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# Programming Model

## General Registers

There are 256 general purpose registers. General purpose registers are 64 bits wide.

Register #0 is always zero.

**Branch Registers**

The processor contains 16 branch registers (BR0-BR15). Several of branch registers are reserved for special purposes.

|  |  |  |
| --- | --- | --- |
| Reg # |  | Usage |
| 0 | Always Zero |  |
| 1 |  | This register is available for general use. |
| 2 |  | This register is available for general use. |
| 3 |  | This register is available for general use. |
| 4 |  | This register is available for general use. |
| 5 |  | This register is available for general use. |
| 6 |  | This register is available for general use. |
| 7 |  | This register is available for general use. |
| 8 |  | This register is available for general use. |
| 9 |  |  |
| 10 |  |  |
| 11 |  |  |
| 12 | Exception Table Pointer | This register points to the exception table in memory. |
| 13 | Exceptioned PC | This register is set when an exception occurs |
| 14 | Interrupted PC | This register is automatically set during a hardware interrupt |
| 15 | Program Counter |  |
|  |  |  |

## Predicates

The processor contains 16 predicate registers each of which hold three flags. These flags are set as the result of a compare operation. The flags represent equality (eq) signed less than (lt) and unsigned less than (ltu). It should be noted that the compare instruction can’t overflow.

|  |  |  |  |
| --- | --- | --- | --- |
| 3 | 2 | 1 | 0 |
| ~ | ltu | lt | eq |

All instructions are executed conditionally determined by the value of a predicate register. The special predicate 00 executes the break vector.

### Predicate Conditions

|  |  |  |  |
| --- | --- | --- | --- |
| Cond. |  | Test |  |
| 0 | PF | 0 | Always false – Instructions predicated with condition zero never execute regardless of the predicate register contents. This is used for extended immediate values as well. |
| 1 | PT | 1 | Always True – The instruction predicated with an always true condition always executes regardless of the predicate register contents. |
| 2 | PEQ | eq | Equal – instruction executes if the predicate register equal flag is set |
| 3 | PNE | !eq | Not Equal – instruction executes if the predicate register equal flag is clear |
| 4 | PLE | lt|eq | Less or Equal – predicate less or equal flag is set |
| 5 | PGT | !(lt|eq) | greater than |
| 6 | PGE | !lt | greater or equal |
| 7 | PLT | lt | less than |
| 8 | PLEU | ltu|eq | unsigned less or equal |
| 9 | PGTU | !(ltu|eq) | unsigned greater than |
| 10 | PGEU | !ltu | unsigned greater or equal |
| 11 | PLTU | ltu | unsigned less than |
|  |  |  |  |

## Instruction Formats

Instructions vary in length from one to eight bytes. There are only a couple of single byte instructions consisting of only a predicate.

All instruction sequences begin with a predicate byte that determines the conditions under which the instruction executes. With the exception of special predicate values, the next field in the instruction is always the opcode byte. All opcodes may be preceded by an extended constant value.

### RR - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | Opcode8 | Pn4 | Pc4 |

### RI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | Opcode8 | Pn4 | Pc4 |

### CMP Register-Register Compare

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 12 | 11 8 | 7 0 | |
| Rb | Ra | Opc | Pt | Predicate | |
| Rb8 | Ra8 | 14 | Pt4 | Pn4 | Pc4 |

### CMPI Register-Immediate Compare

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 31 24 | | 23 16 | | 15 12 | | 11 8 | | 7 0 | |
| Immed | | Ra | | Opc | | Pt | | Predicate | |
| Immed8 | | Ra8 | | 24 | | Pt4 | | Pn4 | Pc4 |
| TST - Register Test Compare | | | | | | | |  | |  | CTRL- Control | | |
| 23 16 | 15 12 | | 11 8 | | 7 0 | | |  | |  | 15 8 | 7 0 | |
| Ra | Opc | | Pt | | Predicate | | |  | |  | Opcode | Predicate | |
| Ra8 | 04 | | Pt4 | | Pn4 | | Pc4 |  | |  | Opcode8 | Pn4 | Pc4 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| BR - Relative Branch | | | |  |  | BRK/NOP | |
| 23 16 | 15 8 | 7 0 | |  |  | 7 0 | |
| Disp. | Opcode | Predicate | |  |  | Predicate | |
| Disp7..0 | Opcode8 | Pn4 | Pc4 |  |  | 0/14 | 04 |

