

# Snow64 Instruction Set

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- Notes
  - There are no Instruction LARs (the typical instruction fetch of most computer processors is used instead).
  - Addresses are 64-bit.
  - Interrupts are supported (this may be a first for a LARs architecture)
  - Port-mapped I/O is supported (this may be a first for a LARs architecture)
- Data LARs:

```
typedef struct packed
{
    // Data field
    union packed
    {
        // This is possibly not valid SystemVerilog because of
        // arrays inside a packed struct, but it makes for nice
        // pseudocode
        logic [7:0] data_8[0:31];

        logic [15:0] data_16[0:15];

        struct packed
        {
            // sign bit, 1 means negative
            logic sign;

            // Exponent, +bias
            logic [7:0] exp;

            // Mantissa; normalized implies 1 MSB
            logic [6:0] mant;
        } data_float_16[0:15];

        logic [31:0] data_32[0:7];
        logic [63:0] data_64[0:3];
    } data;

    // Note that this is a 64-bit structure
    union packed
    {
        struct packed
        {
            logic [63 - 5 : 0] base_ptr;

            logic [4:0] offset;
        } addr_8;

        // Used for both 16-bit integers and the half floats
        struct packed
        {
            logic [63 - 4 : 0] base_ptr;

            logic [3:0] offset;
        } addr_16;

        struct packed
        {
```

```

        logic [63 - 3 : 0] base_ptr;

        logic [2:0] offset;
    } addr_32;

    struct packed
    {
        logic [63 - 2 : 0] base_ptr;

        logic [1:0] offset;
    } addr_64;
} addr;

// Integer Type (used when "is_float_16" is 1'b0):
// 2'b00: 8-bit
// 2'b01: 16-bit
// 2'b10: 32-bit
// 2'b11: 64-bit
logic [1:0] type_of_int;

// These are actually packed 16-bit floats, the implementing the
// high 16 bits of 32-bit IEEE float.
// "type_of_int" is ignored when "is_float_16" is 1'b1.
logic is_float_16;

// Unsigned: 1'b0
// Signed: 1'b1
// Note: unsgn_or_sgn is ignored for floats
logic unsgn_or_sgn;

// Data should be lazily stored to memory if this is 1'b1
// Otherwise, when this is 1'b0, data in this LAR is up to date
// with memory.
logic dirty;

} DataLar;

```

- Registers

- The DLARs themselves (there are 16, but this may be changed later):
  - dzero (always zero),
  - du0 , du1 , du2 , du3 , du4 , du5 , du6 , du7 , du8 , du9 , du10 , du11 (user registers)
  - dlr (standard link register (hardware does not enforce this))
  - dfp (standard frame pointer (hardware does not enforce this))
  - dsp (standard stack pointer (hardware does not enforce this))
- Other registers:
  - pc (the program counter, 64-bit)
  - ie (whether or not interrupts are enabled, 1-bit)
  - ireta (the interrupt return address, 64-bit)
  - idsta (the interrupt destination address, 64-bit; upon an interrupt, the program counter is set to the value in this register)

## Instruction Set

- Note: All invalid instructions are treated as NOPs.
- ALU Instructions: Opcode Group: 0b000
  - Encoding: 000t aaaa bbbb cccc oooo iiii iiii iiii
    - t : operation type: if 0b0 : scalar operation; else: vector operation
    - a : dDest
    - b : dSrc0

