registers *rt* and *rs* are multiplied together and the product left-shifted by one bit position to generate a Q31 fractional format intermediate result. If both multiplicands are equal to -1.0 in Q15 fractional format (0x8000 hexadecimal), the intermediate result is saturated to the maximum positive Q31 fractional value (0x7FFFFFFF hexadecimal). The intermediate result is then sign-extended and accumulated into accumulator *ac* to generate a 64-bit Q32.31 fractional format result.

In the saturating accumulation variant of this instruction, if the accumulation of the intermediate product with the accumulator results in a value that cannot be represented as a Q31 fractional format value, the accumulator is saturated to either the maximum positive Q31 fractional format value (0x7FFFFFFF hexadecimal) or the minimum negative Q31 fractional format value (0x80000000), sign-extended to 64 bits.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If overflow or saturation occurs, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

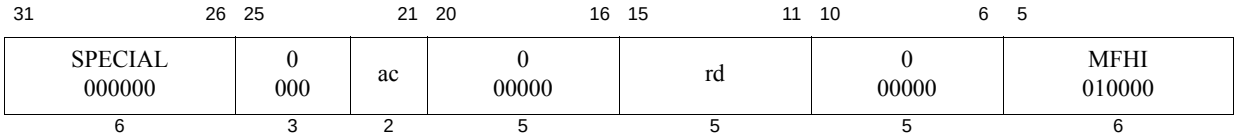
```
MAQ_S.W.PHR
    tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]15..0 )
    tempB63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + ( (tempA31)32 || tempA31..0 )
    ( HI[ac]..0 || LO[ac]..0 )  ← tempB63..32 || tempB31..0

MAQ_SA.W.PHR
    tempA31..0 ← multiplyQ15Q15( ac, GPR[rs]15..0, GPR[rt]15..0 )
    tempA31..0 ← sat32AccumulateQ31( ac, temp )
    tempB63..0 ← (tempA31)32 || tempA31..0
    ( HI[ac]..0 || LO[ac]..0 )  ← tempB63..32 ||  tempB31..0
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The MAQ_SA version of the instruction is useful for compliance with some ITU speech processing codecs that require a 32-bit saturation after every multiply-accumulate operation.



Format: `MFHI rd, ac` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Move from HI register

To copy the special purpose *HI* register to a GPR.

Description: `rd ← HI[ac]`

The *HI* part of accumulator *ac* is copied to the general-purpose register `rd`. The *HI* part of the accumulator is defined to be bits through of the DSP Module accumulator register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

Restrictions:

No data-dependent exceptions are possible.

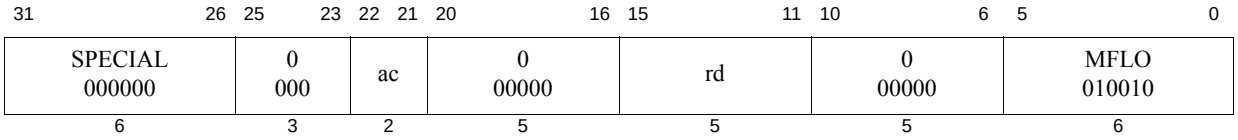
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
GPR[rd]..0 ← HI[ac]..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MFLO rd, ac` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Move from LO register

To copy the special purpose *LO* register to a GPR.

Description: `rd ← LO[ac]`

The *LO* part of accumulator *ac* iscopied to the general-purpose register *rd*. The *LO* part of the accumulator is defined to be bits 0 through of the DSP Module accumulator register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

Restrictions:

No data-dependent exceptions are possible.

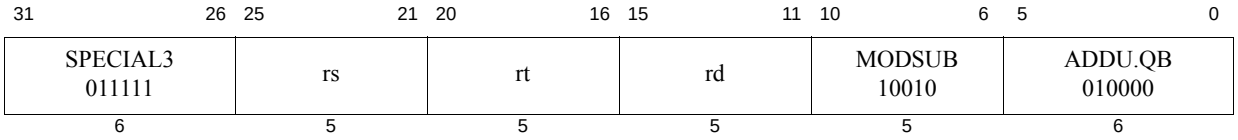
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
GPR[rd]..0 ← LO[ac]..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MODSUB rd, rs, rt` **MIPSDSP**

Purpose: Modular Subtraction on an Index Value

Do a modular subtraction on a specified index value, using the specified decrement and modular roll-around values.

Description: `rd ← (GPR[rs]==0 ? zero_extend(GPR[rt]`$_{23..8}$`) : GPR[rs] - GPR[rt]`$_{7..0}$`)`

The 32-bit value in register *rs* is compared to the value zero. If it is zero, then the index value has reached the bottom of the buffer and must be rolled back around to the top of the buffer. The index value of the top element of the buffer is obtained from bits 8 through 23 in register *rt*; this value is zero-extended to bits and written to destination register *rd*.

If the value of register *rs* is not zero, then it is simply decremented by the size of the elements in the buffer. The size of the elements, in bytes, is specified by bits 0 through 7 of register *rt*, interpreted as an unsigned integer.

This instruction does not modify the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

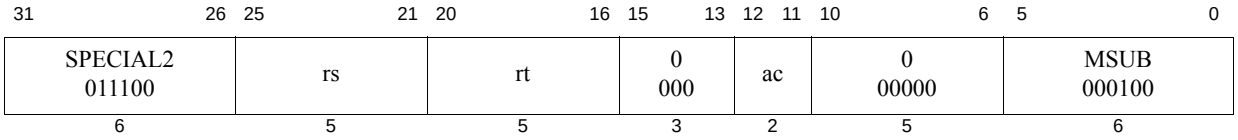
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
decr7..0 ← GPR[rt]7..0
lastindex15..0 ← GPR[rt]23..8
if ( GPR[rs]31..0 = 0x00000000 ) then
   GPR[rd]..0 ← 0(GPRLEN-16) || lastindex15..0
else
   GPR[rd]..0 ← GPR[rs]..0 - decr7..0
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MSUB ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Word and Subtract from Accumulator

To multiply two 32-bit integer words and subtract the 64-bit result from the specified accumulator.

Description: `(HI[ac]||LO[ac]) ← (HI[ac]||LO[ac]) - (rs31..0 * rt31..0)`

The 32-bit signed integer word in register *rs* is multiplied by the corresponding 32-bit signed integer word in register *rt* to produce a 64-bit result. The 64-bit product is subtracted from the specified 64-bit accumulator.

These special registers *HI* and *LO* are specified by the value of *ac*. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

This instruction does not provide the capability of writing directly to a target GPR.

Operation:

```
temp63..0 ← ((GPR[rs]31)32 || GPR[rs]31..0) * ((GPR[rt]31)32 || GPR[rt]31..0)
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - temp63..0
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 ||acc31..0
```

Exceptions:

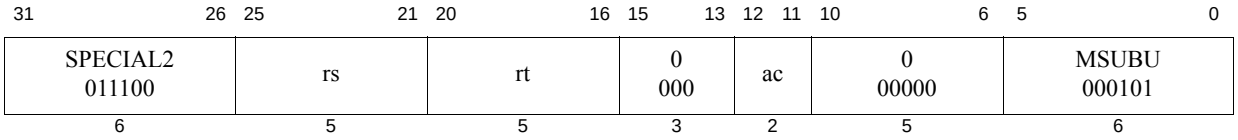
Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



Format: `MSUBU ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Unsigned Word and Add to Accumulator

To multiply two 32-bit unsigned integer words and subtract the 64-bit result from the specified accumulator.

Description: `(HI[ac]||LO[ac]) ← (HI[ac]||LO[ac]) - (rs31..0 * rt31..0)`

The 32-bit unsigned integer word in register *rs* is multiplied by the corresponding 32-bit unsigned integer word in register *rt* to produce a 64-bit result. The 64-bit product is subtracted from the specified 64-bit accumulator.

These special registers *HI* and *LO* are specified by the value of *ac*. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

This instruction does not provide the capability of writing directly to a target GPR.

Operation:

```
temp64..0 ← (0^32 || GPR[rs]31..0 ) * ( 0^32 || GPR[rt]31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) - temp63..0
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 ||acc31..0
```

Exceptions:

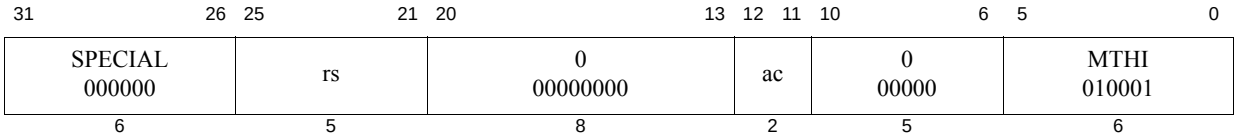
Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



Format: `MTHI rs, ac` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Move to HI register

To copy a GPR to the special purpose *HI* part of the specified accumulator register.

Description: `HI[ac] ← GPR[rs]`

The source register *rs* is copied to the *HI* part of accumulator *ac*. The *HI* part of the accumulator is defined to be bits to of the DSP Module accumulator register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

Restrictions:

A computed result written to the *HI/LO* pair by DIV, DIVU, DDIV, DDIVU, DMULT, DMULTU, MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either HI or LO. Note that this restriction only applies to the original *HI/LO* accumulator pair, and does not apply to the new accumulators, *ac1*, *ac2*, and *ac3*.

If an MTHI instruction is executed following one of these arithmetic instructions, but before an MFLO or MFHI instruction, the contents of *LO* are **UNPREDICTABLE**. The following example shows this illegal situation:

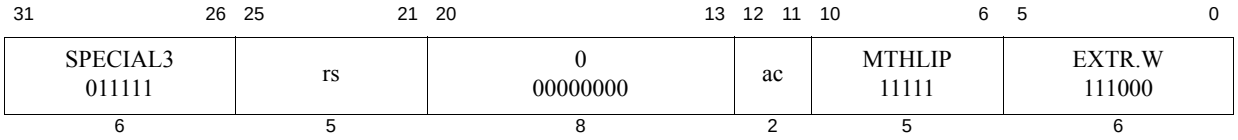
```
MULT r2,r4  # start operation that will eventually write to HI,LO
...         # code not containing mfhi or mflo
MTHI r6
...         # code not containing mflo
MFLO r3     # this mflo would get an UNPREDICTABLE value
```

Operation:

```
HI[ac]..0 ← GPR[rs]..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MTHLIP rs, ac` **MIPSDSP**

Purpose: Copy LO to HI and a GPR to LO and Increment Pos by 32

Copy the LO part of an accumulator to the HI part, copy a GPR to LO, and increment the pos field in the *DSPControl* register by 32.

Description: $ac \leftarrow LO[ac]_{31..0} \;||\; GPR[rs]_{31..0} \;;\; DSPControl_{pos:..0} \mathrel{+}= 32$

The 32 least-significant bits of the specified accumulator are copied to the most-significant bits of the same accumulator. Then the 32 least-significant bits of register *rs* are copied to the least-significant bits of the accumulator. The instruction then increments the value of bits 0 through of the *DSPControl* register (the *pos* field) by 32.

The result of this instruction is **UNPREDICTABLE** if the value of the *pos* field before the execution of the instruction is greater than 32.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

Restrictions:

No data-dependent exceptions are possible.

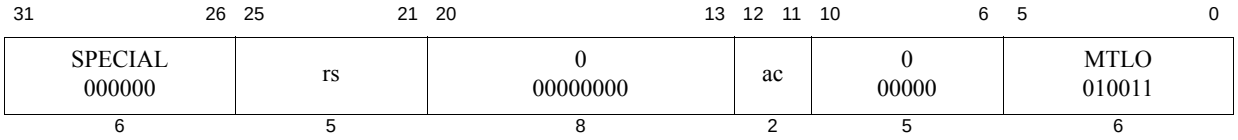
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempA..0 ← GPR[rs]31..0
tempB..0 ← LO[ac]31..0
( HI[ac]..0 || LO[ac]..0 ) ← tempB..0 || tempA..0
oldpos..0 ← DSPControlpos:..0
if ( oldpos..0 > 32 ) then
   DSPControlpos:..0 ← UNPREDICTABLE
else
   DSPControlpos:..0 ← oldpos..0 + 32
endif
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MTLO rs, ac` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Move to LO register

To copy a GPR to the special purpose *LO* part of the specified accumulator register.

Description: `LO[ac] ← GPR[rs]`

Thesource register *rs* is copied to the *LO* part of accumulator *ac*. The *LO* part of the accumulator is defined to be bits 0 to of the DSP Module accumulator register.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

Restrictions:

A computed result written to the *HI/LO* pair by DIV, DIVU, DDIV, DDIVU, DMULT, DMULTU, MULT, or MULTU must be read by MFHI or MFLO before a new result can be written into either HI or LO. Note that this restriction only applies to the original *HI/LO* accumulator pair, and does not apply to the new accumulators, *ac1*, *ac2*, and *ac3*.

If an MTHI instruction is executed following one of these arithmetic instructions, but before an MFLO or MFHI instruction, the contents of *LO* are **UNPREDICTABLE**. The following example shows this illegal situation:

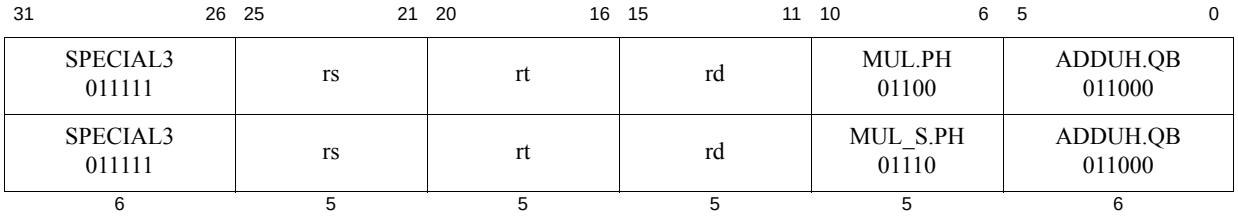
```
MULT r2,r4  # start operation that will eventually write to HI,LO
...         # code not containing mfhi or mflo
MTHI r6
...         # code not containing mflo
MFLO r3     # this mflo would get an UNPREDICTABLE value
```

Operation:

```
LO[ac]..0 ← GPR[rs]..0
```

Exceptions:

Reserved Instruction, DSP Disabled



31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	MUL.PH 01100	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	MUL_S.PH 01110	ADDUH.QB 011000
6	5	5	5	5	6

Format: `MUL[_S].PH`

`MUL.PH rd, rs, rt` **MIPSDSP-R2**

`MUL_S.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Multiply Vector Integer HalfWords to Same Size Products

Multiply two vector halfword values.

Description: $rd \leftarrow (rs_{31..16} * rt_{31..16}) \;||\; (rs_{15..0} * rt_{15..0})$

Each of the two integer halfword elements in register *rs* is multiplied by the corresponding integer halfword element in register *rt* to create a 32-bit signed integer intermediate result.

In the non-saturation version of the instruction, the 16 least-significant bits of each 32-bit intermediate result are written to the corresponding vector element in destination register *rd*.

In the saturating version of the instruction, intermediate results that cannot be represented in 16 bits are clipped to either the maximum positive 16-bit value (0x7FFF hexadecimal) or the minimum negative 16-bit value (0x8000 hexadecimal), depending on the sign of the intermediate result. The saturated results are then written to the destination register.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3*, are unchanged.

In the saturating instruction variant, if either multiplication results in an overflow or underflow, the instruction writes a 1 to bit 21 in the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
MUL.PH
    tempB31..0 ← MultiplyI16I16( GPR[rs]31..16, GPR[rt]31..16 )
    tempA31..0 ← MultiplyI16I16( GPR[rs]15..0, GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0
    HI..0 ← UNPREDICTABLE
    LO..0 ← UNPREDICTABLE

MUL_S.PH
    tempB31..0 ← sat16MultiplyI16I16( GPR[rs]31..16, GPR[rt]31..16 )
    tempA31..0 ← sat16MultiplyI16I16( GPR[rs]15..0, GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0
    HI..0 ← UNPREDICTABLE
    LO..0 ← UNPREDICTABLE

function MultiplyI16I16( a15..0, b15..0 )
```

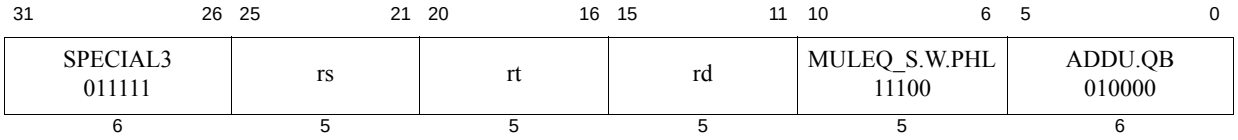
```
    temp31..0 ← a15..0 * b15..0
    if ( temp31..0 > 0x7FFF ) or ( temp31..0 < 0xFFFF8000 ) then
           DSPControlouflag:21 ← 1
    endif
    return temp15..0
endfucntion MultiplyI16I16

function satMultiplyI16I16( a15..0, b15..0 )
    temp31..0 ← a15..0 * b15..0
    if ( temp31..0 > 0x7FFF ) then
       temp31..0 ← 0x00007FFF
       DSPControlouflag:21 ← 1
    else
       if ( temp31..0 < 0xFFFF8000 ) then
          temp31..0 ← 0xFFFF8000
          DSPControlouflag:21 ← 1
       endif
    endif
    return temp15..0
endfucntion satMultiplyI16I16
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that upon the after a GPR-targeting multiply instruction such as MUL, the contents of *HI* and *LO* are **UNPREDICTABLE**. To stay compliant with the base architecture, this multiply instruction states the same requirement. But this requirement does not apply to the new accumulators *ac1-ac3* and hence a pro grammer must save the value in *ac0* (which is the same as *HI* and *LO*) across a GPR-targeting multiply instruction, it needed, while the values in *ac1-ac3* do not need to be saved.



Format: `MULEQ_S.W.PHL rd, rs, rt` **MIPSDSP**

Purpose: Multiply Vector Fractional Left Halfwords to Expanded Width Products

Multiply two Q15 fractional halfword values to produce a Q31 fractional word result, with saturation.

Description: $rd \leftarrow sat32(rs_{31..16} * rt_{31..16})$

The left-most Q15 fractional halfword value from the paired halfword vector in register *rs* is multiplied by the corresponding Q15 fractional halfword value from register *rt.* The result is left-shifted one bit position to create a Q31 format result and written into the destination register *rd*. If both input values are -1.0 in Q15 format (0x8000 in hexadecimal) the result is clamped to the maximum positive Q31 fractional value (0x7FFFFFFF in hexadecimal) before being written to the destination register.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3* are unmodified.