### JSR - Jump To Subroutine

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | Br4 | Brt4 | Opcode8 | Pn4 | Pc4 |

# Instruction Set

### 2ADDU - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 40h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 2 + Rb

#### Description:

Multiply Ra by two and add Rb and place the sum in the target register. This instruction will never cause an overflow exception.

### 2ADDUI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immed | Rb | Ra | Opcode | Predicate | |
| Immed8 | Rb8 | Ra8 | 6Bh8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 2 + immediate

#### Description:

Multiply Ra by two and add immediate and place the sum in the target register. This instruction will never cause an overflow exception.

### 4ADDU - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 57h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 4 + Rb

#### Description:

Multiply Ra by four and add Rb and place the sum in the target register. This instruction will never cause an overflow exception.

### 

### 4ADDUI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immed | Rb | Ra | Opcode | Predicate | |
| Immed8 | Rb8 | Ra8 | 6Ch8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 4 + immediate

#### Description:

Multiply Ra by four and add immediate and place the sum in the target register. This instruction will never cause an overflow exception.

### 8ADDU - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 64h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 8 + Rb

#### Description:

Multiply Ra by eight and add Rb and place the sum in the target register. This instruction will never cause an overflow exception.

### 8ADDUI - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immed | Rb | Ra | Opcode | Predicate | |
| Immed8 | Rb8 | Ra8 | 6Dh8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 8 + immediate

#### Description:

Multiply Ra by eight and add immediate and place the sum in the target register. This instruction will never cause an overflow exception.

### 16ADDU - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 65h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 16 + Rb

#### Description:

Multiply Ra by sixteen and add Rb and place the sum in the target register. This instruction will never cause an overflow exception.

### 16ADDUI - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immed | Rb | Ra | Opcode | Predicate | |
| Immed8 | Rb8 | Ra8 | 6Eh8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra \* 16 + immediate

#### Description:

Multiply Ra by sixteen and add immediate and place the sum in the target register. This instruction will never cause an overflow exception.

### ADD - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 40h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra + Rb

#### Description:

Add two registers and place the sum in the target register. This instruction may cause an overflow exception.

### 

### ADDI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 48h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra + immediate

#### Description:

Add a register and immediate value and place the sum in the target register. This instruction may cause an overflow exception.

### 

### ADDU - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 44h8 | Pn4 | Pc4 |

#### Description:

This instruction will never cause any exceptions.

### ADDUI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 4Ch8 | Pn4 | Pc4 |

### AND - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 50h8 | Pn4 | Pc4 |

### ANDI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 53h8 | Pn4 | Pc4 |

### BR - Relative Branch

|  |  |  |  |
| --- | --- | --- | --- |
| 23 16 | 15 8 | 7 0 | |
| Disp. | Opcode | Predicate | |
| Disp7..0 | A0h8 | Pn4 | Pc4 |

#### Operation:

pc <= pc + displacement

#### Description:

A branch is made relative to the current value of the program counter.

### BRK –Break

|  |  |
| --- | --- |
| 7 0 | |
| Predicate | |
| 04 | 04 |

#### Operation:

<none>

#### Description:

This instruction contains only a predicate byte. The Break exception is executed.

### BSR - Branch To Subroutine

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | 154 | Brt4 | A2h8 | Pn4 | Pc4 |

#### Description:

Normally the BSR instruction is used with an immediate predicate constant in order to extend the address range of the jump. A jump is made to the sum of the sign extended offset supplied in the offset field of the instruction and the specified branch register Br.

The subroutine return address is stored in a branch register specified in the Brt field of the instruction.