- `c` : dSrc1
- `o` : opcode
- `i` : 12-bit signed immediate
- Note: For ALU instructions, any result that doesn't fit in the destination will be truncated to fit into the destination. This affects both scalar and vector operations.
- Note: also, for each of these instructions, the address field is not used as an operand, just the data field.
- Instructions:
  - **add** dDest, dSrc0, dSrc1
    - Opcode: 0x0
    - Scalar Mnemonic: `adds`
    - Vector Mnemonic: `addv`
  - **sub** dDest, dSrc0, dSrc1
    - Opcode: 0x1
    - Scalar Mnemonic: `subs`
    - Vector Mnemonic: `subv`
  - **slt** dDest, dSrc0, dSrc1
    - Opcode: 0x2
    - Scalar Mnemonic: `slts`
    - Vector Mnemonic: `sltv`
    - Note: set less than
    - Note: The signedness of dDest will be used for the operation
  - **mul** dDest, dSrc0, dSrc1
    - Opcode: 0x3
    - Scalar Mnemonic: `muls`
    - Vector Mnemonic: `mulv`
    - Note: If dDest has a larger size than both dSrc0 and dSrc1, then the signedness used for the operation will be that of dDest
    - Note: This operation is not guaranteed to be single cycle, and thus pipeline stalls will be used
  - **div** dDest, dSrc0, dSrc1
    - Opcode: 0x4
    - Scalar Mnemonic: `divs`
    - Vector Mnemonic: `divv`
    - Note: This operation is not guaranteed to be single cycle, and thus pipeline stalls will be used
  - **and** dDest, dSrc0, dSrc1
    - Opcode: 0x5
    - Scalar Mnemonic: `ands`
    - Vector Mnemonic: `andv`
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **orr** dDest, dSrc0, dSrc1
    - Opcode: 0x6
    - Scalar Mnemonic: `orrs`
    - Vector Mnemonic: `orrv`
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **xor** dDest, dSrc0, dSrc1
    - Opcode: 0x7
    - Scalar Mnemonic: `xors`
    - Vector Mnemonic: `xorv`
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **shl** dDest, dSrc0, dSrc1
    - Opcode: 0x8
    - Scalar Mnemonic: `shls`
    - Vector Mnemonic: `shlv`
    - Note: Shift left
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **shr** dDest, dSrc0, dSrc1

- Opcode: 0x9
    - Scalar Mnemonic: `shrs`
    - Vector Mnemonic: `shrv`
    - Note: Shift right
    - Note: dSrc0's signedness is used to determine the type of right shift:
      - If dSrc0 is unsigned, a logic right shift is performed
      - If dSrc0 is signed, an arithmetic right shift is performed
    - Note: dSrc1 is always treated as unsigned (due to being a number of bits to shift by)
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **inv** dDest, dSrc0
    - Opcode: 0xa
    - Scalar Mnemonic: `invs`
    - Vector Mnemonic: `invv`
    - Note: Bitwise invert
    - Note: For floats, this operation treats all operands as 16-bit signed integers.
  - **not** dDest, dSrc0
    - Opcode: 0xb
    - Scalar Mnemonic: `nots`
    - Vector Mnemonic: `notv`
    - Note: Logical not
  - **add** dDest, pc, simm12
    - Opcode: 0xc
    - Scalar Mnemonic: `adds`
    - Vector Mnemonic: `addv`
    - Note: This is useful for pc-relative loads, relative branches, and for getting the return address of a subroutine call into a LAR before jumping to a subroutine.
- Instructions for interacting with special-purpose registers:
    - Opcode Group: 0b001
      - Encoding: `0010 aaaa oooo iiii iiii iiii iiii iiii`
        - `a`: dA
        - `o`: opcode
        - `i`: 20-bit signed immediate
      - Note: all instructions in group 0b001 are scalar operations.
      - Note: `dx.sdata` is simply the current scalar portion of the data LAR called `dx`
      - Instructions:
        - **btru** dA, simm20
          - Opcode: 0x0
          - Effect: `if (dA.sdata != 0) pc <= pc + sign_extend_to_64(simm20);`
        - **bfal** dA, simm20
          - Opcode: 0x1
          - Effect: `if (dA.sdata == 0) pc <= pc + sign_extend_to_64(simm20);`
        - **jmp** dA
          - Opcode: 0x2
          - Effect: `pc <= dA.sdata;`
          - Note: It is suggested to have dA.sdata be at least as large as the largest memory address (which might not be 64-bit if there isn't enough physical memory for that')
        - **ei**
          - Opcode: 0x3
          - Effect: `ie <= 1'b1;`
          - Note: Enable interrupts
        - **di**
          - Opcode: 0x4
          - Effect: `ie <= 1'b0;`
          - Note: Disable interrupts
        - **reti**