If the result is saturated, this instruction writes a 1 to bit 21 in the *ouflag* field of the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← multiplyQ15Q15ouflag21( GPR[rs]31..16, GPR[rt]31..16 )
GPR[rd]..0 ← temp31..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE

function multiplyQ15Q15ouflag21( a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:21 ← 1
   else
      temp31..0 ← ( a15..0 * b15..0 ) << 1
   endif
   return temp31..0
endfunction multiplyQ15Q15ouflag21
```

Exceptions:

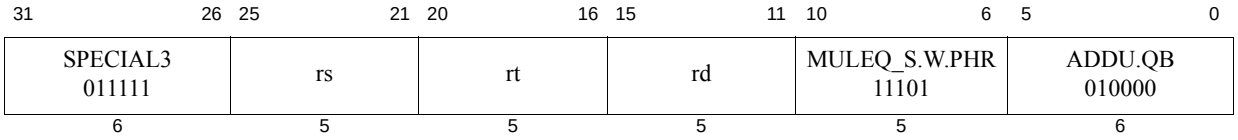
Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture this multiply instruction, MULEQ_S.W.PHL, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULEQ_S.W.PHL instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result

the values in these accumulators need not be saved.



Format: `MULEQ_S.W.PHR rd, rs, rt` **MIPSDSP**

Purpose: Multiply Vector Fractional Right Halfwords to Expanded Width Products

Multiply two Q15 fractional halfword values to produce a Q31 fractional word result, with saturation.

Description: $rd \leftarrow sat32(rs_{15..0} * rt_{15..0})$

The right-most Q15 fractional halfword value from register *rs* is multiplied by the corresponding Q15 fractional halfword value from register *rt.* The result is left-shifted one bit position to create a Q31 format result and written into the destination register *rd*. If both input values are -1.0 in Q15 format (0x8000 in hexadecimal) the result is clamped to the maximum positive Q31 fractional value (0x7FFFFFFF in hexadecimal) before being written to the destination register.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3* are unmodified.

If the result is saturated, this instruction writes a 1 to bit 21 in the *ouflag* field of the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← multiplyQ15Q15ouflag21( GPR[rs]15..0, GPR[rt]15..0 )
GPR[rd]..0 ← temp31..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE

function multiplyQ15Q15ouflag21( a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFFFFFF
      DSPControlouflag:21 ← 1
   else
      temp31..0 ← ( a15..0 * b15..0 ) << 1
   endif
   return temp31..0
endfunction multiplyQ15Q15ouflag21
```

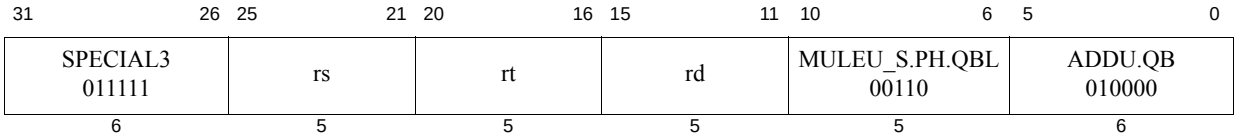
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture this multiply instruction, MULEQ_S.W.PHR, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULEQ_S.W.PHR instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result the values in these accumulators need not be saved.



Format: `MULEU_S.PH.QBL rd, rs, rt` **MIPSDSP**

Purpose: Multiply Unsigned Vector Left Bytes by Halfwords to Halfword Products

Multiply two left-most unsigned byte vector elements in a byte vector by two unsigned halfword vector elements to produce two unsigned halfword results, with saturation.

Description: $rd \leftarrow sat16(rs_{31..24} * rt_{31..16}) \,||\, sat16(rs_{23..16} * rt_{15..0})$

The two left-most unsigned byte elements in four-element byte vector in register *rs* are multiplied as unsigned integer values with the four corresponding unsigned halfword elements from register *rt*. The eight most-significant bits of each 24-bit result are discarded, and the remaining 16 least-significant bits are written to the corresponding elements in halfword vector register *rd*. The instruction saturates the result to the maximum positive value (0xFFFF hexadecimal) if any of the discarded bits from each intermediate result are non-zero.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3* are unmodified.

If either result is saturated this instruction writes a 1 to bit 21 in the *DSPControl* register in the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U16( GPR[rs]31..24, GPR[rt]31..16 )
tempA15..0 ← multiplyU8U16( GPR[rs]23..16, GPR[rt]15..0 )
GPR[rd]..0 ← tempB15..0 || tempA15..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE

function multiplyU8U16( a7..0, b15..0 )
   temp25..0 ← (0 || a) * (0 || b)
   if ( temp25..16> 0x00 ) then
      temp25..0 ← 0^10 || 0xFFFF
      DSPControlouflag:21 ← 1
   endif
   return temp15..0
endfunction multiplyU8U16
```

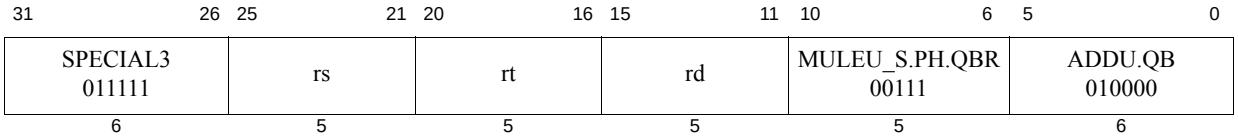
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture this multiply instruction, MULEU_S.PH.QBL, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULEU_S.PH.QBL instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result the values in these accumulators need not be saved.



Format: `MULEU_S.PH.QBR rd, rs, rt` **MIPSDSP**

Purpose: Multiply Unsigned Vector Right Bytes with halfwords to Half Word Products

Element-wise multiplication of unsigned byte elements with corresponding unsigned halfword elements, with saturation.

Description: $rd \leftarrow sat16(rs_{15..8} * rt_{31..16}) \ || \ sat16(rs_{7..0} * rt_{15..0})$

The two right-most unsigned byte elements in four-element byte vector in register *rs* are multiplied as unsigned integer values with the corresponding right-most 16-bit unsigned values from register *rt*. Each result is clipped to preserve the 16 least-significant bits and written back into the respective halfword element positions in the destination register *rd*. The instruction saturates the result to the maximum positive value (0xFFFF hexadecimal) if any of the clipped bits are non-zero.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3* must be unmodified.

This instruction writes a 1 to bit 21 in the *ouflag* field in the *DSPControl* register if either multiplication results in saturation.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← multiplyU8U16( GPR[rs]15..8, GPR[rt]31..16 )
tempA15..0 ← multiplyU8U16( GPR[rs]7..0, GPR[rt]15..0 )
GPR[rd] ← tempB15..0 || tempA15..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE
```

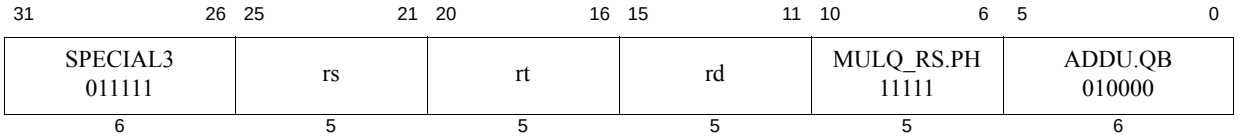
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture this multiply instruction, MULEU_S.PH.QBR, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULEU_S.PH.QBR instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result the values in these accumulators need not be saved.



Format: `MULQ_RS.PH rd, rs, rt` **MIPSDSP**

Purpose: Multiply Vector Fractional Halfwords to Fractional Halfword Products

Multiply Q15 fractional halfword vector elements with rounding and saturation to produce two Q15 fractional halfword results.

Description: $rd \leftarrow rndQ15(rs_{31..16} * rt_{31..16}) \,||\, rndQ15(rs_{15..0} * rt_{15..0})$

The two Q15 fractional halfword elements from register *rs* are separately multiplied by the corresponding Q15 fractional halfword elements from register *rt* to produce 32-bit intermediate results. Each intermediate result is left-shifted by one bit position to produce a Q31 fractional value, then rounded by adding 0x00008000 hexadecimal. The rounded intermediate result is then truncated to a Q15 fractional value and written to the corresponding position in destination register *rd*.

If the two input values to either multiplication are both -1.0 (0x8000 in hexadecimal), the final halfword result is saturated to the maximum positive Q15 value (0x7FFF in hexadecimal) and rounding and truncation are not performed.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3* must be unmodified.

If either result is saturated this instruction writes a 1 to bit 21 in the *DSPControl* register in the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← rndQ15MultiplyQ15Q15( GPR[rs]31..16, GPR[rt]31..16 )
tempA15..0 ← rndQ15MultiplyQ15Q15( GPR[rs]15..0, GPR[rt]15..0 )
GPR[rd]..0 ← tempB15..0 || tempA15..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE

function rndQ15MultiplyQ15Q15( a15..0, b15..0 )
    if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
        temp31..0 ← 0x7FFF0000
        DSPControlouflag:21 ← 1
    else
        temp31..0 ← ( a15..0 * b15..0 ) << 1
        temp31..0 ← temp31..0 + 0x00008000
    endif
    return temp31..16
endfunction rndQ15MultiplyQ15Q15
```

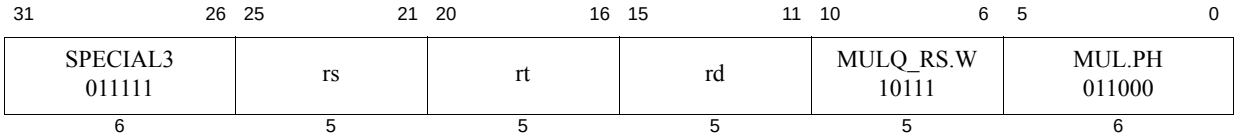
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture, this multiply instruction, MULQ_RS.PH, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULQ_RS.PH instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result, the values in these accumulators need not be saved.



Format: `MULQ_RS.W rd, rs, rt` **MIPSDSP-R2**

Purpose: Multiply Fractional Words to Same Size Product with Saturation and Rounding

Multiply fractional Q31 word values, with saturation and rounding.

Description: $rd \leftarrow round(sat32(rs_{31..0} * rt_{31..0}))$

The Q31 fractional format words in registers *rs* and *rt* are multiplied together and the product shifted left by one bit position to create a 64-bit fractional format intermediate result. The intermediate result is rounded up by adding a 1 at bit position 31, and then truncated by discarding the 32 least-significant bits to create a 32-bit fractional format result. The result is then written to destination register *rd*.

If both input multiplicands are equal to -1 (0x80000000 hexadecimal), rounding is not performed and the maximum positive Q31 fractional format value (0x7FFFFFFF hexadecimal) is written to the destination register.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3*, are unchanged.

This instruction, on an overflow or underflow of the operation, writes a 1 to bit 21 in the *DSPControl* register in the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
if ( GPR[rs]31..0 = 0x80000000 ) and ( GPR[rt]31..0 = 0x80000000 ) then
   temp63..0 ← 0x7FFFFFFF00000000
   DSPControlouflag:21 ← 1
else
   temp63..0 ← ( GPR[rs]31..0 * GPR[rt]31..0 ) << 1
   temp63..0 ← temp63..0 + ( 0^32 || 0x80000000 )
endif
GPR[rd]..0 ← temp63..32
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE
```

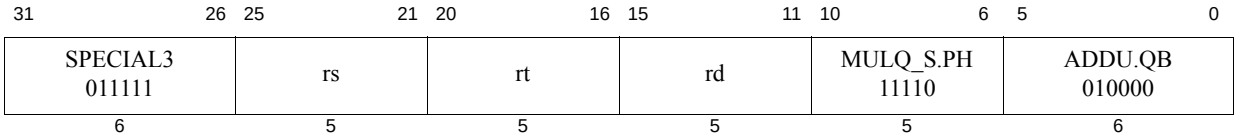
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture, this multiply instruction, MULQ_RS.W, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULQ_RS.W instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result, the values in these accumulators need not be saved.



Format: `MULQ_S.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Multiply Vector Fractional Half-Words to Same Size Products

Multiply two vector fractional Q15 values to create a Q15 result, with saturation.

Description: `rd ← sat16(rs`$_{31..16}$ `* rt`$_{31..16}$`) || sat16(rs`$_{15..0}$ `* rt`$_{15..0}$`)`

The two vector fractional Q15 values in register *rs* are multiplied with the corresponding elements in register *rt* to produce two 32-bit products. Each product is left-shifted by one bit position to create a Q31 fractional word intermediate result. The two 32-bit intermediate results are then each truncated by discarding the 16 least-significant bits of each result, and the resulting Q15 fractional format halfwords are then written to the corresponding positions in destination register *rd*. For each halfword result, if both input multiplicands are equal to -1 (0x8000 hexadecimal), the final halfword result is saturated to the maximum positive Q15 value (0x7FFF hexadecimal).

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators , *ac1*, *ac2*, and *ac3*, must be untouched.

This instruction, on an overflow or underflow of any one of the two vector operation, writes bit 21 in the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← sat16MultiplyQ15Q15( GPR[rs]31..16, GPR[rt]31..16 )
tempA31..0 ← sat16MultiplyQ15Q15( GPR[rs]15..0, GPR[rt]15..0 )
GPR[rd]..0 ← tempB15..0 || tempA15..0
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE

function sat16MultiplyQ15Q15( a15..0, b15..0 )
   if ( a15..0 = 0x8000 ) and ( b15..0 = 0x8000 ) then
      temp31..0 ← 0x7FFF0000
      DSPControlouflag:21 ← 1
   else
      temp31..0 ← ( a15..0 * b15..0 )
      temp31..0 ← ( temp30..0 || 0 )
   endif
   return temp31..16
endfunction sat16MultiplyQ15Q15
```

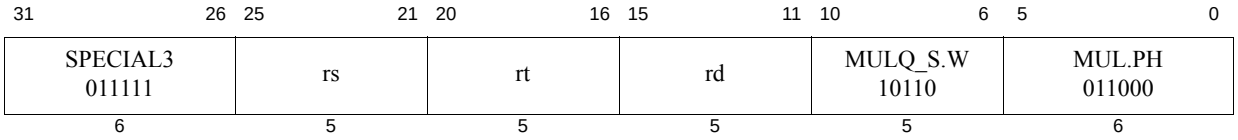
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture, this multiply instruction, MULQ_S.PH, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULQ_S.PH instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result, the values in these accumulators need not be saved.



Format: `MULQ_S.W rd, rs, rt` **MIPSDSP-R2**

Purpose: Multiply Fractional Words to Same Size Product with Saturation

Multiply two Q31 fractional format word values to create a fractional Q31 result, with saturation.

Description: $rd \leftarrow sat32(rs_{31..0} * rt_{31..0})$

The Q31 fractional format words in registers *rs* and *rt* are multiplied together to create a 64-bit fractional format intermediate result. The intermediate result is left-shifted by one bit position, and then truncated by discarding the 32 least-significant bits to create a Q31 fractional format result. This result is then written to destination register *rd*.

If both input multiplicands are equal to -1 (0x80000000 hexadecimal), the product is clipped to the maximum positive Q31 fractional format value (0x7FFFFFFF hexadecimal), and written to the destination register.

To stay compliant with the base architecture, this instruction leaves the base *HI*/*LO* pair (accumulator *ac0*) **UNPREDICTABLE** after the operation completes. The other DSP Module accumulators, *ac1*, *ac2*, and *ac3*, are unchanged.

This instruction, on an overflow or underflow of the operation, writes a 1 to bit 21 in the *DSPControl* register in the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
if ( GPR[rs]31..0 = 0x80000000 ) and ( GPR[rt]31..0 = 0x80000000 ) then
   temp63..0 ← 0x7FFFFFFF00000000
   DSPControlouflag:21 ← 1
else
   temp63..0 ← ( GPR[rs]31..0 * GPR[rt]31..0 ) << 1
endif
GPR[rd]..0 ← temp63..32
HI[0]..0 ← UNPREDICTABLE
LO[0]..0 ← UNPREDICTABLE
```

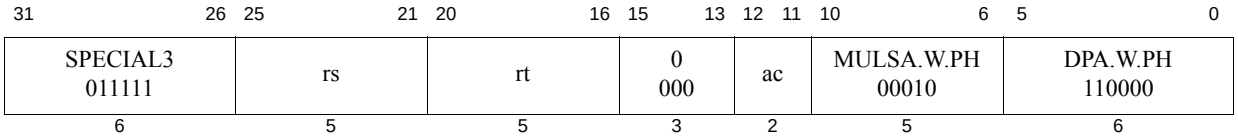
Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

The base architecture states that after a GPR-targeting multiply instruction such as MUL, the contents of registers *HI* and *LO* are **UNPREDICTABLE**. To maintain compliance with the base architecture, this multiply instruction, MULQ_S.W, has the same requirement. Software must save and restore the *ac0* register if the previous value in the *ac0* register is needed following the MULQ_S.W instruction.

Note that the requirement on *HI* and *LO* does not apply to the new accumulator registers *ac1*, *ac2*, and *ac3*; as a result, the values in these accumulators need not be saved.



Format: `MULSA.W.PH ac, rs, rt` **MIPSDSP-R2**

Purpose: Multiply and Subtract Vector Integer Halfword Elements and Accumulate

To multiply and subtract two integer vector elements using full-size intermediate products, accumulating the result into the specified accumulator.

Description: $ac \leftarrow ac + ((rs_{31..16} * rt_{31..16}) - (rs_{15..0} * rt_{15..0}))$

Each of the two halfword integer elements from register *rt* are multiplied by the corresponding elements in *rs* to create two word results. The right-most result is subtracted from the left-most result to generate the intermediate result, which is then added to the specified 64-bit accumulator.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

This instruction does not set any bits of the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

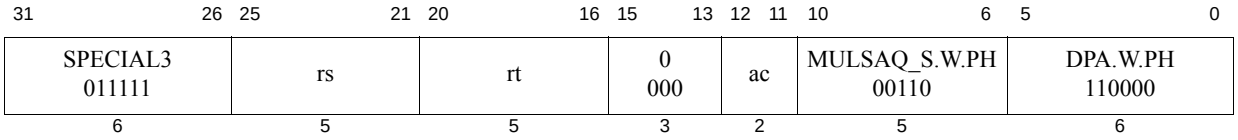
The operands must be a value in the specified format. If they are not, the result is **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← (GPR[rs]31..16 * GPR[rt]31..16)
tempA31..0 ← (GPR[rs]15..0 * GPR[rt]15..0)
dotp32..0 ← ( (tempB31) || tempB31..0 ) - ( (tempA31) || tempA31..0 )
acc63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + ( (dotp32)31 || dotp32..0 )
( HI[ac]..0 || LO[ac]..0 ) ← acc63..32 || acc31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MULSAQ_S.W.PH ac, rs, rt` **MIPSDSP**

Purpose: Multiply And Subtract Vector Fractional Halfwords And Accumulate

Multiply and subtract two Q15 fractional halfword vector elements using full-size intermediate products, accumulating the result from the specified accumulator, with saturation.

Description: $ac \leftarrow ac + (sat32(rs_{31..16} * rt_{31..16}) - sat32(rs_{15..0} * rt_{15..0}))$

The two corresponding Q15 fractional values from registers *rt* and *rs* are multiplied together and left-shifted by 1 bit to generate two Q31 fractional format intermediate products. If the input multiplicands to either of the multiplications are both -1.0 (0x8000 hexadecimal), the intermediate result is saturated to 0x7FFFFFFF hexadecimal.

The two intermediate products (named left and right) are summed with alternating sign to create a sum-of-products, i.e., the sign of the right product is negated before summation. The sum-of-products is then sign-extended to 64 bits and accumulated into the specified 64-bit accumulator, producing a Q32.31 result.

The value of *ac* can range from 0 to 3; a value of 0 refers to the original *HI*/*LO* register pair of the architecture.

If saturation occurs, a 1 is written to one of bits 16 through 19 of the *DSPControl* register, within the *ouflag* field. The value of *ac* determines which of these bits is set: bit 16 corresponds to *ac0*, bit 17 to *ac1*, bit 18 to *ac2*, and bit 19 to *ac3*.

Restrictions:

No data-dependent exceptions are possible.

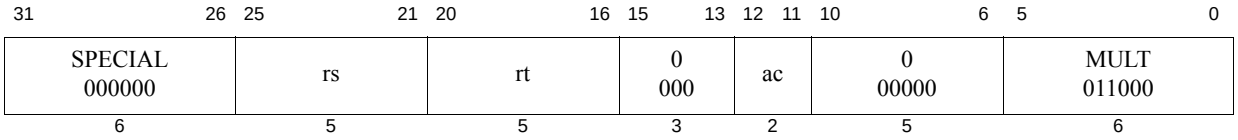
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB31..0 ← multiplyQ15Q15( ac, rs31..16, rt31..16 )
tempA31..0 ← multiplyQ15Q15( ac, rs15..0, rt15..0 )
dotp63..0 ← ( (tempB31)32 || tempB31..0 ) - ( (tempA31)32 || tempA31..0 )
tempC63..0 ← ( HI[ac]31..0 || LO[ac]31..0 ) + dotp63..0
( HI[ac]..0 || LO[ac]..0 ) ← tempC63..32 || tempC31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `MULT ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Word

To multiply two 32-bit signed integers, writing the 64-bit result to the specified accumulator.

