# Schwap CPU Design Documentation

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Winter 2015/2016

## 1 Registers

There are a total of 76 16-bit registers; 12 are fixed and 64 (spilt into 16 groups of 4) "schwapable" registers.

### 1.1 Register Names and Descriptions

| Name | Number | Description | Saved Across Call? |
|---|---|---|---|
| $0 | 0 | The Value 0 | - |
| $pc | 1 | Program Counter | Yes |
| $sp | 2 | Stack Pointer | Yes |
| $ra | 3 | Return Address | Yes |
| $s0 - $s3 | 4 - 7 | User Temporary Saved | Yes |
| $t0 - $t3 | 8 - 11 | User Temporaries | No |
| $h0 - $h3 | 12 - 15 | Schwap | - |

### 1.2 Schwap Registers

The "schwap" registers are registers that appear to be swapped using a command. There is no data movement when schwapping, it only changes which registers the $h0 - $h3 refer to. There are 8 groups the user can switch between and 8 reserved groups. Using "rsh 16" will return to the previous used group.

#### 1.2.1 Schwap Group Numbers, Descriptions, and Uses

| Group Number | ID | Uses | Saved Across Call? |
|---|---|---|---|
| 0 - 7 | 0 - 3 | User Temporaries | No |
| 8 | 0 - 3 | I/O for devices 0 - 3 | - |
| 9 | 0 - 3 | Arguments 0 - 3 | No |
| 10 | 0 - 3 | Return Values 0 - 3 | No |
| 11 | 0 - 3 | System Call Values 0 - 3 | No |
| 12 | 0 - 3 | Kernel Reserved | No |
| 13 | 0 - 3 | Temporary Restore | No |
| 14 | 0 | Exception Cause | No |
| | 1 | Exception Status | No |
| | 2 | EPC | No |
| | 3 | Exception Temporary | No |
| 15 | 0 - 3 | Assembler Temporaries | No |
| 16 | - | Go to the last used group | - |

# 2 Instructions

All instructions are 16-bits. The destination register is also used as a source unless otherwise noted. All offsets are bit shifted left by 1 since all instructions are 2 bytes long.

## 2.1 Instruction Types and Bit Layouts

Instructions can be manually translated by putting the bits for each of the components of the instructions in the places listed by the diagrams for each type. The OP codes, function codes, and types can by found on the ”Core Instructions” (2.2) table. The destination and source are register numbers, which can be found under the ”Register Names and Descriptions” (1.1) table. Schwap group numbers can be found under the ”Schwap Group Numbers, Descriptions, and Uses” (1.2.1) table.

### 2.1.1 A-Type

Used for all ALU operations. It consists of a 4-bit OP code, 4-bit destination, 4-bit source, and a 4-bit function code.

| OP Code | Destination | Source | Func. Code |
|---|---|---|---|
| 15 12 | 11 8 | 7 4 | 3 0 |

### 2.1.2 B-Type

Used for branching. It consists of a 4-bit OP code, 4-bit 1st source, 4-bit 2nd source, and a (signed) 4-bit offset.

| OP Code | Source 0 | Source 1 | Offset |
|---|---|---|---|
| 15 12 | 11 8 | 7 4 | 3 0 |

### 2.1.3 H-Type

Used for schwapping. It consists of a 4-bit OP code, 8 unused bits, and a 5-bit schwap group number.

| OP Code | | Group |
|---|---|---|
| 15 12 | | 4 0 |

### 2.1.4 J-Type

Used for jumping. It consists of a 4-bit OP code, 4-bit source, and an 8-bit (signed) offset.

| OP Code | Source | Offset |
|---|---|---|
| 15 12 | 11 8 | 7 0 |

### 2.1.5 R-Type

Used for reading and writing memory. It consists of a 4-bit OP code, 4-bit destination (not used as a source), 4-bit source, and a 4-bit (unsigned) offset.

| OP Code | Destination | Source | Offset |
|---|---|---|---|
| 15 12 | 11 8 | 7 4 | 3 0 |

### 2.1.6 S-Type

Used for sudo. Only has a 4-bit OP code.