- Opcode: 0x5
    - Effect: `ie <= 1'b1; pc <= ireta;`
    - Note: Return from an interrupt
  - **cpy** dA, ie
    - Opcode: 0x6
    - Effect: `dA.sdata <= ie; // acts differently if dA is tagged as a float`
  - **cpy** dA, ireta
    - Opcode: 0x7
    - Effect: `dA.sdata <= ireta;`
    - Note: It is suggested to have dA.sdata be at least as large as the largest memory address (which might not be 64-bit if there isnt enough physical memory for that')
  - **cpy** dA, idsta
    - Opcode: 0x8
    - Effect: `dA.sdata <= idsta;`
    - Note: It is suggested to have dA.sdata be at least as large as the largest memory address (which might not be 64-bit if there isnt enough physical memory for that')
  - **cpy** ie, dA
    - Opcode: 0x9
    - Effect: `ie <= (dA.sdata != 0);`
  - **cpy** ireta, dA
    - Opcode: 0xa
    - Effect: `ireta <= dA.sdata;`
    - Note: It is suggested to have dA.sdata be at least as large as the largest memory address (which might not be 64-bit if there isnt enough physical memory for that')
  - **cpy** idsta, dA
    - Opcode: 0xb
    - Effect: `idsta <= dA.sdata;`
    - Note: It is suggested to have dA.sdata be at least as large as the largest memory address (which might not be 64-bit if there isnt enough physical memory for that')
- Load Instructions: Opcode Group: 0b010
    - Encoding: `0100 aaaa bbbb cccc oooo iiii iiii iiii`
      - `a` : dDest
      - `b` : dSrc0
      - `c` : dSrc1
      - `o` : opcode
      - `i` : 12-bit signed immediate
    - Effect:
      - Load LAR-sized data from 64-bit address computed as follows: `(dB.address + extend_to_64(dC.sdata) + (sign_extend_to_64(simm12)))`
        - This 64-bit address is referred to as the "effective address".
      - The type of extension of the `extend_to_64(dC.sdata)` expression is based upon the type of `dC` .
        - If `dC` is tagged as an unsigned integer, zero-extension is performed.
        - If `dC` is tagged as a signed integer, sign-extension is performed.
        - If `dC` is tagged as a BFloat16, `dC.sdata` is casted to a 64-bit signed integer. (This one is weird... normally, addressing isn't done with floating point numbers!).
      - Due to associativity of the LARs, these instructions will not actually load from memory if the effective address's data already loaded into a LAR.
    - Instructions:
      - **ldu8** dA, dB, dC, simm12
        - Opcode: 0x0
        - Note: unsigned 8-bit integer(s)
      - **lds8** dA, dB, dC, simm12
        - Opcode: 0x1
        - Note: signed 8-bit integer(s)