Description: $ac \leftarrow rs_{31..0} * rt_{31..0}$

The 32-bit signed integer value in register *rt* is multiplied by the corresponding 32-bit signed integer value in register *rs*, to produce a 64-bit result that is written to the specified accumulator register.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

Operation:

```
temp63..0 ← ((GPR[rs]31)32 || GPR[rs]31..0) * ((GPR[rt31)32 || GPR[rt]31..0)
( HI[ac]..0 || LO[ac]..0 ) ← temp63..32 || temp31..0
```

Exceptions:

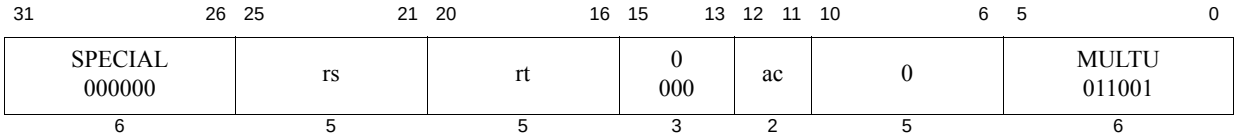
Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



Format: `MULTU ac, rs, rt` **MIPS32 pre-Release 6, MIPSDSP**

Purpose: Multiply Unsigned Word

To multiply 32-bit unsigned integers, writing the 64-bit result to the specified accumulator.

Description: $ac \leftarrow rs_{31..0} * rt_{31..0}$

The 32-bit unsigned integer value in register *rt* is multiplied by the corresponding 32-bit unsigned integer value in register *rs*, to produce a 64-bit unsigned result that is written to the specified accumulator register.

The value of *ac* selects an accumulator numbered from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

In Release 6 of the MIPS Architecture, accumulators are eliminated from MIPS32.

No arithmetic exception occurs under any circumstances.

Restrictions:

Operation:

```
temp64..0 ← ( 0^32 || GPR[rs]31..0 ) * ( 0^32 || GPR[rt]31..0 )
( HI[ac]..0 || LO[ac]..0 ) ← temp63..32 || temp31..0
```

Exceptions:

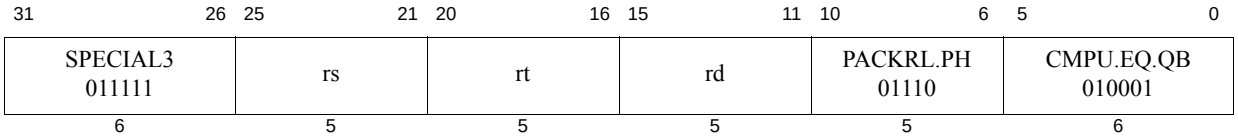
Reserved Instruction, DSP Disabled

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 register *rt*. This may reduce the latency of the instruction on those processors which implement data-dependent instruction latencies.



Format: `PACKRL.PH rd, rs, rt` **MIPSDSP**

Purpose: Pack a Vector of Halfwords from Vector Halfword Sources

Pick two elements for a halfword vector using the right halfword and left halfword respectively from the two source registers.

Description: $rd \leftarrow rs_{15..0} \mid\mid rt_{31..16}$

The right halfword element from register *rs* and the left halfword register *rt* are packed into the two halfword positions of the destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

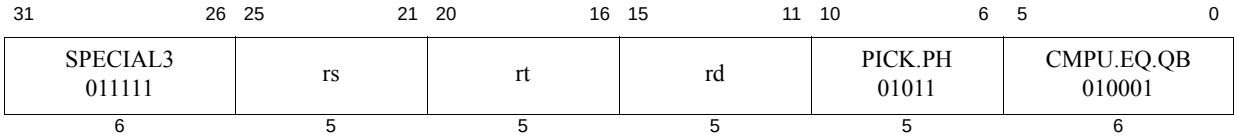
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← GPR[rs]15..0
tempA15..0 ← GPR[rt]31..16
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PICK.PH rd, rs, rt` **MIPSDSP**

Purpose: Pick a Vector of Halfword Values Based on Condition Code Bits

Select two halfword elements from e ither of two source registers based on condition code bits, writing the selected elements to the destination register.

Description: $rd \leftarrow pick(cc_{25}, rs_{31..16}, rt_{31..16}) \ || \ pick(cc_{24}, rs_{15..0}, rt_{15..0})$

The two right-most condition code bits in the *DSPControl* register are used to select halfword values from the corresponding element of either source register *rs* or source register *rt*. If the value of the corresponding condition code bit is 1, then the halfword value is selected from register *rs*; otherwise, it is selected from *rt*. The selected halfwords are written to the destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

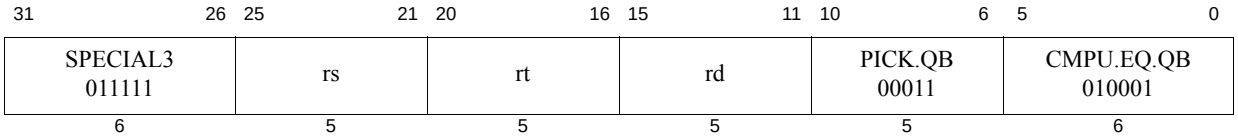
The operands must be in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

$$tempB_{15..0} \leftarrow (DSPControl_{ccond:25} = 1 \ ? \ GPR[rs]_{31..16} : GPR[rt]_{31..16})$$
$$tempA_{15..0} \leftarrow (DSPControl_{ccond:24} = 1 \ ? \ GPR[rs]_{15..0} : GPR[rt]_{15..0})$$
$$GPR[rd]_{..0} \leftarrow tempB_{15..0} \ || \ tempA_{15..0}$$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PICK.QB rd, rs, rt` **MIPSDSP**

Purpose: Pick a Vector of Byte Values Based on Condition Code Bits

Select four byte elements from either of two source regist ers based on condition code bits, writing the selected elements to the destination register.

Description: $rd \leftarrow pick(cc_{27}, rs_{31..24}, rt_{31..24}) \;||\; pick(cc_{26}, rs_{23..16}, rt_{23..16}) \;||\; pick(cc_{25}, rs_{15..8}, rt_{15..8}) \;||\; pick(cc_{24}, rs_{7..0}, rt_{7..0})$

Four condition code bits in the *DSPControl* register are used to select byte values from the corresponding byte element of either source register *rs* or source register *rt*. If the value of the corresponding condition code bit is 1, then the byte value is selected from register *rs*; otherwise, it is selected from *rt*. The selected bytes are written to the destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

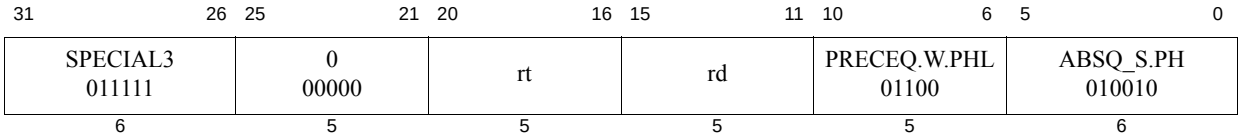
The operands must be in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← ( DSPControlccond:27 = 1 ? GPR[rs]31..24 : GPR[rt]31..24 )
tempC7..0 ← ( DSPControlccond:26 = 1 ? GPR[rs]23..16 : GPR[rt]23..16 )
tempB7..0 ← ( DSPControlccond:25 = 1 ? GPR[rs]15..8 : GPR[rt]15..8 )
tempA7..0 ← ( DSPControlccond:24 = 1 ? GPR[rs]7..0 : GPR[rt]7..0 )
GPR[rd]..0 ← tempD7..0|| tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQ.W.PHL rd, rt` **MIPSDSP**

Purpose: Precision Expand Fractional Halfword to Fractional Word Value

Expand the precision of a Q15 fractional value taken from the left element of a paired halfword vector to create a Q31 fractional word value.

Description: $rd \leftarrow expand\_prec(rt_{31..16})$

The left Q15 fractional halfword value from the in register *rt* is expanded to a Q31 fractional value and written to destination register *rd*. The precision expansion is achieved by appending 16 least-significant zero bits to the original halfword value to generate the 32-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

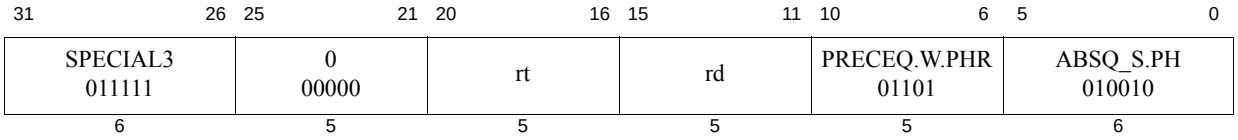
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← GPR[rt]31..16 || 0^16
GPR[rd]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQ.W.PHR rd, rt` **MIPSDSP**

Purpose: Precision Expand Fractional Halfword to Fractional Word Value

Expand the precision of a Q15 fractional value taken from the right element of a paired halfword vector to create a Q31 fractional word value.

Description: $rd \leftarrow expand\_prec(rt_{15..0})$

The right Q15 fractional halfword value from the in register *rt* is expanded to a Q31 fractional value and written to destination register *rd*. The precision expansion is achieved by appending 16 least-significant zero bits to the original halfword value to generate the 32-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

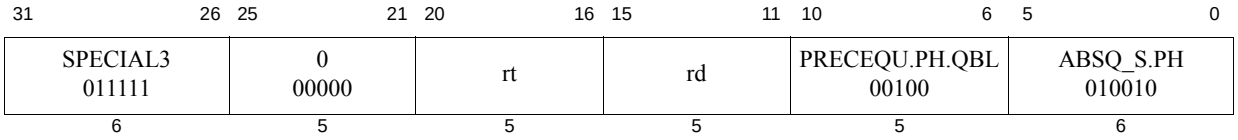
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← GPR[rt]15..0 || 0^16
GPR[rd]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQU.PH.QBL rd, rt` **MIPSDSP**

Purpose: Precision Expand two Unsigned Bytes to Fractional Halfword Values

Expand the precision of two unsigned byte values taken from the two left-most elements of a quad byte vector to create two Q15 fractional halfword values.

Description: $rd \leftarrow expand\_prec(rt_{31..24}) \mid\mid expand\_prec(rt_{23..16})$

The two left-most unsigned integer byte values from the four byte elements in register *rt* are expanded to create two Q15 fractional values that are then written to destination register *rd*. The precision expansion is achieved by prepending a single zero bit (for positive sign) to the original byte value and appending seven least-significant zeros to generate each 16-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

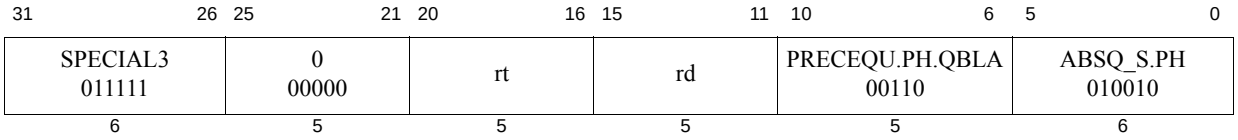
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

$$tempB_{15..0} \leftarrow 0^1 \mid\mid GPR[rt]_{31..24} \mid\mid 0^7$$
$$tempA_{15..0} \leftarrow 0^1 \mid\mid GPR[rt]_{23..16} \mid\mid 0^7$$
$$GPR[rd]_{..0} \leftarrow tempB_{15..0} \mid\mid tempA_{15..0}$$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQU.PH.QBLA rd, rt` **MIPSDSP**

Purpose: Precision Expand two Unsigned Bytes to Fractional Halfword Values

Expand the precision of two unsigned byte values taken from the two left-alternate aligned elements of a quad byte vector to create two Q15 fractional halfword values.

Description: $rd \leftarrow expand\_prec(rt_{31..24}) \mid\mid expand\_prec(rt_{15..8})$

The two left-alternate aligned unsigned integer byte values from the four byte elements in register *rt* are expanded to create two Q15 fractional values that are then written to destination register *rd*. The precision expansion is achieved by pre-pending a single zero bit (for positive sign) to the original byte value and appending seven least-significant zeros to generate each 16-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

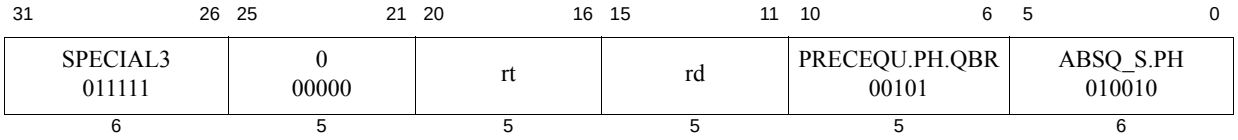
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

$$tempB_{15..0} \leftarrow 0^{1} \mid\mid GPR[rt]_{31..24} \mid\mid 0^{7}$$
$$tempA_{15..0} \leftarrow 0^{1} \mid\mid GPR[rt]_{15..8} \mid\mid 0^{7}$$
$$GPR[rd]_{..0} \leftarrow tempB_{15..0} \mid\mid tempA_{15..0}$$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQU.PH.QBR rd, rt` **MIPSDSP**

Purpose: Precision Expand two Unsigned Bytes to Fractional Halfword Values

Expand the precision of two unsigned byte values taken from the two right-most elements of a quad byte vector to create two Q15 fractional halfword values.

Description: $rd \leftarrow expand\_prec(rt_{15..8}) \ || \ expand\_prec(rt_{7..0})$

The two right-most unsigned integer byte values from the four byte elements in register *rt* are expanded to create two Q15 fractional values that are then written to destination register *rd*. The precision expansion is achieved by prepending a single zero bit (for positive sign) to the original byte value and appending seven least-significant zeros to generate each 16-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

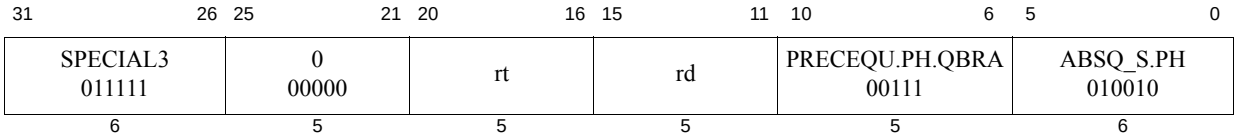
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^1 || GPR[rt]15..8 || 0^7
tempA15..0 ← 0^1 || GPR[rt]7..0 || 0^7
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEQU.PH.QBRA rd, rt` **MIPSDSP**

Purpose: Precision Expand two Unsigned Bytes to Fractional Halfword Values

Expand the precision of two unsigned byte values taken from the two right-alternate aligned elements of a quad byte vector to create two Q15 fractional halfword values.

Description: `rd ← expand_prec(rt`$_{23..16}$`) || expand_prec(rt`$_{7..0}$`)`

The two right-alternate aligned unsigned integer byte values from the four byte elements in register `rt` are expanded to create two Q15 fractional values that are then written to destination register *rd*. The precision expansion is achieved by pre-pending a single zero bit (for positive sign) to the original byte value and appending seven least-significant zeros to generate each 16-bit fractional value.

Restrictions:

No data-dependent exceptions are possible.

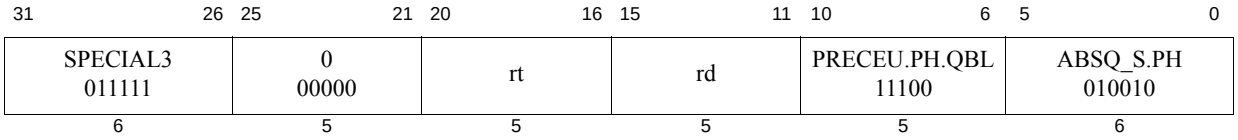
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^1 || GPR[rt]23..16 || 0^7
tempA15..0 ← 0^1 || GPR[rt]7..0 || 0^7
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEU.PH.QBL rd, rt` **MIPSDSP**

Purpose: Precision Expand Two Unsigned Bytes to Unsigned Halfword Values

Expand the precision of two unsigned byte values taken from the two left-most elements of a quad byte vector to create two unsigned halfword values.

Description: $rd \leftarrow expand\_prec8u16(rt_{31..24}) \mid\mid expand\_prec8u16(rt_{23..16})$

The two left-most unsigned integer byte values from the four byte elements in register *rt* are expanded to create two unsigned halfword values that are then written to destination register *rd*. The precision expansion is achieved by prepending eight most-significant zeros to each original value to generate each 16 bit unsigned value.

Restrictions:

No data-dependent exceptions are possible.

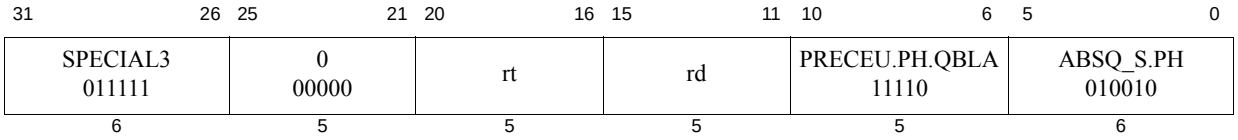
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

$$tempB_{15..0} \leftarrow 0^8 \mid\mid GPR[rt]_{31..24}$$
$$tempA_{15..0} \leftarrow 0^8 \mid\mid GPR[rt]_{23..16}$$
$$GPR[rd]_{..0} \leftarrow tempB_{15..0} \mid\mid tempA_{15..0}$$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEU.PH.QBLA rd, rt` **MIPSDSP**

Purpose: Precision Expand Two Unsigned Bytes to Unsigned Halfword Values

Expand the precision of two unsigned integer byte values taken from the two left-alternate aligned positions of a quad byte vector to create four unsigned halfword values.

Description: `rd ← expand_prec8u16(rt`$_{31..24}$`) || expand_prec8u16(rt`$_{15..8}$`)`

The two left-alternate aligned unsigned integer byte values from the four right-most byte elements in register `rt` are each expanded to unsigned halfword values and written to destination register *rd*. The precision expansion is achieved by pre-pending eight most-significant zero bits to the original byte value to generate each 16 bit unsigned halfword value.

Restrictions:

No data-dependent exceptions are possible.

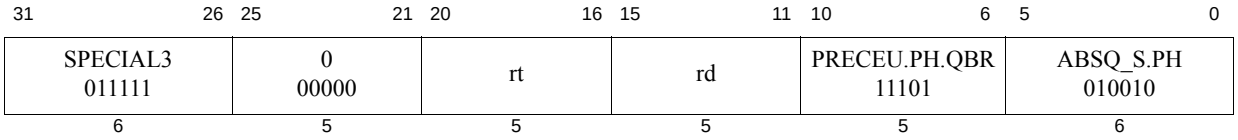
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^8 || GPR[rt]31..24
tempA15..0 ← 0^8 || GPR[rt]15..8
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEU.PH.QBR rd, rt` **MIPSDSP**

Purpose: Precision Expand two Unsigned Bytes to Unsigned Halfword Values

Expand the precision of two unsigned integer byte values taken from the two right-most elements of a quad byte vector to create two unsigned halfword values.

Description: $rd \leftarrow expand\_prec8u16(rt_{15..8}) \ || \ expand\_prec8u16(rt_{7..0})$

The two right-most unsigned integer byte values from the four byte elements in register *rt* are expanded to create two unsigned halfword values that are then written to destination register *rd*. The precision expansion is achieved by prepending eight most-significant zero bits to each original value to generate each 16 bit halfword value.