### CLI – Clear Interrupt Mask

|  |  |  |
| --- | --- | --- |
| 15 8 | 7 0 | |
| Opcode | Predicate | |
| F0h8 | Pn4 | Pc4 |

#### Operation:

im = 0

#### Description:

This instruction is used to enable interrupts.

### CMP Register-Register Compare

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 12 | 11 8 | 7 0 | |
| Rb | Ra | Opc | Pt | Predicate | |
| Rb8 | Ra8 | 14 | Pt4 | Pn4 | Pc4 |

### CMPI Register-Immediate Compare

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 12 | 11 8 | 7 0 | |
| Immed | Ra | Opc | Pt | Predicate | |
| Immed8 | Ra8 | 24 | Pt4 | Pn4 | Pc4 |

#### Operation:

if signed Ra < signed immediate

P.lt = true

else

P.lt = false

if unsigned Ra < unsigned immediate

P.ltu = true

else

P.ltu = false

if Ra = immediate

P.eq = true

else

P.eq = false

#### Description:

The register immediate compare instruction compares a register to an immediate value and sets the flags in the target predict register as a result.

### EOR - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 52h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra ^ Rb

#### Description:

Logically exclusive or register with register and place result in target register.

### EORI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 55h8 | Pn4 | Pc4 |

### IMM64,IMM56,IMM48,IMM40,IMM32,IMM24,IMM16

### Immediate Extensions

The immediate extension predicates are used to extend the immediate constant of the following instruction. The extensions may add from one to seven bytes more to the constant.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Immediate | | | | | | | Predicate | |
| Immediate63..8 | | | | | | | 84 | 04 |
| Immediate55..8 | | | | | | 74 | 04 |
| Immediate47..8 | | | | | 64 | 04 |
| Immediate39..8 | | | | 54 | 04 |
| Immediate31..8 | | | 44 | 04 |
| Immediate23..8 | | 34 | 04 |
| Immediate15..8 | 24 | 04 |

### INT –Interrupt

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | Ch4 | Eh4 | A5h8 | Pn4 | Pc4 |

#### Description:

This instruction calls a system function located as the sum of the offset times 16 plus branch register 12. The return address is stored in the IPC register (Branch register #14).

The offset field of this instruction cannot be extended.

### JMP - Jump To Address

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | Br4 | 04 | A2h8 | Pn4 | Pc4 |

#### Operation:

pc = Br[n] + offset

#### Description:

This is an alternate mnemonic for the JSR instruction.

Normally the JMP instruction is used with an immediate predicate constant in order to extend the address range of the jump. A jump is made to the sum of the sign extended offset supplied in the offset field of the instruction and the specified branch register Br.

### JSR - Jump To Subroutine Instruction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | Br4 | Brt4 | A2h8 | Pn4 | Pc4 |

#### Operation:

Br[t] = pc

pc = Br[n] + offset

#### Description:

Normally the JSR instruction is used with an immediate predicate constant in order to extend the address range of the jump. A jump is made to the sum of the sign extended offset supplied in the offset field of the instruction and the specified branch register Br.

The subroutine return address is stored in a branch register specified in the Brt field of the instruction.

### LOOP – Loop Branch

|  |  |  |  |
| --- | --- | --- | --- |
| 23 16 | 15 8 | 7 0 | |
| Disp. | Opcode | Predicate | |
| Disp7..0 | A4h8 | Pn4 | Pc4 |

#### Operation:

If lc <> 0

pc <= pc + displacement

lc = lc - 1

#### Description:

A branch is made relative to the current value of the program counter if the loop count register is non-zero. The loop count register is decremented by this instruction.