| OP Code | |
|---|---|
| 15 12 | |

## 2.2 Core Instructions

| OP Code | Function Code | Name | Type | Syntax | Meaning | Description |
|---|---|---|---|---|---|---|
| 0x0 and 0x1† | 0x0 | add | A | add [dest], [src]<br>add [dest], [immediate] | dest + = src<br>dest + = immediate | Adds 2 Integers |
| | 0x1 | adu | A | adu [dest], [src]<br>adu [dest], [immediate] | dest + = src<br>dest + = immediate | Adds 2 Unsigned Integers |
| | 0x2 | sub | A | sub [dest], [src]<br>sub [dest], [immediate] | dest − = src<br>dest − = immediate | Subtracts 2 Integers |
| | 0x3 | sbu | A | sbu [dest], [src]<br>sbu [dest], [immediate] | dest − = src<br>dest − = immediate | Subtracts 2 Unsigned Integers |
| | 0x4 | sll | A | sll [dest], [immediate] | dest <<= immediate | Left Logical Bit shift |
| | 0x5 | srl | A | srl [dest], [immediate] | dest >>= immediate | Right Logical Bit shift |
| | 0x6 | sra | A | sra [dest], [immediate] | dest >>>= immediate | Right Arithmetic Bit shift |
| | 0x7 | and | A | and [dest], [src]<br>and [dest], [immediate] | dest & = src<br>dest & = immediate | Ands 2 Values |
| | 0x8 | orr | A | orr [dest], [src]<br>orr [dest], [immediate] | dest ∥ = src<br>dest ∥ = immediate | Ors 2 Values |
| | 0x9 | xor | A | xor [dest], [src]<br>xor [dest], [immediate] | dest ˆ = src<br>dest ˆ = immediate | Xors 2 Values |
| | 0xA | not | A | not [dest], [src]<br>not [dest], [immediate] | dest = ∼src<br>dest = ∼immediate | Bitwise Nots 2 Values |
| | 0xB | tsc | A | tsc [dest], [src]<br>tsc [dest], [immediate] | dest = ∼src + 1<br>dest = ∼immediate + 1 | Converts a number to 2's compliment |
| | 0xF | cpy | A | cpy [dest], [src]<br>cpy [dest], [immediate] | dest = src<br>dest = immediate | Copies a value |
| 0x2 | - | jr | J | jr [regNumber] | PC = regNumber | Sets the PC to the value in the register |
| 0x3 | - | rsh | H | rsh [groupNumber] | - | Sets the schwappable registers to use |
| 0x4 | - | beq | B | beq [src0], [src1], label | - | Branches to the label if src0 == src1 |
| 0x5 | - | bnq | B | bnq [src0], [src1], label | - | Branches to the label if src0 != src1 |
| 0x6 | - | bgt | B | bgt [src0], [src1], label | - | Branches to the label if src0 > src1 |
| 0x7 | - | r | R | r [dest], [src] | - | Moves the value in memory at the address in src into dest |
| 0x8 | - | w | R | w [dest], [src] | - | Moves the value in dest to the address in src in memory |
| 0xF | - | sudo | S | sudo | - | Same as "syscall" in MIPS |

†0x0 is used for instructions which do not use an immediate, 0x1 is used if the instruction does use an immediate

## 2.3 Pseudo Instructions

| Name | Syntax | Actual Code | Description |
|---|---|---|---|
| j | j label | jr [instructionNumber] | Jumps to the instruction at the label by using jr and the instruction number |
| jal | jal label | cpy $ra, $pc<br>j [label] | Stores the return address and then jumps to the label |
| beq | beq [src0], [src1], label | bnq [src0], [src1], Next<br>j label<br>Next: | Branches to the label if src0 == src1† |
| bnq | bnq [src0], [src1], label | beq [src0], [src1], Next<br>j label<br>Next: | Branches to the label if src0 != src1† |
| bgt | bgt [src0], [src1], label | bgt [src0], [src1], Next1<br>j Next2<br>Next1:<br>j label<br>Next2: | Branches to the label if src0 > src1† |

†Will become pseudo instruction iff the branch is more than 7 instructions down and 8 instructions up.