Restrictions:

No data-dependent exceptions are possible.

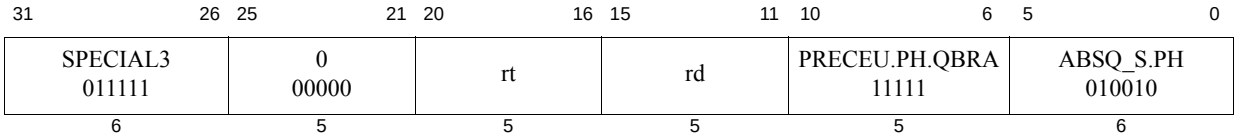
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^8 || GPR[rt]15..8
tempA15..0 ← 0^8 || GPR[rt]7..0
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECEU.PH.QBRA rd, rt` **MIPSDSP**

Purpose: Precision Expand Two Unsigned Bytes to Unsigned Halfword Values

Expand the precision of two unsigned byte values taken from the two right-alternate aligned positions of a quad byte vector to create two unsigned halfword values.

Description: `rd ← expand_prec8u16(rt`$_{23..16}$`) || expand_prec8u16(rt`$_{7..0}$`)`

The two right-alternate aligned unsigned integer byte values from the four byte elements in register *rt* are each expanded to unsigned halfword values and written to destination register *rd*. The precision expansion is achieved by pre-pending eight most-significant zero bits to the original byte value to generate each 16 bit unsigned halfword value.

Restrictions:

No data-dependent exceptions are possible.

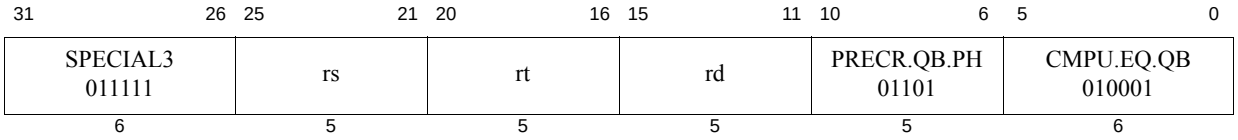
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^8 || GPR[rt]23..16
tempA15..0 ← 0^8 || GPR[rt]7..0
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECR.QB.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Precision Reduce Four Integer Halfwords to Four Bytes

Reduce the precision of four integer halfwords to four byte values.

Description: $rd \leftarrow rs_{23..16} \,||\, rs_{7..0} \,||\, rt_{23..16} \,||\, rt_{7..0}$

The 8 least-significant bits from each of the two integer halfword values in registers *rs* and *rt* are taken to produce four byte-sized results that are written to the four byte elements in destination register *rd*. The two bytes values obtained from *rs* are written to the two left-most destination byte elements, and the two bytes obtained from *rt* are written to the two right-most destination byte elements.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← GPR[rs]23..16
tempC7..0 ← GPR[rs]7..0
tempB7..0 ← GPR[rt]23..16
tempA7..0 ← GPR[rt]7..0
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	sa	PRECR_SRA.PH.W 11110	CMPU.EQ.QB 010001
SPECIAL3 011111	rs	rt	sa	PRECR_SRA_R.PH.W 11111	CMPU.EQ.QB 010001
6	5	5	5	5	6

Format: `PRECR_SRA[_R].PH.W`

`PRECR_SRA.PH.W rt, rs, sa` **MIPSDSP-R2**

`PRECR_SRA_R.PH.W rt, rs, sa` **MIPSDSP-R2**

Purpose: Precision Reduce Two Integer Words to Halfwords after a Right Shift

Do an arithmetic right shift of two integer words with optional rounding, and then reduce the precision to halfwords.

Description: $rt \leftarrow (round(rt>>shift))_{15..0} \mid\mid (round(rs>>shift))_{15..0}$

The two words in registers *rs* and *rt* are right shifted arithmetically by the specified shift amount *sa* to create interim results. The 16 least-significant bits of each interim result are then written to the corresponding elements of destination register *rt*.

In the rounding version of the instruction, a value of 1 is added at the most-significant discarded bit position after the shift is performed. The 16 least-significant bits of each interim result are then written to the corresponding elements of destination register *rt*.

The shift amount *sa* is interpreted as a five-bit unsigned integer taking values between 0 and 31.

This instruction does not write any bits of the *ouflag* field in the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

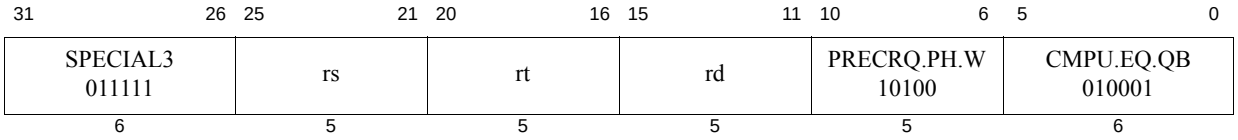
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
PRECR_SRA.PH.W
   if (sa4..0 = 0) then
      tempB15..0 ← GPR[rt]15..0
      tempA15..0 ← GPR[rs]15..0
   else
      tempB15..0 ← ( (GPR[rt]31)sa || GPR[rt]31..sa )
      tempA15..0 ← ( (GPR[rs]31)sa || GPR[rs]31..sa )
   endif
   GPR[rt]..0 ← tempB15..0 || tempA15..0

PRECR_SRA_R.PH.W
   if (sa4..0 = 0) then
      tempB16..0 ← ( GPR[rt]15..0 || 0 )
      tempA16..0 ← ( GPR[rs]15..0 || 0 )
   else
      tempB32..0 ← ( (GPR[rt]31)sa || GPR[rt]31..sa-1 ) + 1
      tempA32..0 ← ( (GPR[rs]31)sa || GPR[rs]31..sa-1 ) + 1
   endif
   GPR[rt]..0 ← tempB16..1 || tempA16..1
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECRQ.PH.W rd, rs, rt` **MIPSDSP**

Purpose: Precision Reduce Fractional Words to Fractional Halfwords

Reduce the precision of two fractional words to produce two fractional halfword values.

Description: $rd \leftarrow rt_{31..16} \mid\mid rs_{31..16}$

The 16 most-significant bits from each of the Q31 fractional word values in registers *rs* and *rt* are written to destination register *rd*, creating a vector of two Q15 fractional values. The fractional word from the *rs* register is used to create the left-most Q15 fractional value in *rd*, and the fractional word from the *rt* register is used to create the right-most Q15 fractional value.

Restrictions:

No data-dependent exceptions are possible.

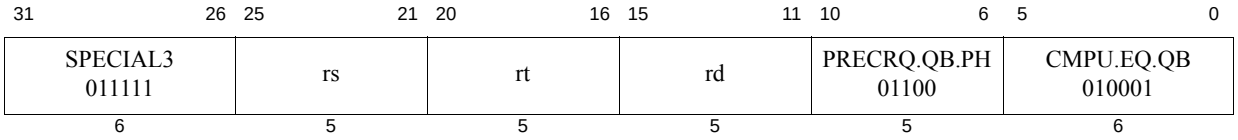
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← GPR[rs]31..16
tempA15..0 ← GPR[rt]31..16
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECRQ.QB.PH rd, rs, rt` **MIPSDSP**

Purpose: Precision Reduce Four Fractional Halfwords to Four Bytes

Reduce the precision of four fractional halfwords to four byte values.

Description: $rd \leftarrow rs_{31..24} \,||\, rs_{15..8} \,||\, rt_{31..24} \,||\, rt_{15..8}$

The Q15 fractional values in registers *rs* and *rt* are truncated by dropping the eight least significant bits from each value to produce four fractional byte values. The four fractional byte values are written to the four byte elements of destination register *rd*. The two values obtained from register *rt* are placed in the two right-most byte positions in the destination register, and the two values obtained from register *rs* are placed in the two remaining byte positions.

Restrictions:

No data-dependent exceptions are possible.

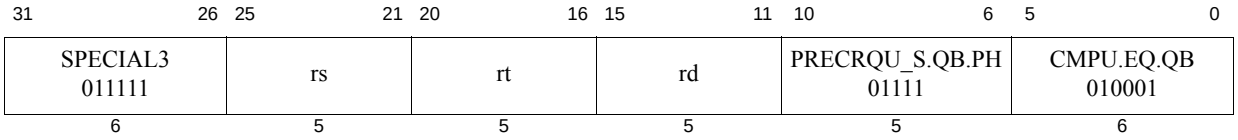
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← GPR[rs]31..24
tempC7..0 ← GPR[rs]15..8
tempB7..0 ← GPR[rt]31..24
tempA7..0 ← GPR[rt]15..8
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECRQU_S.QB.PH rd, rs, rt` **MIPSDSP**

Purpose: Precision Reduce Fractional Halfwords to Unsigned Bytes With Saturation

Reduce the precision of four fractional halfwords with saturation to produce four unsigned byte values, with saturation.

Description: `rd ← sat(reduce_prec(`$rs_{31..16}$`)) || sat(reduce_prec(`$rs_{15..0}$`)) || sat(reduce_prec(`$rt_{31..16}$`)) || sat(reduce_prec(`$rt_{15..0}$`))`

The four Q15 fractional halfwords from registers *rs* and *rt* are used to create four unsigned byte values that are written to corresponding elements of destination register *rd*. The two halfwords from the *rs* register and the two halfwords from the *rt* register are used to create the four unsigned byte values.

Each unsigned byte value is created from the Q15 fractional halfword input value after first examining the sign and magnitude of the halfword. If the sign of the halfword value is positive and the value is greater than 0x7F80 hexadecimal, the result is clamped to the maximum positive 8-bit value (255 decimal, 0xFF hexadecimal). If the sign of the halfword value is negative, the result is clamped to the minimum positive 8-bit value (0 decimal, 0x00 hexadecimal). Otherwise, the sign bit is discarded from the input and the result is taken from the eight most-significant bits that remain.

If clamping was needed to produce any of the unsigned output values, bit 22 of the *DSPControl* register is set to 1.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

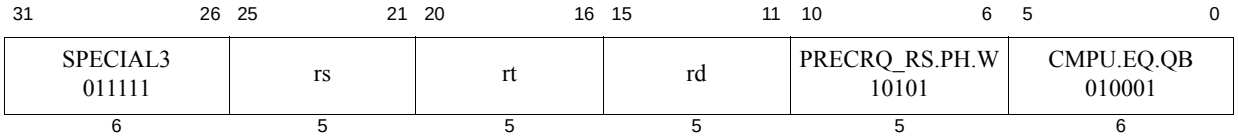
Operation:

```
tempD7..0 ← sat8ReducePrecision( GPR[rs]31..16 )
tempC7..0 ← sat8ReducePrecision( GPR[rs]15..0 )
tempB7..0 ← sat8ReducePrecision( GPR[rt]31..16 )
tempA7..0 ← sat8ReducePrecision( GPR[rt]15..0 )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function sat8ReducePrecision( a15..0 )
   sign ← a15
   mag14..0 ← a14..0
   if ( sign = 0 ) then
      if ( mag14..0 > 0x7F80 ) then
         temp7..0 ← 0xFF
         DSPControlouflag:22 ← 1
      else
         temp7..0 ← mag14..7
      endif
   else
      temp7..0 ← 0x00
      DSPControlouflag:22 ← 1
   endif
   return temp7..0
```

```
endfunction sat8ReducePrecision
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PRECRQ_RS.PH.W rd, rs, rt` **MIPSDSP**

Purpose: Precision Reduce Fractional Words to Halfwords With Rounding and Saturation

Reduce the precision of two fractional words to produce two fractional halfword values, with rounding and saturation.

Description: $rd \leftarrow truncQ15SatRound(rs_{31..0}) \ || \ truncQ15SatRound(rt_{31..0})$

The two Q31 fractional word values in each of registers *rs* and *rt* are used to create two Q15 fractional halfword values that are written to the two halfword elements in destination register *rd*. The fractional word from the *rs* register is used to create the left-most Q15 fractional halfword result in *rd*, and the fractional word from the *rt* register is used to create the right-most halfword value.

Each input Q31 fractional value is rounded and saturated before being truncated to create the Q15 fractional halfword result. First, the value 0x00008000 is added to the input Q31 value to round even, creating an interim rounded result. If this addition causes overflow, the interim rounded result is saturated to the maximum Q31 value (0x7FFFFFFF hexadecimal). Then, the 16 least-significant bits of the interim rounded and saturated result are discarded and the 16 most-significant bits are written to the destination register in the appropriate position.

If either of the rounding operations results in overflow and saturation, a 1 is written to bit 22 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

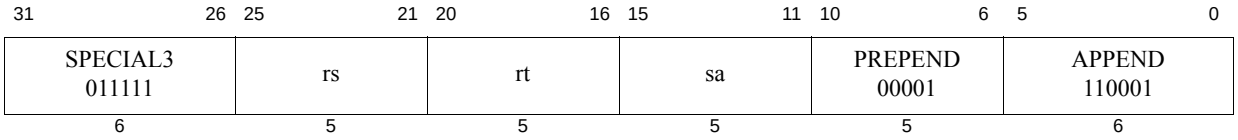
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← trunc16Sat16Round( GPR[rs]31..0 )
tempA15..0 ← trunc16Sat16Round( GPR[rt]31..0 )
GPR[rd]..0 ← tempB15..0 || tempA15..0

function trunc16Sat16Round( a31..0 )
   temp32..0 ← ( a31 || a31..0 ) + 0x00008000
   if ( temp32 ≠ temp31 ) then
      temp32..0 ← 0 || 0x7FFFFFFF
      DSPControlouflag:22 ← 1
   endif
   return temp31..16
endfunction trunc16Sat16Round
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `PREPEND rt, rs, sa` **MIPSDSP-R2**

Purpose: Right Shift and Prepend Bits to the MSB

Logically right-shift the first source register, replacing the bits emptied by the shift with bits from the source register.

Description: $rt \leftarrow rs_{sa-1..0} \mid\mid (rt >> sa)$

The word value in register *rt* is logically right-shifted by the specified shift amount *sa*, and *sa* bits from the least-significant positions of register *rs* are written into the *sa* most-significant bits emptied by the shift. The result is then written to destination register *rt*.

Restrictions:

No data-dependent exceptions are possible.

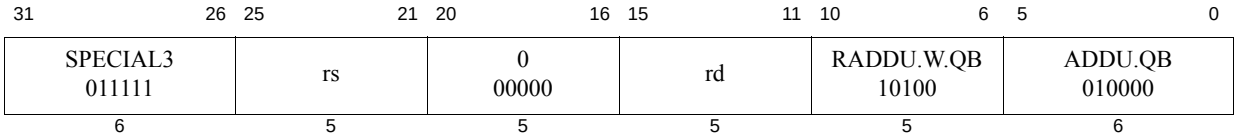
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
if ( sa4..0 = 0 ) then
   temp31..0 ← GPR[rt]31..0
else
   temp31..0 ← ( GPR[rs]sa-1..0 || GPR[rt]31..sa )
endif
GPR[rt]..0 = temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `RADDU.W.QB rd, rs` **MIPSDSP**

Purpose: Unsigned Reduction Add Vector Quad Bytes

Reduction add of four unsigned byte values in a vector register to produce an unsigned word result.

Description: $rd \leftarrow zero\_extend(rs_{31..24} + rs_{23..16} + rs_{15..8} + rs_{7..0})$

The unsigned byte elements in register *rs* are added together as unsigned 8-bit values, and the result is zero extended to a word and written to register *rd*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

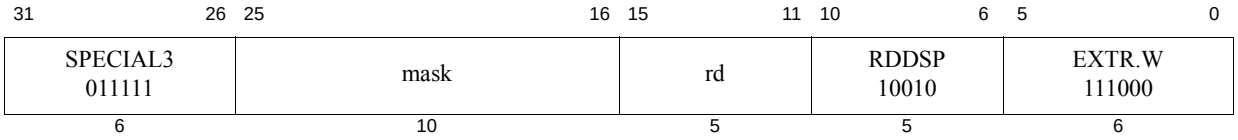
Operation:

$$temp_{9..0} \leftarrow (0^2 \,||\, GPR[rs]_{31..24}) + (0^2 \,||\, GPR[rs]_{23..16}) + (0^2 \,||\, GPR[rs]_{15..8}) + (0^2 \,||\, GPR[rs]_{7..0})$$

$$GPR[rd]_{..0} \leftarrow 0^{(GPRLEN-10)} \,||\, temp_{9..0}$$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `RDDSP`

`RDDSP rd, mask` **MIPSDSP**

`RDDSP rd` **Assembly Idiom**

Purpose: Read DSPControl Register Fields to a GPR

To copy selected fields from the special-purpose *DSPControl* register to the specified GPR.

Description: `rd ← select(mask, DSPControl)`

Selected fields in the special register *DSPControl* are copied into the corresponding bits of destination register *rd*. Each of bits 0 through 5 of the *mask* operand corresponds to a specific field in the *DSPControl* register. A mask bit value of 1 indicates that the bits from the corresponding field in *DSPControl* will be copied into the same bit positions in register *rd*, and a mask bit value of 0 indicates that the corresponding bit positions in *rd* will be set to zero. Bits 6 through 9 of the *mask* operand are ignored.

The table below shows the correspondence between the bits in the *mask* operand and the fields in the *DSPControl* register; mask bit 0 is the least-significant bit in *mask*.

For example, to copy only the bits from the scount field in *DSPControl*, the value of the *mask* operand used will be 2 decimal (0x02 hexadecimal). After execution of the instruction, bits 7 through 12 of register *rd* will have the value of bits 7 through 12 from the scount field in *DSPControl*. The remaining bits in register *rd* will be set to zero.

The one-operand version of the instruction provides a convenient assembly idiom that allows the programmer to read all fields in the *DSPControl* register into the destination register, i.e., it is equivalent to specifying a *mask* value of 31 decimal (0x1F hexadecimal).

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

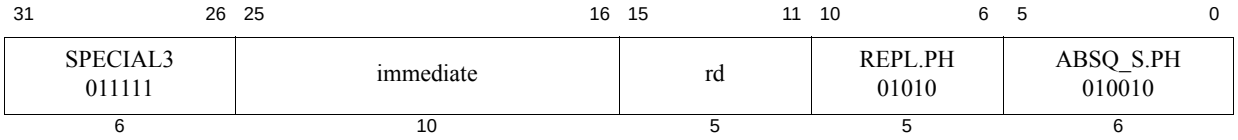
Operation:

```
temp..0 ← 0
if ( mask0 = 1 ) then
   temp..0 ← DSPControlpos:..0
endif
if ( mask1 = 1 ) then
   temp12..7 ← DSPControlscount:12..7
endif
if ( mask2 = 1 ) then
   temp13 ← DSPControlc:13
endif
if ( mask3 = 1 ) then
   temp23..16 ← DSPControlouflag:23..16
endif
if ( mask4 = 1 ) then
   temp..24 ← DSPControlccond:..24
endif
```

```
if ( mask5 = 1 ) then
   temp14 ← DSPControlefi:14
endif

GPR[rd]..0 ← temp..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `REPL.PH rd, immediate` **MIPSDSP**

Purpose: Replicate Immediate Integer into all Vector Element Positions

Replicate a sign-extended, 10-bit signed immediate integer value into the two halfwords in a halfword vector.