### MFSPR – Special Register-Register

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Spr | Opcode | Predicate | |
| Rt8 | Spr8 | A8h8 | Pn4 | Pc4 |

#### Operation:

Rt = Spr[n]

#### Special Purpose Registers

|  |  |  |  |
| --- | --- | --- | --- |
| Reg # |  |  |  |
| 0 | MID | Machine ID |  |
| 1 | FEAT | Features |  |
| 2 | TICK | Tick count |  |
| 3 | LC | Loop Counter |  |
| 4 | PREGS | Predicate register array |  |
|  |  |  |  |

### MTSPR –Register-Special Register

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 8 | 7 0 | |
| Spr | Ra | Opcode | Predicate | |
| Spr8 | Ra8 | A9h8 | Pn4 | Pc4 |

#### Operation:

Spr[n] = Ra

### NOP – No Operation

|  |  |
| --- | --- |
| 7 0 | |
| Predicate | |
| 14 | 04 |

#### Operation:

<none>

#### Description:

This instruction contains only a predicate byte.

### OR - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 51h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra | Rb

### ORI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 54h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra | imm

### RTE – Return From Exception Routine

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Br | ~ | Opcode | Predicate | |
| D4 | 04 | A3h8 | Pn4 | Pc4 |

#### Operation**:**

pc = Br[13]

Flags = FlagsBackup

#### Description:

This is a specialized version of the RTS instruction. The program counter is loaded with the value contained in the specified branch register. The register must be branch register #13 (Dh) which is the EPC register.

### RTI – Return From Interrupt Routine

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Br | ~ | Opcode | Predicate | |
| E4 | 04 | A3h8 | Pn4 | Pc4 |

#### Operation:

pc = Br[14]

Flags = FlagsBackup

Flags.im = 0

#### Description:

This is a specialized version of the RTS instruction. The program counter is loaded with the value contained in the specified branch register. The register must be branch register #14 (Eh) which is the IPC register.

### RTS – Return From Subroutine

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Br | ~ | Opcode | Predicate | |
| Br4 | 04 | A3h8 | Pn4 | Pc4 |

#### Operation:

pc = Br[N]

#### **Description**:

The program counter is loaded with the value contained in the specified branch register.

### SEI – Set Interrupt Mask

|  |  |  |
| --- | --- | --- |
| 15 8 | 7 0 | |
| Opcode | Predicate | |
| F1h8 | Pn4 | Pc4 |

#### Operation:

im = 1

### STSB – Store String Byte

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 8 | 7 0 | |
| Rb | Ra | Opcode | Predicate | |
| Rb8 | Ra8 | 9Ah8 | Pn4 | Pc4 |

#### Operation:

If LC <> 0

mem[Ra] = Rb[7:0]

Ra = Ra + 1

LC = LC – 1

### STSW – Store String Word

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 31 24 | 23 16 | 15 8 | 7 0 | |
| Rb | Ra | Opcode | Predicate | |
| Rb8 | Ra8 | 9Ah8 | Pn4 | Pc4 |

#### Operation:

If LC <> 0

mem[Ra] = Rb

Ra = Ra + 8

LC = LC – 1

### SUB - Register-Register

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Rt | Rb | Ra | Opcode | Predicate | |
| Rt8 | Rb8 | Ra8 | 418 | Pn4 | Pc4 |

#### Operation:

Rt = Ra - Rb

#### Description:

This instruction subtracts one register from another and places the result into a third register.

### SUBI - Register-Immediate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 39 32 | 31 24 | 23 16 | 15 8 | 7 0 | |
| Immediate | Rt | Ra | Opcode | Predicate | |
| Immediate7..0 | Rt8 | Ra8 | 49h8 | Pn4 | Pc4 |

#### Operation:

Rt = Ra – Imm

#### Description:

This instruction subtracts an immediate value from a register and places the result into a register.

### SYS –Call system routine

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Disp. | Br | Brt | Opcode | Predicate | |
| Offset7..0 | Ch4 | Dh4 | A5h8 | Pn4 | Pc4 |

#### Description:

This instruction calls a system function located as the sum of the offset times 16 plus branch register 12. The return address is stored in the EPC register (Branch register #13).

### TST - Register Test Compare

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 23 16 | 15 12 | 11 8 | 7 0 | |
| Ra | Opc | Pt | Predicate | |
| Ra8 | 04 | Pt4 | Pn4 | Pc4 |

#### Description:

The register test compare compares a register against the value zero and sets the predicate flags appropriately.