# 3 Examples

## 3.1 Basic Use Examples

### 3.1.1 Loading an immediate into a register

```
ldi $t0, 32     #Loads 32 into t0
```

### 3.1.2 Iteration and Conditionals

This is an example of which will iterate over 4 array elements in memory and add 32 to each of them. It will stop repeating after the 4 elements using beq.

```
        # There is a base memory address for an array in memory at s0
        ldi $t0, 8
        cpy $t1, $0
loop:
        r   $t2, 0($s0)
        add $t2, 32
        w   0($s0), $t2
        add $t1, 2
        beq $t0, $t1, loop
```

### 3.1.3 I/O

To get input:

```
rsh 8           # Switch to the IO schwap
cpy $t0, $h0    # Copy the input from device 0 into t0
```

To give output:

```
rsh 8           # Switch to the IO schwap
cpy $h0, $t0    # Copy the output for device 0 from t0
```

## 3.2 relPrime and gcd Implementation

### 3.2.1 Assembly

```
RelPrime:
        rsh     9                   #set schwap
        cpy     $s2, $ra            #save $ra
        cpy     $s0, $h0            #copy n out of schwap
        li      $s1, 0x2            #load 2 to m
        rsh     9                   #set schwap to args
While:
        cpy     $h0, $s0            #set a0 to n
        cpy     $h1, $s1            #set a1 to m
        jl      GCD                 #call GCD
        rsh     10                  #set schwap
        li      $t0, 0x1            #load immediate 0x1 to t0
        bne     $h0, $t0, Done      #branch to done if r0 != 1
        add     $s1, 0x1            #add 1 to m
        j       While               #jump to the start of the loop
Done:
        rsh     10                  #load return registers
        cpy     $h0, $s1            #set r0 to m
        jr      $s2, 0              #return to the previous function
```

```
GCD:
        rsh     9                   #schwap to argument register
Base:
        bne     $h0, $z0, GMain     #a!=0 go to GMain
        cpy     $t0, $h1            #copy h1 to t0 for RSH
        rsh     10                  #schwap to return registers
        cpy     $h0, $t0            #load t0 to r1
        jr      $ra, 0              #return
GMain:
        beq     $h1, $z0, Exit      #jump to exit if b is zero
        bgt     $h0, $h1, If        #jump to If if a>b
Else:
        sub     $h1, $h0            #else: b=b-a
        j       GMain               #loop
If:
        sub     $h0, $h1            #if: a=a-b
        j       GMain               #loop
Exit:
        cpy     $t0, $h0            #copy h0 to t0 for rsh schwap
        rsh     10                  #make sure we're in the right spot
        cpy     $h0, $t0            #copy t0 to h0
        jr      $ra                 #return
```

### 3.2.2 Machine Code

| RelPrime | | GCD | |
|---|---|---|---|
| PC | Hex | PC | Hex |
| 00 | 3009 | 42 | 3009 |
| 02 | 063F | 44 | 5C05 |
| 04 | 04CF | 46 | 085F |
| 06 | 050E | 48 | 300A |
| 08 | 0002 | 4A | 0A8F |
| 0A | 3009 | 4C | 2300 |
| 0C | 0C4F | 4E | 4B05 |
| 0E | 0D5F | 50 | 0C0F |
| 10 | 031F | 52 | 0072 |
| 12 | 300F | 54 | 2C00 |
| 14 | 0C0F | 56 | 301F |
| 16 | 0042 | 58 | 6CD7 |
| 18 | 2C00 | 5A | 0DC2 |
| 1A | 301F | 5C | 300F |
| 1C | 300A | 5E | 0C0F |
| 1E | 080E | 60 | 004E |
| 20 | 0001 | 62 | 2C00 |
| 22 | 4C85 | 64 | 301F |
| 24 | 0C0F | 66 | 0CD2 |
| 26 | 000A | 68 | 300F |
| 28 | 2C00 | 6A | 0C0F |
| 2A | 301F | 6C | 004E |
| 2C | 0500 | 6E | 2C00 |
| 2E | 0001 | 70 | 301F |
| 30 | 300F | 72 | 08CF |
| 34 | 0C0F | 74 | 300A |
| 36 | 000C | 76 | 0C8F |
| 38 | 2C00 | 78 | 2300 |
| 3A | 301F | | |
| 3C | 300A | | |
| 3E | 0C5F | | |
| 40 | 2600 | | |