Description: `rd ← sign_extend(immediate) || sign_extend(immediate)`

The specified 10-bit signed immediate integer value is sign-extended to 16 bits and replicated into the two halfword positions in destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

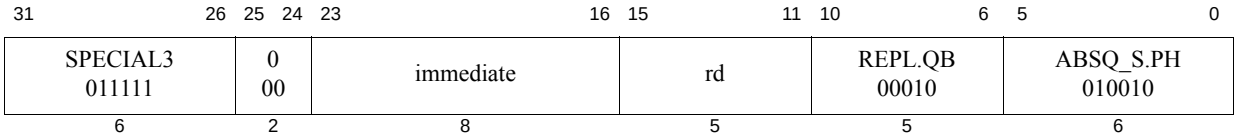
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

$temp_{15..0} \leftarrow (immediate_{9})^{6} \,||\, immediate_{9..0}$
$GPR[rd]_{..0} \leftarrow temp_{15..0} \,||\, temp_{15..0}$

Exceptions:

Reserved Instruction, DSP Disabled



Format: `REPL.QB rd, immediate` **MIPSDSP**

Purpose: Replicate Immediate Integer into all Vector Element Positions

Replicate a immediate byte into all elements of a quad byte vector.

Description: `rd ← immediate || immediate || immediate || immediate`

The specified 8-bit signed immediate value is replicated into the four byte elements of destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

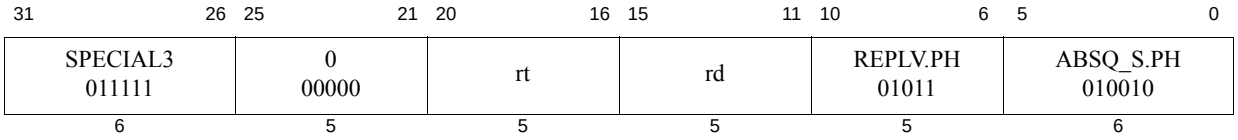
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp7..0 ← immediate7..0
GPR[rd]..0 ← temp7..0 || temp7..0 || temp7..0 || temp7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `REPLV.PH rd, rt` **MIPSDSP**

Purpose: Replicate a Halfword into all Vector Element Positions

Replicate a variable halfword into the elements of a halfword vector.

Description: $rd \leftarrow rt_{15..0} \mid\mid rt_{15..0})$

The halfword value in register *rt* is replicated into the two halfword elements of destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

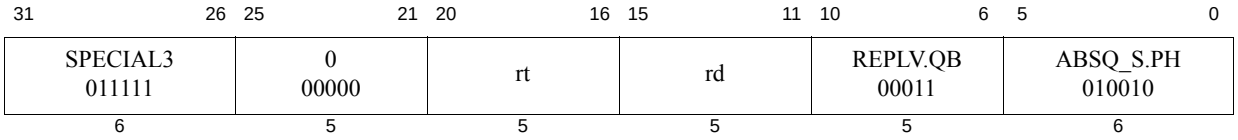
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp15..0 ← GPR[rt]15..0
GPR[rd]..0 ← temp15..0 || temp15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `REPLV.QB rd, rt` **MIPSDSP**

Purpose: Replicate Byte into all Vector Element Positions

Replicate a variable byte into all elements of a quad byte vector.

Description: $rd \leftarrow rt_{7..0} \,||\, rt_{7..0} \,||\, rt_{7..0} \,||\, rt_{7..0}$

The byte value in register *rt* is replicated into the four byte elements of destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

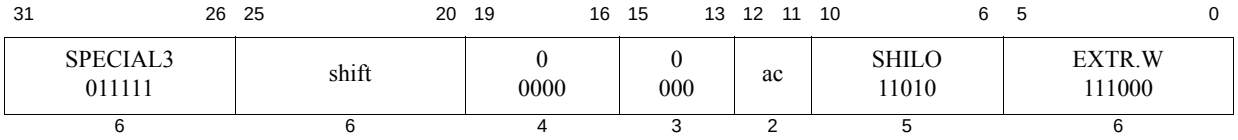
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp7..0 ← GPR[rt]7..0
GPR[rd]..0 ← temp7..0 || temp7..0 || temp7..0 || temp7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHILO ac, shift` **MIPSDSP**

Purpose: Shift an Accumulator Value Leaving the Result in the Same Accumulator

Shift the *HI*/*LO* paired value in a 64-bit accumulator either left or right, leaving the result in the same accumulator.

Description: `ac ← (shift >= 0) ? (ac >> shift) : (ac << -shift)`

The *HI*/*LO* register pair is treated as a single 64-bit accumulator that is shifted logically by *shift* bits, with the result of the shift written back to the source accumulator. The *shift* argument is a six-bit signed integer value: a positive argument results in a right shift of up to 31 bits, and a negative argument results in a left shift of up to 32 bits.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

Restrictions:

No data-dependent exceptions are possible.

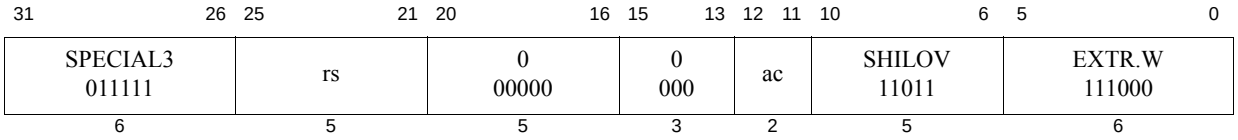
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
sign ← shift5
shift5..0 ← ( sign = 0 ? shift5..0 : -shift5..0 )
if ( shift5..0 = 0 ) then
   temp63..0 ← (HI[ac]31..0 || LO[ac]31..0)
else
   if (sign = 0) then
      temp63..0 ← 0shift || (( HI[ac]31..0 || LO[ac]31..0 ) >> shift )
   else
      temp63..0 ← (( HI[ac]31..0 || LO[ac]31..0 ) << shift ) || 0shift
   endif
endif
( HI[ac]..0 || LO[ac]..0 ) ← temp63..32 || temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHILOV ac, rs` **MIPSDSP**

Purpose: Variable Shift of Accumulator Value Leaving the Result in the Same Accumulator

Shift the *HI*/*LO* paired value in an accumulator either left or right by the amount specified in a GPR, leaving the result in the same accumulator.

Description: `ac ← ( GPR[rs]`$_{6..0}$ `>= 0) ? (ac >> GPR[rs]`$_{6..0}$`) : (ac << -GPR[rs]`$_{6..0}$`)`

The *HI*/*LO* register pair is treated as a single 64-bit accumulator that is shifted logically by *shift* bits, with the result of the shift written back to the source accumulator. The *shift* argument is provided by the six least-significant bits of register *rs*; the remaining bits of *rs* are ignored. The *shift* argument is interpreted as a six-bit signed integer: a positive argument results in a right shift of up to 31 bits, and a negative argument results in a left shift of up to 32 bits.

The value of *ac* can range from 0 to 3. When *ac*=0, this refers to the original *HI*/*LO* register pair of the architecture.

Restrictions:

No data-dependent exceptions are possible.

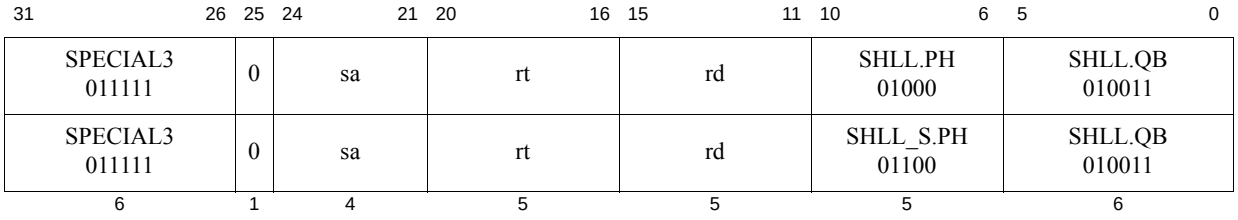
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
sign ← GPR[rs]5
shift5..0 ← ( sign = 0 ? GPR[rs]5..0 : -GPR[rs]5..0 )
if ( shift5..0 = 0 ) then
   temp63..0 ← ( HI[ac]31..0 || LO[ac]31..0 )
else
   if ( sign = 0 ) then
      temp63..0 ← 0shift || (( HI[ac]31..0 || LO[ac]31..0 ) >> shift )
   else
      temp63..0 ← (( HI[ac]31..0 || LO[ac]31..0 ) << shift ) || 0shift
   endif
endif
( HI[ac]..0 || LO[ac]..0 ) ← temp63..32 || temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25	24–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	0	sa	rt	rd	SHLL.PH 01000	SHLL.QB 010011
SPECIAL3 011111	0	sa	rt	rd	SHLL_S.PH 01100	SHLL.QB 010011
6	1	4	5	5	5	6

Format: `SHLL[_S].PH`

`SHLL.PH rd, rt, sa` **MIPSDSP**

`SHLL_S.PH rd, rt, sa` **MIPSDSP**

Purpose: Shift Left Logical Vector Pair Halfwords

Element-wise shift of two independent halfwords in a vector data type by a fixed number of bits, with optional saturation.

Description: $rd \leftarrow sat16(rt_{31..16} << sa) \mid\mid (rt_{15..0} << sa)$

The two halfword values in register *rt* are each independently shifted left, inserting zeros into the least-significant bit positions emptied by the shift. In the saturating version of the instruction, if the shift results in an overflow the intermediate result is saturated to either the maximum positive or the minimum negative 16-bit value, depending on the sign of the original unshifted value. The two independent results are then written to the corresponding halfword elements of destination register *rd*.

This instruction writes a 1 to bit 22 in the *DSPControl* register in the *ouflag* field if any of the left shift operations results in an overflow or saturation.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

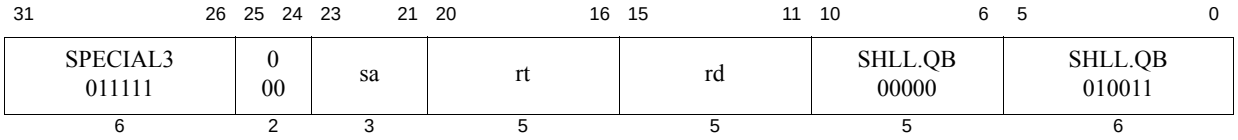
Operation:

```
SHLL.PH
    tempB15..0 ← shift16Left( GPR[rt]31..16, sa )
    tempA15..0 ← shift16Left( GPR[rt]15..0, sa )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

SHLL_S.PH
    tempB15..0 ← sat16ShiftLeft( GPR[rt]31..16, sa )
    tempA15..0 ← sat16ShiftLeft( GPR[rt]15..0, sa )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function shift16Left( a15..0, s3..0 )
    if ( s3..0 = 0 ) then
        temp15..0 ← a15..0
    else
        sign ← a15
        temp15..0 ← ( a15-s..0 || 0s )
        discard15..0 ← ( sign(16-s) || a14..14-(s-1) )
        if (( discard15..0 ≠ 0x0000 ) and ( discard15..0 ≠ 0xFFFF )) then
            DSPControlouflag:22 ← 1
        endif
    endif
```

```
    return temp15..0
endfunction shift16Left

function sat16ShiftLeft( a15..0, s3..0 )
    if ( s3..0 = 0 ) then
        temp15..0 ← a15..0
    else
        sign ← a15
        temp15..0 ← ( a15-s..0 || 0s )
        discard15..0 ← ( sign(16-s) || a14..14-(s-1) )
        if (( discard15..0 ≠ 0x0000 ) and ( discard15..0 ≠ 0xFFFF )) then
            temp15..0 ← ( sign = 0 ? 0x7FFF : 0x8000 )
            DSPControlouflag:22 ← 1
        endif
    endif
    return temp15..0
endfunction sat16ShiftLeft
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHLL.QB rd, rt, sa` **MIPSDSP**

Purpose: Shift Left Logical Vector Quad Bytes

Element-wise left shift of four independent bytes in a vector data type by a fixed number of bits.

Description: $rd \leftarrow (rt_{31..24} << sa) \mid\mid (rt_{23..16} << sa) \mid\mid (rt_{15..8} << sa) \mid\mid (rt_{7..0} << sa)$

The four byte values in register *rt* are each independently shifted left by *sa* bits and the *sa* least significant bits of each value are set to zero. The four independent results are then written to the corresponding byte elements of destination register *rd*.

This instruction writes a 1 to bit 22 in the *DSPControl* register in the *ouflag* field if any of the left shift operations results in an overflow.

Restrictions:

No data-dependent exceptions are possible.

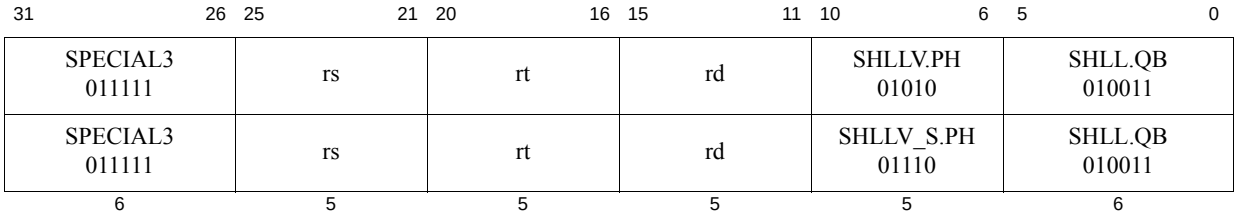
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← shift8Left( GPR[rt]31..24, sa2..0 )
tempC7..0 ← shift8Left( GPR[rt]23..16, sa2..0 )
tempB7..0 ← shift8Left( GPR[rt]15..8, sa2..0 )
tempA7..0 ← shift8Left( GPR[rt]7..0, sa2..0 )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function shift8Left( a7..0, s2..0 )
   if ( s2..0 = 0 ) then
      temp7..0 ← a7..0
   else
      sign ← a7
      temp7..0 ← ( a7-s..0 || 0s )
      discard7..0 ← ( sign(8-s) || a6..6-(s-1) )
      if ( discard7..0 ≠ 0x00 ) then
         DSPControlouflag:22 ← 1
      endif
   endif
   return temp7..0
endfunction shift8Left
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SHLLV.PH 01010	SHLL.QB 010011
SPECIAL3 011111	rs	rt	rd	SHLLV_S.PH 01110	SHLL.QB 010011
6	5	5	5	5	6

Format: `SHLLV[_S].PH`

`SHLLV.PH rd, rt, rs` **MIPSDSP**

`SHLLV_S.PH rd, rt, rs` **MIPSDSP**

Purpose: Shift Left Logical Variable Vector Pair Halfwords

Element-wise left shift of the two right-most independent halfwords in a vector data type by a variable number of bits, with optional saturation.

Description: `rd ← sat16(rt`$_{31..16}$ `<< rs`$_{3..0}$`) || sat16(rt`$_{15..0}$ `<< rs`$_{3..0}$`)`

The two halfword values in register *rt* are each independently shifted left by *shift* bits, inserting zeros into the least-significant bit positions emptied by the shift. In the saturating version of the instruction, if the shift results in an overflow the intermediate result is saturated to either the maximum positive or the minimum negative 16-bit value, depending on the sign of the original unshifted value. The two independent results are then written to the corresponding halfword elements of destination register *rd*.

The four least-significant bits of *rs* provide the shift value, interpreted as a four-bit unsigned integer; the remaining bits of *rs* are ignored.

This instruction writes a 1 to bit 22 in the *DSPControl* register in the ouflag field if any of the left shift operations results in an overflow or saturation.

Restrictions:

No data-dependent exceptions are possible.

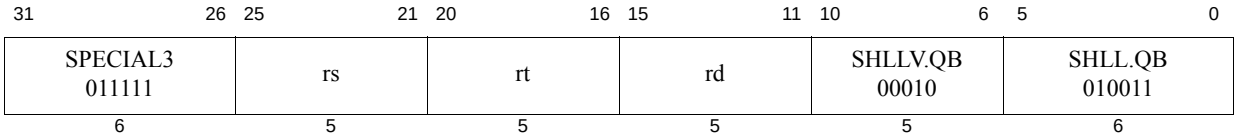
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
SHLLV.PH
    tempB15..0 ← shift16Left( GPR[rt]31..16, GPR[rs]3..0 )
    tempA15..0 ← shift16Left( GPR[rt]15..0, GPR[rs]3..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

SHLLV_S.PH
    tempB15..0 ← sat16ShiftLeft( GPR[rt]31..16, GPR[rs]3..0 )
    tempA15..0 ← sat16ShiftLeft( GPR[rt]15..0, GPR[rs]3..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHLLV.QB rd, rt, rs` **MIPSDSP**

Purpose: Shift Left Logical Variable Vector Quad Bytes

Element-wise left shift of four independent bytes in a vector data type by a variable number of bits.

Description: $rd \leftarrow (rt_{31..24} << rs_{2..0}) \,||\, (rt_{23..16} << rs_{2..0}) \,||\, (rt_{15..8} << rs_{2..0}) \,||\, (rt_{7..0} << rs_{2..0})$

The four byte values in register *rt* are each independently shifted left by *sa* bits, inserting zeros into the least-significant bit positions emptied by the shift. The four independent results are then written to the corresponding byte elements of destination register *rd*.

The three least-significant bits of *rs* provide the shift value, interpreted as a three-bit unsigned integer; the remaining bits of *rs* are ignored.

This instruction writes a 1 to bit 22 in the *DSPControl* register in the *ouflag* field if any of the left shift operations results in an overflow.

Restrictions:

No data-dependent exceptions are possible.

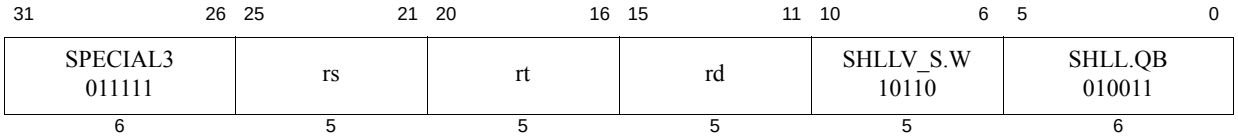
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← shift8Left( GPR[rt]31..24, GPR[rs]2..0 )
tempC7..0 ← shift8Left( GPR[rt]23..16, GPR[rs]2..0 )
tempB7..0 ← shift8Left( GPR[rt]15..8, GPR[rs]2..0 )
tempA7..0 ← shift8Left( GPR[rt]7..0, GPR[rs]2..0 )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHLLV_S.W rd, rt, rs` **MIPSDSP**

Purpose: Shift Left Logical Variable Vector Word

A left shift of the word in a vector data type by a variable number of bits, with optional saturation.

Description: $rd \leftarrow sat32(rt_{31..0} << rs_{4..0})$

The word element in register *rt* is shifted left by *shift* bits, inserting zeros into the least-significant bit positions emptied by the shift. If the shift results in an overflow the intermediate result is saturated to either the maximum positive or the minimum negative 32-bit value, depending on the sign of the original unshifted value.

The shifted result is then written to destination register *rd*.

The five least-significant bits of *rs* are used as the shift value, interpreted as a five-bit unsigned integer; the remaining bits of *rs* are ignored.

This instruction writes a 1 to bit 22 in the *DSPControl* register in the *ouflag* field if either of the left shift operations results in an overflow or saturation.

Restrictions:

No data-dependent exceptions are possible.

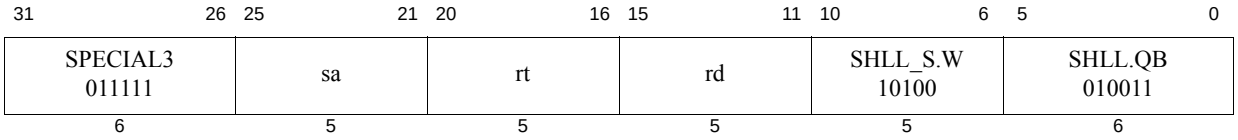
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← sat32ShiftLeft( GPR[rt]31..0, GPR[rs]4..0 )
GPR[rd]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHLL_S.W rd, rt, sa` **MIPSDSP**

Purpose: Shift Left Logical Word with Saturation

To execute a left shift of a word with saturation by a fixed number of bits.

Description: `rd ← sat32(rt << sa)`

The 32-bit word in register *rt* is shifted left by *sa* bits, with zeros inserted into the bit positions emptied by the shift. If the shift results in a signed overflow, the shifted result is saturated to either the maximum positive (hexadecimal 0x7FFFFFFF) or minimum negative (hexadecimal 0x80000000) 32-bit value, depending on the sign of the original unshifted value. The shifted result is then written to destination register *rd*.

The instruction's *sa* field specifies the shift value, interpreted as a five-bit unsigned integer.

If the shift operation results in an overflow and saturation, this instruction writes a 1 to bit 22 of the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

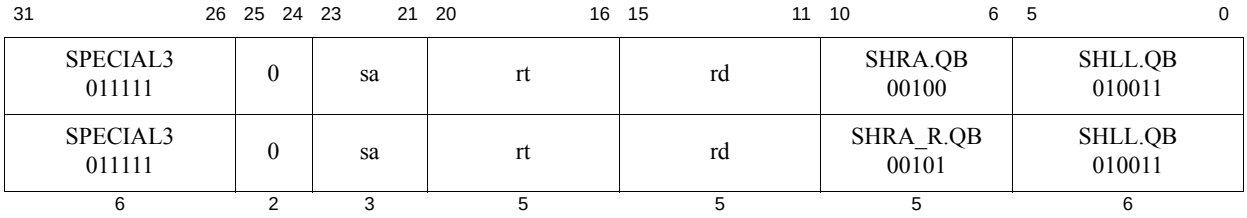
```
temp31..0 ← sat32ShiftLeft( GPR[rt]31..0, sa4..0 )
GPR[rd]..0 ← temp31..0

function sat32ShiftLeft( a13..0, s4..0 )
   if ( s = 0 ) then
      temp31..0 ← a
   else
      sign ← a31
      temp31..0 ← ( a31-s..0 || 0s )
      discard31..0 ← ( sign(32-s) || a30..30-(s-1) )
      if (( discard31..0 ≠ 0x00000000 ) and ( discard31..0 ≠ 0xFFFFFFFF )) then
         temp31..0 ← ( sign = 0 ? 0x7FFFFFFF : 0x80000000 )
         DSPControlouflag:22 ← 1
      endif
   endif
   return temp31..0
endfunction sat32ShiftLeft
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

To do a logical left shift of a word in a register without saturation, use the SLL instruction.



31 26	25 24	23 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	0	sa	rt	rd	SHRA.QB 00100	SHLL.QB 010011
SPECIAL3 011111	0	sa	rt	rd	SHRA_R.QB 00101	SHLL.QB 010011
6	2	3	5	5	5	6

Format: `SHRA[_R].QB`

`SHRA.QB rd, rt, sa` **MIPSDSP-R2**

`SHRA_R.QB rd, rt, sa` **MIPSDSP-R2**

Purpose: Shift Right Arithmetic Vector of Four Bytes

To execute an arithmetic right shift on four independent bytes by a fixed number of bits.

Description: $rd \leftarrow round(rt_{31..24} >> sa) \mid\mid round(rt_{23..16} >> sa) \mid\mid round(rt_{15..8} >> sa) \mid\mid round(rt_{7..0} >> sa)$

The four byte elements in register *rt* are each shifted right arithmetically by *sa* bits, then written to the corresponding vector elements in destination register *rd*. The *sa* argument is interpreted as an unsigned three-bit integer taking values from zero to seven.

In the rounding variant of the instruction, a value of 1 is added at th e most significant discarded bit position of each result prior to writing the rounded result to the destination register.

Restrictions:

No data-dependent exceptions are possible.

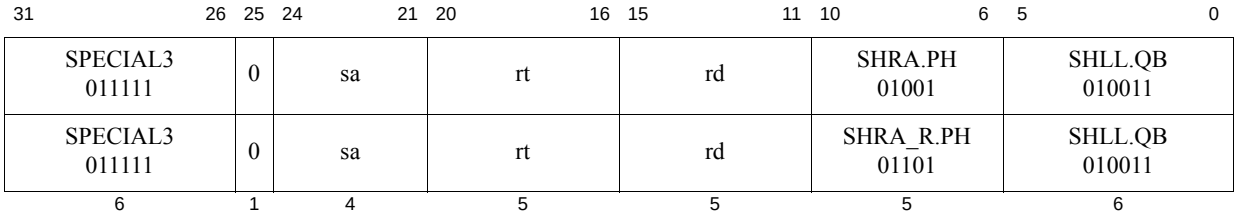
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
SHRA.QB
   tempD7..0 ← ( GPR[rt]31)^sa || GPR[rt]31..24+sa )
   tempC7..0 ← ( GPR[rt]23)^sa || GPR[rt]23..16+sa )
   tempB7..0 ← ( GPR[rt]15)^sa || GPR[rt]15..8+sa )
   tempA7..0 ← ( GPR[rt]7)^sa || GPR[rt]7..sa )
   GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

SHRA_R.QB
   if ( sa2..0 = 0 ) then
      tempD7..0 ← GPR[rt]31..24
      tempC7..0 ← GPR[rt]23..16
      tempB7..0 ← GPR[rt]15..8
      tempA7..0 ← GPR[rt]7..0
   else
      tempD8..0 ← ( GPR[rt]31)^sa || GPR[rt]31..24+sa-1 ) + 1
      tempC8..0 ← ( GPR[rt]23)^sa || GPR[rt]23..16+sa-1 ) + 1
      tempB8..0 ← ( GPR[rt]15)^sa || GPR[rt]15..8+sa-1 ) + 1
      tempA8..0 ← ( GPR[rt]7)^sa || GPR[rt]7..sa-1 ) + 1
   endif
   GPR[rd]..0 ← tempD8..1 || tempC8..1 || tempB8..1 || tempA8..1
   endif
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25	24–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	0	sa	rt	rd	SHRA.PH 01001	SHLL.QB 010011
SPECIAL3 011111	0	sa	rt	rd	SHRA_R.PH 01101	SHLL.QB 010011
6	1	4	5	5	5	6

Format: `SHRA[_R].PH`

`SHRA.PH rd, rt, sa` **MIPSDSP**

`SHRA_R.PH rd, rt, sa` **MIPSDSP**

Purpose: Shift Right Arithmetic Vector Pair Halfwords

Element-wise arithmetic right-shift of two independent halfwords in a vector data type by a fixed number of bits, with optional rounding.

Description: $rd \leftarrow rnd16(rt_{31..16} >> sa) \,||\, rnd16(rt_{15..0} >> sa)$

The two halfword values in register *rt* are each independently shifted right by *sa* bits, with each value's original sign bit duplicated into the *sa* most-significant bits emptied by the shift.

In the non-rounding variant of this instruction, the two independent results are then written to the corresponding halfword elements of destination register *rd*.

In the rounding variant of the instruction, a 1 is added at the most-significant discarded bit position before the results are written to destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
SHRA.PH
    tempB15..0 ← shift16RightArithmetic( GPR[rt]31..16, sa )
    tempA15..0 ← shift16RightArithmetic( GPR[rt]15..0, sa )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

SHRA_R.PH
    tempB15..0 ← rnd16ShiftRightArithmetic( GPR[rt]31..16, sa )
    tempA15..0 ← rnd16ShiftRightArithmetic( GPR[rt]15..0, sa )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function shift16RightArithmetic( a15..0, s3..0 )
    if ( s3..0 = 0 ) then
        temp15..0 ← a15..0
    else
        sign ← a15
        temp15..0 ← ( signs || a15..s )
    endif
    return temp15..0
endfunction shift16RightArithmetic

function rnd16ShiftRightArithmetic( a15..0, s3..0 )
    if ( s3..0 = 0 ) then
```

```
        temp16..0 ← ( a15..0 || 0 )
    else
        sign ← a15
        temp16..0 ← ( signs || a15..s-1 )
    endif
    temp16..0 ← temp + 1
    return temp16..1
endfunction rnd16ShiftRightArithmetic
```

Exceptions:

Reserved Instruction, DSP Disabled

31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	SHRAV.PH 01011	SHLL.QB 010011
SPECIAL3 011111	rs	rt	rd	SHRAV_R.PH 01111	SHLL.QB 010011
6	5	5	5	5	6

Format: `SHRAV[_R].PH`

`SHRAV.PH rd, rt, rs` **MIPSDSP**

`SHRAV_R.PH rd, rt, rs` **MIPSDSP**

Purpose: Shift Right Arithmetic Variable Vector Pair Halfwords

Element-wise arithmetic right shift of two independent halfwords in a vector data type by a variable number of bits, with optional rounding.

Description: $rd \leftarrow rnd16(rt_{31..16} >> rs_{3..0}) \ || \ rnd16(rt_{15..0} >> rs_{3..0})$

The two halfword values in register *rt* are each independently shifted right, with each value's original sign bit duplicated into the most-significant bits emptied by the shift. In the non-rounding variant of this instruction, the two independent results are then written to the corresponding halfword elements of destination register *rd*.

In the rounding variant of this instruction, a 1 is added at the most-significant discarded bit position before the results are written to destination register *rd*.

The shift amount *sa* is given by the four least-significant bits of register *rs*; the remaining bits of *rs* are ignored.

Restrictions:

No data-dependent exceptions are possible.

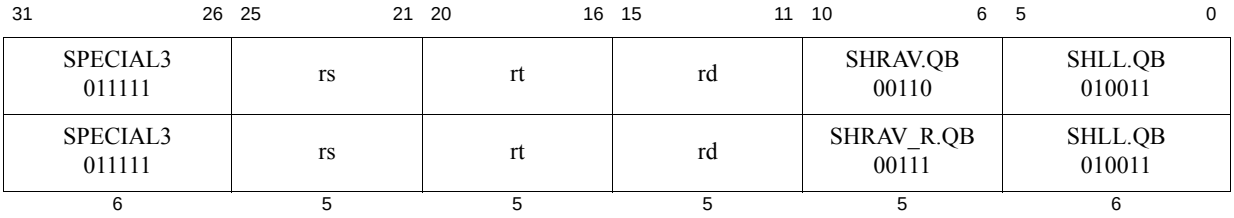
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
SHRAV.PH
    tempB15..0 ← shift16RightArithmetic( GPR[rt]31..16, GPR[rs]3..0 )
    tempA15..0 ← shift16RightArithmetic( GPR[rt]15..0, GPR[rs]3..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

SHRAV_R.PH
    tempB15..0 ← rnd16ShiftRightArithmetic( GPR[rt]31..16, GPR[rs]3..0 )
    tempA15..0 ← rnd16ShiftRightArithmetic( GPR[rt]15..0, GPR[rs]3..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SHRAV.QB 00110	SHLL.QB 010011
SPECIAL3 011111	rs	rt	rd	SHRAV_R.QB 00111	SHLL.QB 010011
6	5	5	5	5	6

Format: `SHRAV[_R].QB`

```
SHRAV.QB      rd, rt, rs                                  MIPSDSP-R2
SHRAV_R.QB    rd, rt, rs                                  MIPSDSP-R2
```

Purpose: Shift Right Arithmetic Variable Vector of Four Bytes

To execute an arithmetic right shift on four independent bytes by a variable number of bits.

Description: $rd \leftarrow round(rt_{31..24} >> rs_{2..0}) \,||\, round(rt_{23..16} >> rs_{2..0}) \,||\, round(rt_{15..8} >> rs_{2..0}) \,||\, round(rt_{7..0} >> rs_{2..0})$

The four byte elements in register *rt* are each shifted right arithmetically by *sa* bits, then written to the corresponding byte elements in destination register *rd*. The *sa* argument is provided by the three least-significant bits of register *rs*, interpreted as an unsigned three-bit integer taking values from zero to seven. The remaining bits of *rs* are ignored.

In the rounding variant of the instruction, a value of 1 is added at th e most significant discarded bit position of each result prior to writing the rounded result to the destination register.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

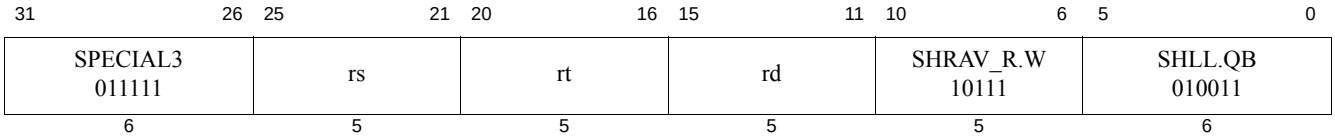
Operation:

```
SHRAV.QB
    sa2..0 ← GPR[rs]2..0
    if ( sa2..0 = 0 ) then
        tempD7..0 ← GPR[rt]31..24
        tempC7..0 ← GPR[rt]23..16
        tempB7..0 ← GPR[rt]15..8
        tempA7..0 ← GPR[rt]7..0
    else
        tempD7..0 ← ( GPR[rt]31)sa || GPR[rt]31..24+sa )
        tempC7..0 ← ( GPR[rt]23)sa || GPR[rt]23..16+sa )
        tempB7..0 ← ( GPR[rt]15)sa || GPR[rt]15..8+sa )
        tempA7..0 ← ( GPR[rt]7)sa || GPR[rt]7..sa )
    endif
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

SHRAV_R.QB
    sa2..0 ← GPR[rs]2..0
    if ( sa2..0 = 0 ) then
        tempD8..0 ← ( GPR[rt]31..24 || 0)
        tempC8..0 ← ( GPR[rt]23..16 || 0)
        tempB8..0 ← ( GPR[rt]15..8 || 0)
        tempA8..0 ← ( GPR[rt]7..0 || 0)
    else
```

```
        tempD8..0 ← ( GPR[rt]31)sa || GPR[rt]31..24+sa-1 ) + 1
        tempC8..0 ← ( GPR[rt]23)sa || GPR[rt]23..16+sa-1 ) + 1
        tempB8..0 ← ( GPR[rt]15)sa || GPR[rt]15..8+sa-1 ) + 1
        tempA8..0 ← ( GPR[rt]7)sa || GPR[rt]7..sa-1 ) + 1
    endif
    GPR[rd]..0 ← tempD8..1 || tempC8..1 || tempB8..1 || tempA8..1
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHRAV_R.W rd, rt, rs` **MIPSDSP**

Purpose: Shift Right Arithmetic Variable Word with Rounding

Arithmetic right shift with rounding of a signed 32-bit word by a variable number of bits.

Description: $rd \leftarrow rnd32(rt_{31..0} >> rs_{4..0})$

The word value in register *rt* is shifted right, with the value's original sign bit duplicated into the most-significant bits emptied by the shift. A 1 is then added at the most-significant discarded bit position before the result is written to destination register *rd*.

The shift amount *sa* is given by the five least-significant bits of register *rs*; the remaining bits of *rs* are ignored.

Restrictions:

No data-dependent exceptions are possible.

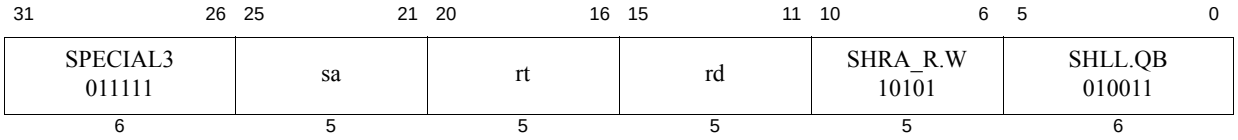
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← rnd32ShiftRightArithmetic( GPR[rt]31..0, GPR[rs]4..0 )
GPR[rd]..0 ← temp31..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHRA_R.W rd, rt, sa` **MIPSDSP**

Purpose: Shift Right Arithmetic Word with Rounding

To execute an arithmetic right shift with rounding on a word by a fixed number of bits.

Description: $rd \leftarrow rnd32(rt_{31:0} >> sa)$

The word in register *rt* is shifted right by *sa* bits, and the sign bit is duplicated into the *sa* bits emptied by the shift. The shifted result is then rounded by adding a 1 bit to the most-significant discarded bit. The rounded result is then written to the destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

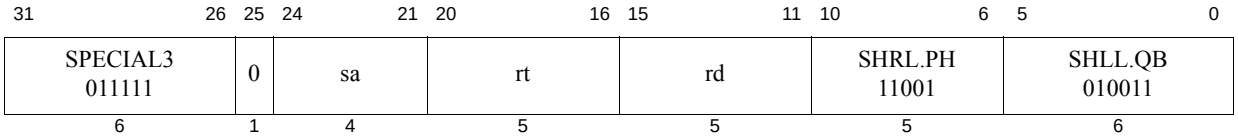
```
temp31..0 ← rnd32ShiftRightArithmetic( GPR[rt]31..0, sa4..0 )
GPR[rd]..0 ← temp32..1

function rnd32ShiftRightArithmetic( a31..0, s4..0 )
   if ( s4..0 = 0 ) then
      temp32..0 ← ( a31..0 || 0 )
   else
      sign ← a31
      temp32..0 ← ( signs || a31..s-1 )
   endif
   temp32..0 ← temp + 1
   return temp32..1
endfunction rnd32ShiftRightArithmetic
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

To do an arithmetic right shift of a word in a register without rounding, use the SRA instruction.



Format: `SHRL.PH rd, rt, sa` **MIPSDSP-R2**

Purpose: Shift Right Logical Two Halfwords

To execute a right shift of two independent halfwords in a vector data type by a fixed number of bits.

Description: $rd \leftarrow (rt_{31..16} >> sa) \mid\mid (rt_{15..0} >> sa)$

The two halfwords in register *rt* are independently logically shifted right, inserting zeros into the bit positions emptied by the shift. The two halfword results are then written to the corresponding halfword elements in destination register *rd*.

The shift amount is provided by the *sa* field, which is interpreted as a four bit unsigned integer taking values between 0 and 15.

Restrictions:

No data-dependent exceptions are possible.

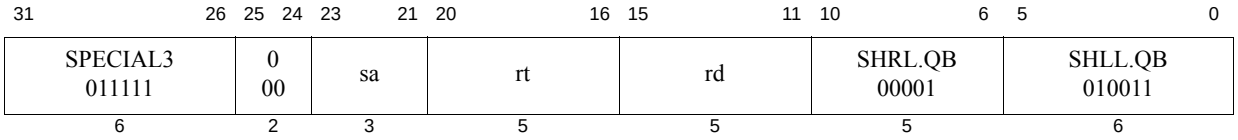
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempB15..0 ← 0^sa || GPR[rt]31..sa+16
tempA15..0 ← 0^sa || GPR[rt]15..sa
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHRL.QB rd, rt, sa` **MIPSDSP**

Purpose: Shift Right Logical Vector Quad Bytes

Element-wise logical right shift of four independent bytes in a vector data type by a fixed number of bits.

Description: $rd \leftarrow rt_{31..24} >> sa) \;||\; (rt_{23..16} >> sa) \;||\; (rt_{15..8} >> sa) \;||\; (rt_{7..0} >> sa)$

The four byte values in register *rt* are each independently shifted right by *sa* bits and the *sa* most-significant bits of each value are set to zero. The four independent results are then written to the corresponding byte elements of destination register *rd*.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

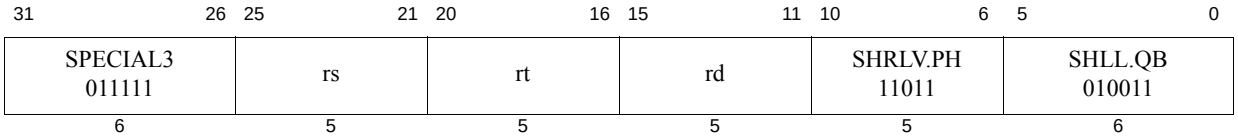
```
tempD7..0 ← shift8Right( GPR[rt]31..24, sa )
tempC7..0 ← shift8Right( GPR[rt]23..16, sa )
tempB7..0 ← shift8Right( GPR[rt]15..8, sa )
tempA7..0 ← shift8Right( GPR[rt]7..0, sa )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function shift8Right( a7..0, s2..0 )
    if ( s2..0 = 0 ) then
        temp7..0 ← a7..0
    else
        temp7..0 ← ( 0^s || a7..s )
    endif
    return temp7..0
endfunction shift8Right
```

Exceptions:

Reserved Instruction, DSP Disabled

Programming Notes:

To do a logical left shift of a word in a register without saturation, use the SLL instruction.



Format: `SHRLV.PH rd, rt, rs` **MIPSDSP-R2**

Purpose: Shift Variable Right Logical Pair of Halfwords

To execute a right shift of two independent halfwords in a vector data type by a variable number of bits.

Description: $rd \leftarrow (rt_{31..16} >> rs_{3..0}) \;||\; (rt_{15..0} >> rs_{3..0})$

The two halfwords in register *rt* are independently logically shifted right, inserting zeros into the bit positions emptied by the shift. The two halfword results are then written to the corresponding halfword elements in destination register *rd*.

The shift amount is provided by the four least-significant bits of register *rs*, which is interpreted as a four bit unsigned integer taking values between 0 and 15. The remaining bits of *rs* are ignored.

Restrictions:

No data-dependent exceptions are possible.

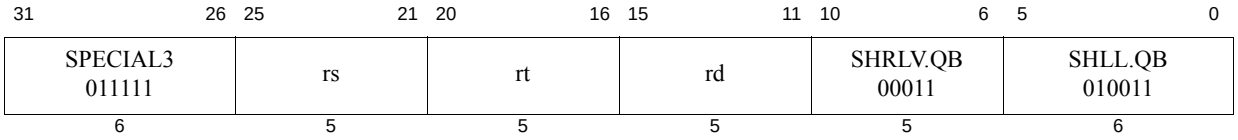
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
sa3..0 ← GPR[rs]3..0
tempB15..0 ← 0^sa || GPR[rt]31..sa+16
tempA15..0 ← 0^sa || GPR[rt]15..sa
GPR[rd]..0 ← tempB15..0 || tempA15..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SHRLV.QB rd, rt, rs` **MIPSDSP**

Purpose: Shift Right Logical Variable Vector Quad Bytes

Element-wise logical right shift of four independent bytes in a vector data type by a variable number of bits.

Description: $rd \leftarrow (rt_{31..24} >> rs_{2..0}) \,||\, (rt_{23..16} >> rs_{2..0}) \,||\, (rt_{15..8} >> rs_{2..0}) \,||\, (rt_{7..0} >> rs_{2..0})$

The four byte values in register *rt* are each independently shifted right, inserting zeros into the most-significant bit positions emptied by the shift. The four independent results are then written to the corresponding byte elements of destination register *rd*.

The three least-significant bits of *rs* provide the shift value, interpreted as an unsigned integer; the remaining bits of *rs* are ignored.

Restrictions:

No data-dependent exceptions are possible.

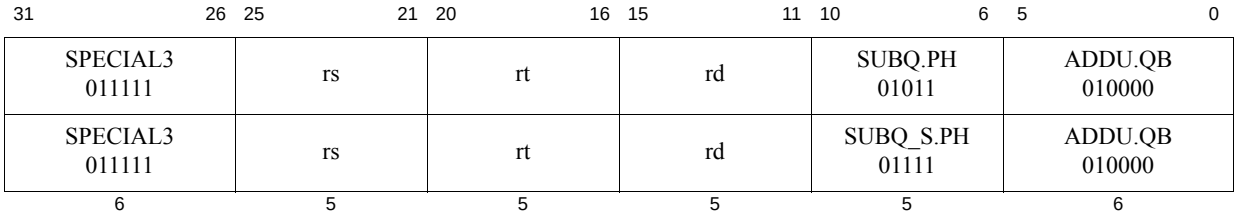
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
tempD7..0 ← shift8Right( GPR[rt]31..24, GPR[rs]2..0 )
tempC7..0 ← shift8Right( GPR[rt]23..16, GPR[rs]2..0 )
tempB7..0 ← shift8Right( GPR[rt]15..8, GPR[rs]2..0 )
tempA7..0 ← shift8Right( GPR[rt]7..0, GPR[rs]2..0 )
GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SUBQ.PH 01011	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	SUBQ_S.PH 01111	ADDU.QB 010000
6	5	5	5	5	6

Format: `SUBQ[_S].PH`

`SUBQ.PH rd, rs, rt` **MIPSDSP**

`SUBQ_S.PH rd, rs, rt` **MIPSDSP**

Purpose: Subtract Fractional Halfword Vector

Element-wise subtraction of one vector of Q15 fractional halfword values from another to produce a vector of Q15 fractional halfword results, with optional saturation.

Description: $rd \leftarrow sat16(rs_{31..16} - rt_{31..16}) \ || \ sat16(rs_{15..0} - rt_{15..0})$

The two fractional halfwords in register *rt* are subtracted from the corresponding fractional halfword elements in register *rs*.

For the non-saturating version of this instruction, each result is written to the corresponding element in register *rd*. In the case of overflow or underflow, the result modulo 2 is written to register *rd*.

For the saturating version of the instruction, the subtraction is performed using signed saturating arithmetic. If the operation results in an overflow or an underflow, the result is clamped to either the largest representable value (0x7FFF hexadecimal) or the smallest representable value (0x8000 hexadecimal), respectively, before being written to the destination register *rd*.

For both instructions, if any of the individual subtractions result in underflow, overflow, or saturation, a 1 is written to bit 20 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

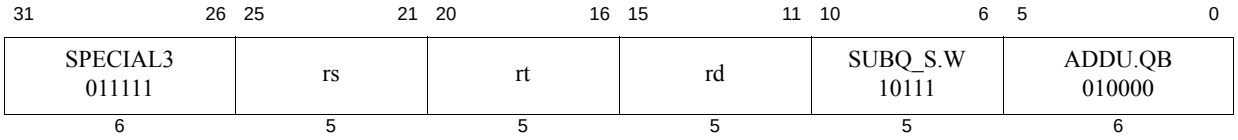
Operation:

```
SUBQ.PH:
    tempB15..0 ← subtract16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← subtract16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

SUBQ_S.PH:
    tempB15..0 ← sat16Subtract( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← sat16Subtract( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function subtract16( a15..0, b15..0 )
    temp16..0 ← ( a15 || a15..0 ) - ( b15 || b15..0 )
    if ( temp16 ≠ temp15 ) then
        DSPControlouflag:20 ← 1
    endif
    return temp15..0
endfunction subtract16
```

```
function sat16Subtract( a15..0, b15..0 )
   temp16..0 ← ( a15 || a15..0 ) - ( b15|| b15..0 )
   if ( temp16 ≠ temp15 ) then
      if ( temp16 = 0 ) then
         temp ← 0x7FFF
      else
         temp ← 0x8000
      endif
      DSPControlouflag:20 ← 1
   endif
   return temp15..0
endfunction sat16Subtract
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `SUBQ_S.W rd, rs, rt` **MIPSDSP**

Purpose: Subtract Fractional Word

One Q31 fractional word is subtracted from another to produce a Q31 fractional result, with saturation.

Description: $rd \leftarrow sat32(rs_{31..0} - rt_{31..0})$

The Q31 fractional word in register *rt* is subtracted from the corresponding fractional word in register *rs*, and the 32-bit result is written to destination register *rd*. The subtraction is performed using signed saturating arithmetic. If the operation results in an overflow or an underflow, the result is clamped to either the largest representable value (0x7FFFFFFF hexadecimal) or the smallest representable value (0x80000000 hexadecimal), respectively, before being sign-extended and written to the destination register *rd*.

If the subtraction results in underflow, overflow, or saturation, a 1 is written to bit 20 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

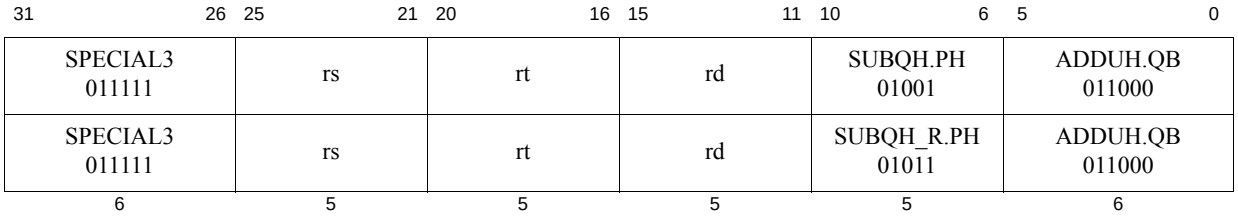
The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
temp31..0 ← sat32Subtract( GPR[rs]31..0 , GPR[rt]31..0 )
GPR[rd]..0 ← temp31..0

function sat32Subtract( a31..0, b31..0 )
   temp32..0 ← ( a31 || a31..0 ) - ( b31 || b31..0 )
   if ( temp32 ≠ temp31) then
      if ( temp32 = 0 ) then
         temp31..0 ← 0x7FFFFFFF
      else
         temp31..0 ← 0x80000000
      endif
      DSPControlouflag:20 ← 1
   endif
   return temp31..0
endfunction sat32Subtract
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SUBQH.PH 01001	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	SUBQH_R.PH 01011	ADDUH.QB 011000
6	5	5	5	5	6

Format: `SUBQH[_R].PH`

`SUBQH.PH rd, rs, rt` **MIPSDSP-R2**

`SUBQH_R.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Subtract Fractional Halfword Vectors And Shift Right to Halve Results

Element-wise fractional subtraction of halfword vectors, with a right shift by one bit to halve each result, with optional rounding.

Description: $rd \leftarrow round((rs_{31..16} - rt_{31..16}) >> 1) \,||\, round((rs_{15..0} - rt_{15..0}) >> 1)$

Each element from the two halfword values in register *rt* is subtracted from the corresponding halfword element in register *rs* to create an interim 17-bit result.

In the non-rounding instruction variant, each interim result is then shifted right by one bit before being written to the corresponding halfword element of destination register *rd*.

In the rounding version of the instruction, a value of 1 is added at the least-significant bit position of each interim result; the interim result is then right-shifted by one bit and written to the destination register.

This instruction does not modify the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

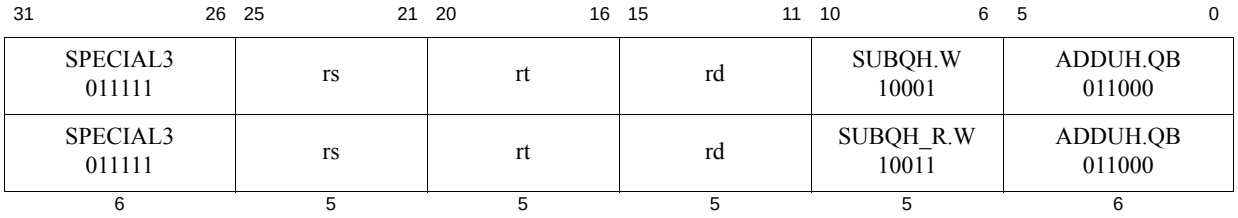
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
ADDQH.PH
    tempB15..0 ← rightShift1SubQ16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← rightShift1SubQ16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

ADDQH_R.PH
    tempB15..0 ← roundRightShift1SubQ16( GPR[rs]31..16 , GPR[rt]31..16 )
    tempA15..0 ← roundRightShift1SubQ16( GPR[rs]15..0 , GPR[rt]15..0 )
    GPR[rd]..0 ← tempB15..0 || tempA15..0

function rightShift1SubQ16( a15..0 , b15..0 )
    temp16..0 ← (( a15 || a15..0 ) - ( b15 || b15..0 ))
    return temp16..1
endfunction rightShift1SubQ16

function roundRightShift1SubQ16( a15..0 , b15..0 )
    temp16..0 ← (( a15 || a15..0 ) - ( b15 || b15..0 ))
    temp16..0 ← temp16..0 + 1
    return temp16..1
endfunction roundRightShift1SubQ16
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SUBQH.W 10001	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	SUBQH_R.W 10011	ADDUH.QB 011000
6	5	5	5	5	6

Format: `SUBQH[_R].W`

`SUBQH.W rd, rs, rt` **MIPSDSP-R2**

`SUBQH_R.W rd, rs, rt` **MIPSDSP-R2**

Purpose: Subtract Fractional Words And Shift Right to Halve Results

Fractional subtraction of word vectors, with a right shift by one bit to halve the result, with optional rounding.

Description: `rd ← round((rs`$_{31..0}$ `- rt`$_{31..0}$`) >> 1)`

The word in register *rt* is subtracted from the word in register *rs* to create an interim 33-bit result.

In the non-rounding instruction variant, the interim result is then shifted right by one bit before being written to the destination register *rd*.

In the rounding version of the instruction, a value of 1 is added at the least-significant bit position of the interim result; the interim result is then right-shifted by one bit and written to the destination register.

This instruction does not modify the *DSPControl* register.

Restrictions:

No data-dependent exceptions are possible.

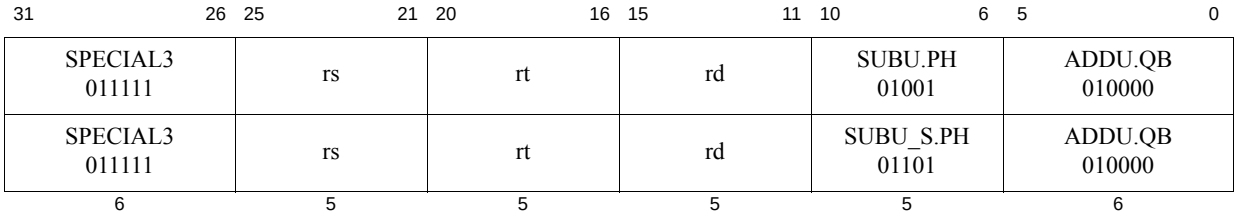
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
ADDQH.W
    tempA31..0 ← rightShift1SubQ32( GPR[rs]31..0 , GPR[rt]31..0 )
    GPR[rd]..0 ← tempA31..0

ADDQH_R.W
    tempA31..0 ← roundRightShift1SubQ32( GPR[rs]31..0 , GPR[rt]31..0 )
    GPR[rd]..0 ← tempA31..0

function rightShift1SubQ32( a31..0 , b31..0 )
    temp32..0 ← (( a31 || a31..0 ) - ( b31 || b31..0 ))
    return temp32..1
endfunction rightShift1SubQ32

function roundRightShifttSubQ32( a31..0 , b31..0 )
    temp32..0 ← (( a31 || a31..0 ) - ( b31 || b31..0 ))
    temp32..0 ← temp32..0 + 1
    return temp32..1
endfunction roundRightShift1SubQ32
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SUBU.PH 01001	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	SUBU_S.PH 01101	ADDU.QB 010000
6	5	5	5	5	6

Format: `SUBU[_S].PH`

`SUBU.PH rd, rs, rt` **MIPSDSP-R2**

`SUBU_S.PH rd, rs, rt` **MIPSDSP-R2**

Purpose: Subtract Unsigned Integer Halfwords

Element-wise subtraction of pairs of unsigned integer halfwords, with optional saturation.

Description: $rd \leftarrow sat16(rs_{31..16} - rt_{31..16}) \,||\, sat16(rs_{15..0} - rt_{15..0})$

The two unsigned integer halfwords in register *rs* are subtracted from the corresponding unsigned integer halfwords in register *rt*. The unsigned results are then written to the corresponding element in destination register *rd*.

In the saturating version of the instruction, if either subtraction results in an underflow the result is clamped to the minimum unsigned integer halfword value (0x0000 hexadecimal), before being written to the destination register *rd*.

For both instruction variants, if either subtraction causes an underflow the instruction writes a 1 to bit 20 in the *DSPControl* register in the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

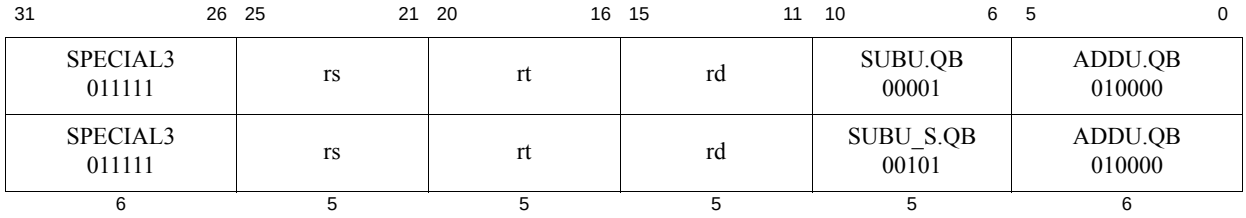
Operation:

```
SUBU.PH
   tempB15..0 ← subtractU16U16( GPR[rt]31..16 , GPR[rs]31..16 )
   tempA15..0 ← subtractU16U16( GPR[rt]15..0 , GPR[rs]15..0 )
   GPR[rd]..0 ← tempB15..0 || tempA15..0

SUBU_S.PH
   tempB15..0 ← satU16SubtractU16U16( GPR[rt]31..16 , GPR[rs]31..16 )
   tempA15..0 ← satU16SubtractU16U16( GPR[rt]15..0 , GPR[rs]15..0 )
   GPR[rd]..0 ← tempB15..0 || tempA15..0

function subtractU16U16( a15..0, b15..0 )
   temp16..0 ← ( 0 || a15..0 ) - ( 0 || b15..0 )
   if ( temp16 = 1 ) then
      DSPControlouflag:20 ← 1
   endif
   return temp15..0
endfunction subtractU16U16

function satU16SubtractU16U16( a15..0, b15..0 )
   temp16..0 ← ( 0 || a15..0 ) - ( 0 || b15..0 )
   if ( temp16 = 1 ) then
      temp15..0 ← 0x0000
      DSPControlouflag:20 ← 1
```

```
        endif
        return temp15..0
    endfunction satU16SubtractU16U16
```

Exceptions:

Reserved Instruction, DSP Disabled



31–26	25–21	20–16	15–11	10–6	5–0
SPECIAL3 011111	rs	rt	rd	SUBU.QB 00001	ADDU.QB 010000
SPECIAL3 011111	rs	rt	rd	SUBU_S.QB 00101	ADDU.QB 010000
6	5	5	5	5	6

Format: `SUBU[_S].QB`

`SUBU.QB rd, rs, rt` **MIPSDSP**

`SUBU_S.QB rd, rs, rt` **MIPSDSP**

Purpose: Subtract Unsigned Quad Byte Vector

Element-wise subtraction of one vector of unsigned byte values from another to produce a vector of unsigned byte results, with optional saturation.

Description: $rd \leftarrow sat8(rs_{31..24} - rt_{31..24}) \,||\, sat8(rs_{23..16} - rt_{23..16}) \,||\, sat8(rs_{15..8} - rt_{15..8}) \,||\, sat8(rs_{7..0} - rt_{7..0})$

The four byte elements in *rt* are subtracted from the corresponding byte elements in register *rs*.

For the non-saturating version of the instruction, the result modulo 256 is written into the corresponding position in register *rd*.

For the saturating version of the instruction the subtraction is performed using unsigned saturating arithmetic. If the subtraction results in underflow, the value is clamped to the smallest representable value (0 decimal, 0x00 hexadecimal) before being written to the destination register *rd*.

For each instruction, if any of the individual subtractions result in underflow or saturation, a 1 is written to bit 20 in the *DSPControl* register within the *ouflag* field.

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

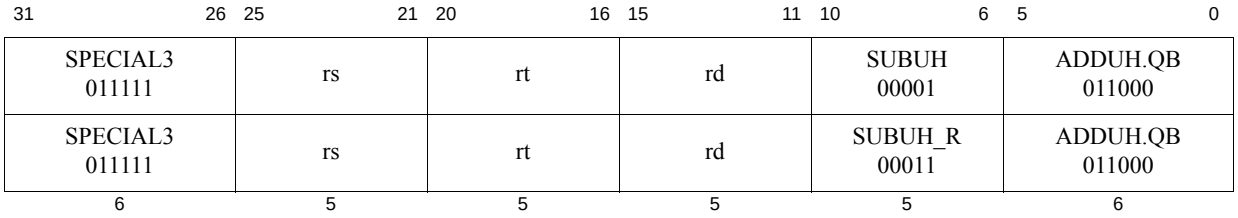
Operation:

```
SUBU.QB:
    tempD7..0 ← subtractU8( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← subtractU8( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← subtractU8( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← subtractU8( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

SUBU_S.QB:
    tempD7..0 ← satU8Subtract( GPR[rs]31..24 , GPR[rt]31..24 )
    tempC7..0 ← satU8Subtract( GPR[rs]23..16 , GPR[rt]23..16 )
    tempB7..0 ← satU8Subtract( GPR[rs]15..8 , GPR[rt]15..8 )
    tempA7..0 ← satU8Subtract( GPR[rs]7..0 , GPR[rt]7..0 )
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

function subtractU8( a7..0, b7..0 )
    temp8..0 ← ( 0 || a7..0 ) - ( 0 || b7..0 )
    if ( temp8 = 1 ) then
        DSPControlouflag:20 ← 1
```

```
    endif
    return temp7..0
endfunction subtractU8

function satU8Subtract( a7..0, b7..0 )
    temp8..0 ← ( 0 || a7..0 ) - ( 0 || b7..0 )
    if ( temp8 = 1 ) then
        temp7..0 ← 0x00
        DSPControlouflag:20 ← 1
    endif
    return temp7..0
endfunction satU8Subtract
```

Exceptions:

Reserved Instruction, DSP Disabled



31 26	25 21	20 16	15 11	10 6	5 0
SPECIAL3 011111	rs	rt	rd	SUBUH 00001	ADDUH.QB 011000
SPECIAL3 011111	rs	rt	rd	SUBUH_R 00011	ADDUH.QB 011000
6	5	5	5	5	6

Format: `SUBUH[_R].QB`

`SUBUH.QB rd, rs, rt` **MIPSDSP-R2**

`SUBUH_R.QB rd, rs, rt` **MIPSDSP-R2**

Purpose: Subtract Unsigned Bytes And Right Shift to Halve Results

Element-wise subtraction of two vectors of unsigned bytes, with a one-bit right shift to halve results and optional rounding.

Description: `rd ← round((rs`$_{31..24}$ `- rt`$_{31..24}$`)>>1) || round((rs`$_{23..16}$ `- rt`$_{23..16}$`)>>1) || round((rs`$_{15..8}$ `- rt`$_{15..8}$`)>>1) || round((rs`$_{7..0}$ `- rt`$_{7..0}$`)>>1)`

The four unsigned byte values in register *rt* are subtracted from the corresponding unsigned byte values in register *rs*. Each unsigned result is then halved by shifting right by one bit position. The byte results are then written to the corresponding elements of destination register *rd*.

In the rounding variant of the instruction, a value of 1 is added to the result of each subtraction at the discarded bit position before the right shift.

The results of this instruction never overflow; no bits of the *ouflag* field in the *DSPControl* register are written.

Restrictions:

No data-dependent exceptions are possible.

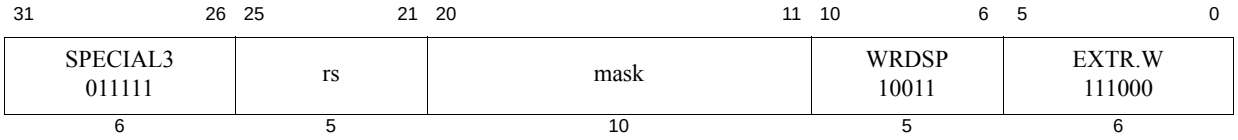
The operands must be a value in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
SUBUH.QB
    tempD7..0 ← ( ( 0 || GPR[rs]31..24 ) - ( 0 || GPR[rt]31..24 )) >> 1
    tempC7..0 ← ( ( 0 || GPR[rs]23..16 ) - ( 0 || GPR[rt]23..16 )) >> 1
    tempB7..0 ← ( ( 0 || GPR[rs]15..8 ) - ( 0 || GPR[rt]15..8 )) >> 1
    tempA7..0 ← ( ( 0 || GPR[rs]7..0 ) - ( 0 || GPR[rt]7..0 )) >> 1
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0

SUBUH_R.QB
    tempD7..0 ← ( ( 0 || GPR[rs]31..24 ) - ( 0 || GPR[rt]31..24 ) + 1) >> 1
    tempC7..0 ← ( ( 0 || GPR[rs]23..16 ) - ( 0 || GPR[rt]23..16 ) + 1) >> 1
    tempB7..0 ← ( ( 0 || GPR[rs]15..8 ) - ( 0 || GPR[rt]15..8 ) + 1) >> 1
    tempA7..0 ← ( ( 0 || GPR[rs]7..0 ) - ( 0 || GPR[rt]7..0 ) + 1) >> 1
    GPR[rd]..0 ← tempD7..0 || tempC7..0 || tempB7..0 || tempA7..0
```

Exceptions:

Reserved Instruction, DSP Disabled



Format: `WRDSP`
`WRDSP rs, mask` **MIPSDSP**
`WRDSP rs` **Assembly Idiom**

Purpose: Write Fields to DSPControl Register from a GPR

To copy selected fields from the specified GPR to the special-purpose DSPControl register.

Description: `DSPControl ← select(mask, GPR[rs])`

Selected fields in the special register *DSPControl* are overwritten with the corresponding bits from the source GPR *rs*. Each of bits 0 through 5 of the *mask* operand corresponds to a specific field in the *DSPControl* register. A mask bit value of 1 indicates that the field will be overwritten using the bits from the same bit positions in register *rs*, and a mask bit value of 0 indicates that the corresponding field will be unchanged. Bits 6 through 9 of the *mask* operand are ignored.

The table below shows the correspondence between the bits in the *mask* operand and the fields in the *DSPControl* register; mask bit 0 is the least-significant bit in *mask*.

For example, to overwrite only the scount field in *DSPControl*, the value of the *mask* operand used will be 2 decimal (0x02 hexadecimal). After execution of the instruction, the scount field in *DSPControl* will have the value of bits 7 through 12 of the specified source register *rs* and the remaining bits in *DSPControl* are unmodified.

The one-operand version of the instructi on provides a convenient assembly idiom that allows the programmer to write all the allowable fields in the *DSPControl* register from the source GPR, i.e., it is equivalent to specifying a *mask* value of 31 decimal (0x1F hexadecimal).

Restrictions:

No data-dependent exceptions are possible.

The operands must be values in the specified format. If they are not, the results are **UNPREDICTABLE** and the values of the operand vectors become **UNPREDICTABLE**.

Operation:

```
newbits31..0 ← 032
overwrite31..0 ← 0xFFFFFFFF
if ( mask0 = 1 ) then
   overwrite..0 ← 0
   newbits..0 ← GPR[rs]..0
endif
if ( mask1 = 1 ) then
   overwrite12..7 ← 06
   newbits12..7 ← GPR[rs]12..7
endif
if ( mask2 = 1 ) then
   overwrite13 ← 0
   newbits13 ← GPR[rs]13
endif
if ( mask3 = 1 ) then
   overwrite23..16 ← 08
```

```
    newbits23..16 ← GPR[rs]23..16
endif
if ( mask4 = 1 ) then
    overwrite31..24 ← 0^8
    newbits31..24 ← GPR[rs]31..24
endif
if ( mask5 = 1 ) then
    overwrite14 ← 0
    newbits14 ← GPR[rs]14
endif

DSPControl ← DSPControl and overwrite31..0
DSPControl ← DSPControl or new31..0
```

Exceptions:

Reserved Instruction, DSP Disabled

Appendix A

Endian-Agnostic Reference to Register Elements

A.1 Using Endian-Agnostic Instruction Names

Certain instructions being proposed in the Module only operate on a subset of the operands in the register. In most cases, this is simply the left (**L**) or right (**R**) half of the register. Some instructions refer to the left alternating (**LA**) or right alternating (**RA**) elements of the register. But this type of reference does not take the endian-ness of the processor and memory into account. Since the DSP Module instructions do not take the endian-ness into account and simply use the left or right part of the register, this section describes a method by which users can take advantage of user-defined macros to translate the given instruction to the appropriate one for a given processor endian-ness.

An example is given below that uses actual element numbers in the mnemonics to be endian-agnostic.

In the MIPS32 architecture, the following conventions could be used:

- PH0 refers to halfword element 0 (from a pair in the specified register).
- PH1 refers to halfword element 1.
- QB01 refers to byte elements 0 and 1 (from a quad in the specified register).
- QB23 refers to byte elements 2 and 3.
- QB02 refers to (even) byte elements 0 and 2.
- QB13 refers to (odd) byte elements 1 and 3.

The even and odd subsets are mainly used in storing, computing on, and loading complex numbers that have a real and imaginary part. If the real and imaginary parts of a complex number are stored in consecutive memory locations, then computations that involve only the real or only the imaginary parts must first extract these to a different register. This can most effectively be done using the even and odd formats of the relevant operations.

Note that these mnemonics are translated by the assembler to underlying real instructions that operate on absolute element positions in the register based on the endian-ness of the processor.

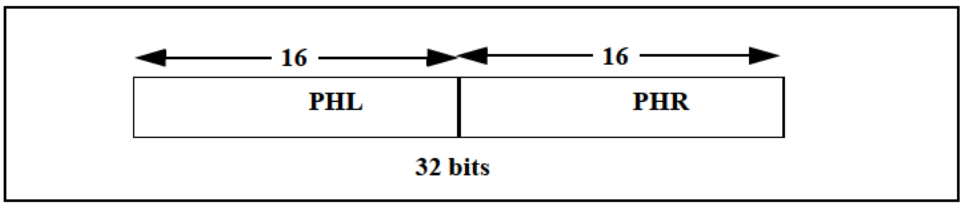
A.2 Mapping Endian-Agnostic Instruction Names to DSP Module Instructions

To illustrate this process, we will use one instruction as an example. This can be repeated for all the relevant instructions in the Module.

The **MULEQ_S** instruction multiplies fractional data operands to expanded full-size results in a destination register with optional saturation. Since the result occupies twice the width of the input operands, only half the operands from the source registers are operated on at a time. So the complete instruction mnemonic would be given as

MULEQ_S.W.PH0 rd, rs, rt where the second part (after the first dot) indicates the size of the result, and the third part (after the second dot) indicates the element of the source register being used, which in this example is the 0^{th} element. The real instructions that the hardware implements are **MULEQ_S.W.PHL** and **MULEQ_S.W.PHR** which operate on the left halfword element and the right halfword element respectively, of the given source registers, as shown in Figure A.1. The user can map the user instruction (with **.PH0**) to the **MULEQ_S.W.PHL** real instruction if the processor is big-endian or to the real instruction **MULEQ_S.W.PHR** if the processor is little-endian.

Figure A.1 The Endian-Independent PHL and PHR Elements in a GPR for the MIPS32 Architecture



Then **MULEQ_S.W.PH1 rd, rs, rt** instruction can be mapped to **MULEQ_S.W.PHR** if the processor is big-endian (see Figure A.2), and to **MULEQ_S.W.PHL** real instruction if the processor is little-endian (see Figure A.3).

Figure A.2 The Big-Endian PH0 and PH1 Elements in a GPR for the MIPS32 Architecture

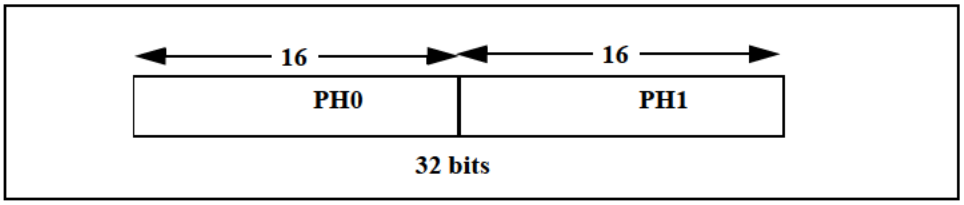
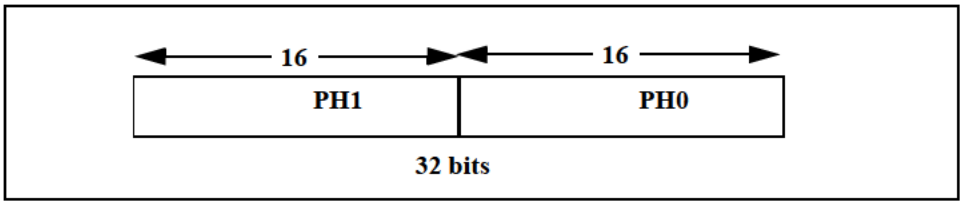


Figure A.3 The Little-Endian PH0 and PH1 Elements in a GPR for the MIPS32 Architecture



To specify the even and odd type operations, a user instruction (to use odd elements) such as **PRECEQ_S.PH.QB02** (which precision expands the values) would be mapped to **PRECEQ_S.PH.QBLA** or **PRECEQ_S.PH.QBRA** depending on whether the endian-ness of the processor was big or little, respectively. (**LA** stands for left-alternating and **RA** for right-alternating).

Figure A.4 The Endian-Independent QBL and QBR Elements in a GPR for the MIPS32 Architecture

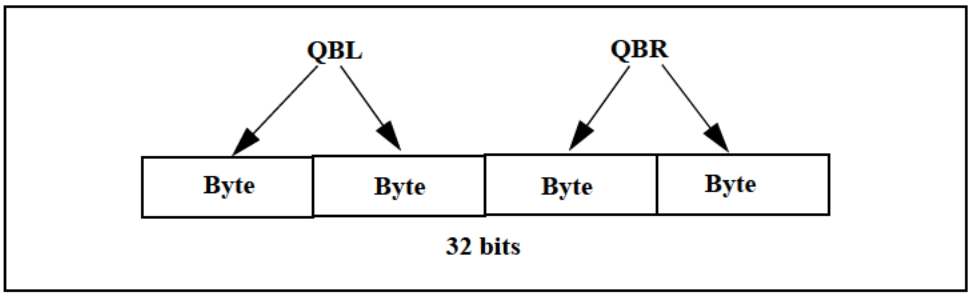
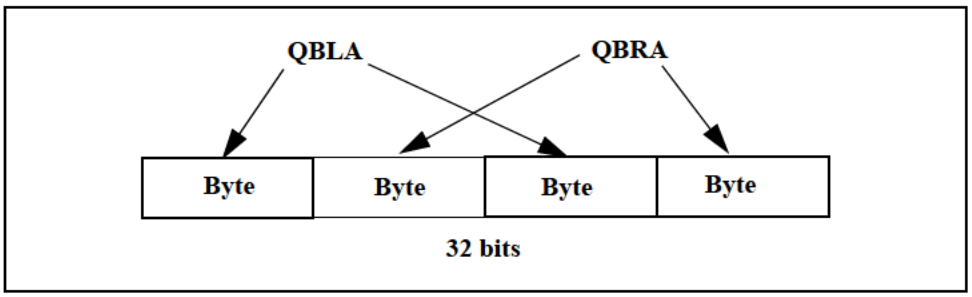


Figure A.5 The Endian-Independent QBLA and QBRA Elements in a GPR for the MIPS32 Architecture



Appendix B

Revision History

Vertical change bars in the left page margin note the location of changes to this document since its last release.

NOTE: Change bars on figure titles are used to denote a potential change in the figure itself.

Version	Date	Comments
1.00	6 July, 2005	Initial revision
1.10	30 January, 2006	Typographical fixes.
2.00	12 January, 2007	Added the DSP Module Rev2 instructions to the specification and related material.
2.10	18 May, 2007	Allow MADD, MADDU, MSUB, MSUBU, MULT, and MULTU that access ac1-ac3 to be in the DSP Module (Revision 1) version. Fix typographical errors.
2.20	July 15, 2008	• Update copyrights. • Update contact information.
2.21	January 02, 2009	• EXTR.W, EXTR_R.W, EXTR_RS.W, EXTRV.W, EXTRV_R.W and EXTRV_RS.W all set DSPControl_ouflag for overflow/saturation, even for intermediate values.
2.22	January 06, 2009	• SHRA[_R].* Operation description was incorrectly not using the rounded intermediate values. • PRECRQU_S* instructions set bit 22 in DSPControl if clamping occurred. • DPAQX_S.W.PH, PDAQX_SA.W.PH, DPSQX_S.W.PH, DPSQX_SA.W.PH were incorrectly marked DSP Module Rev1 instructions, actually Rev2 instructions.
2.23	June 26, 2009	• MADD, MADDU, MSUB, MSUBU, MULT and MULTU description pages listed these as Rev2 DSPASE, when they were actually included in Rev1.
2.24	September 03, 2009	• No content change. Rev 2.23 was generated with incorrect script parameters.
2.25	April 06, 2010	• Title change to match microMIPS32/64 and updated MIPS32/64 base ISA document sets. • microMIPS mentioned in “About This Book” chapter. • Got rid of blank page.
2.30	October 20, 2010	• Some clean-up for microMIPS version. Those edits are not visible for MIPS32/64 versions.
2.31	March 20, 2011	• Reclassification of microMIPS AFP version. No changes for MIPS32/64.
2.32	March 21,2011	• Edit for microMIPS. No changes for MIPS32/64.
2.33	April 23,2011	• Remove the x fields in the instruction encoding diagrams. Replace them with explicit binary values. • MUL.PH & MUL_S.PH had wrong minor opcode mnemonic string in the instruction description page. Binary value was correct. • EXTR.W and EXTRV.W pseudocode – comparison checks are for 33bit values not 32bit values. • PRECR_SRA[_R].PH.W, PRECR_SRA[_R]~~.QH~~.PW not listed as DSPRev2 in Summary.

Version	Date	Comments
2.34	May 6, 2011	• SPECIAL3 SHLL.QB instruction sub-class opcode changed from SLL.QB to SHLL.QB. • SPECIAL3 DPAQ.W.PH instruction sub-class name changed to DPA.W.PH • SHRA_R.W with shift amount 0 does not round – changed the pseudocode and created a new function, `rnd32ShiftRightArithmetic()`, which is shared with SHRAV_R.W. • SHRAV_R.W does not operate element-wise and the rounding is not optional – changed the description accordingly. • Pseudocode functions `shift16Left()`, `sat16ShiftLeft()`, and `sat32ShiftLeft()` fixed to show the correct discarded bits. • Pseudocode function `shift8Left()` fixed to handle unsigned bytes and to show the correct discarded bits. • MULQ_[R]S instructions' pseodocode fixed to use a 64-bit temporary for the overflow condition. • Added a new pseudocode function for MUL.PH to set *DSPControl* bit 21 in case of overflow. • Changed pseudocode function `sat16MultiplyQ15Q15()` to set *DSPControl* bit 21 in case of overflow. • Added a new pseudocode function for MULEQ_S.W.PHL and MULEQ_S.W.PHR to set *DSPControl* bit 21 in case of overflow. • MODSUB pseudocode changed to use all 32 bits of source register. • Resorted some of the instructions in alphabetical order.
2.40	December 16, 2012	• DSP ASE -> DSP Module • Updated logos on Cover • Updated copyright text
2.41	July 16, 2013	• New cover page and legal text.
3.00	November 7, 2014	• Release 6 new BPOSGE32C instruction.
3.01	December 15, 2014	• New BPOSGE32C instruction • Modified Section 3.10 to note changes due to Release 6 of MIPS Architecture • Modified Section 3.2 and 3.11 to note detection of Rev 3.0. • Removed DSP3P references