- **ldu16** dA, dB, dC, simm12
    - Opcode: 0x2
    - Note: unsigned 16-bit integer(s)
  - **lds16** dA, dB, dC, simm12
    - Opcode: 0x3
    - Note: signed 16-bit integer(s)
  - **ldu32** dA, dB, dC, simm12
    - Opcode: 0x4
    - Note: unsigned 32-bit integer(s)
  - **lds32** dA, dB, dC, simm12
    - Opcode: 0x5
    - Note: signed 32-bit integer(s)
  - **ldu64** dA, dB, dC, simm12
    - Opcode: 0x6
    - Note: unsigned 64-bit integer(s)
  - **lds64** dA, dB, dC, simm12
    - Opcode: 0x7
    - Note: signed 64-bit integer(s)
  - **ldf16** dA, dB, dC, simm12
    - Opcode: 0x8
    - Note: BFloat16 format floating point number.
- Store Instructions: Opcode Group: 0b011
  - Encoding: 0110 aaaa bbbb cccc oooo iiii iiii iiii
    - a : dA
    - b : dB
    - c : dC
    - o : opcode
    - i : 12-bit signed immediate
  - Note: These are actually type conversion instructions as actual writes to memory are done lazily
  - Effect:
    - These instructions marks dA as dirty, change its address to the effective address (see next bullet), and sets its type.
    - The 64-bit effective address is computed as follows:  $(dB.address + extend\_to\_64(dC.sdata) + (sign\_extend\_to\_64(simm12)))$
    - The type of extension of the `extend_to_64(dC.sdata)` expression is based upon the type of dC .
      - If dC is tagged as an unsigned integer, zero-extension is performed.
      - If dC is tagged as a signed integer, sign-extension is performed.
      - If dC is tagged as a BFloat16, dC.sdata is casted to a 64-bit signed integer. (This one is weird... normally, addressing isn't done with floating point numbers!).
  - Instructions:
    - **stu8** dA, dB, dC, simm12
      - Opcode: 0x0
      - Note: unsigned 8-bit integer(s)
    - **sts8** dA, dB, dC, simm12
      - Opcode: 0x1
      - Note: signed 8-bit integer(s)
    - **stu16** dA, dB, dC, simm12
      - Opcode: 0x2
      - Note: unsigned 16-bit integer(s)
    - **sts16** dA, dB, dC, simm12
      - Opcode: 0x3
      - Note: signed 16-bit integer(s)

- **stu32** dA, dB, dC, simm12
    - Opcode: 0x4
    - Note: unsigned 32-bit integer(s)
  - **sts32** dA, dB, dC, simm12
    - Opcode: 0x5
    - Note: signed 32-bit integer(s)
  - **stu64** dA, dB, dC, simm12
    - Opcode: 0x6
    - Note: unsigned 64-bit integer(s)
  - **sts64** dA, dB, dC, simm12
    - Opcode: 0x7
    - Note: signed 64-bit integer(s)
  - **stf16** dA, dB, dC, simm12
    - Opcode: 0x8
    - Note: BFloat16 format floating point number.
- Port-mapped Input/Output Instructions: Opcode Group: 0b100
    - Encoding: 100t aaaa bbbb oooo iiii iiii iiii iiii
      - t : operation type: if 0b0 : scalar operation; else: vector operation
      - a : dA
      - b : dB
      - o : opcode
      - i : 16-bit signed immediate
    - Note: dx.sdata is simply the current scalar portion of the data LAR called dx
    - Note: For the in... instructions, the entirety of dA.data is set to the received data. The type of dA is set based upon the instruction opcode.
    - Note: For outs , dA.sdata is sent to the output port, along with the type of data (in case the particular I/O port cares).
    - Note: For outv , the entirety of dA.data is sent to the output port, along with the type of data (in case the particular I/O port cares).
    - Note: For each of these instructions, the I/O address used is computed by the formula  $\text{cast\_to\_64}(\text{dB.sdata}) + \text{sign\_extend\_to\_64}(\text{simm16})$
    - Instructions:
      - **inu8** dA, dB, simm16
        - Opcode: 0x0
        - Note: unsigned 8-bit integer(s)
      - **ins8** dA, dB, simm16
        - Opcode: 0x1
        - Note: signed 8-bit integer(s)
      - **inu16** dA, dB, simm16
        - Opcode: 0x2
        - Note: unsigned 16-bit integer(s)
      - **ins16** dA, dB, simm16
        - Opcode: 0x3
        - Note: signed 16-bit integer(s)
      - **inu32** dA, dB, simm16
        - Opcode: 0x4
        - Note: unsigned 32-bit integer(s)
      - **ins32** dA, dB, simm16
        - Opcode: 0x5
        - Note: signed 32-bit integer(s)
      - **inu64** dA, dB, simm16
        - Opcode: 0x6
        - Note: unsigned 64-bit integer(s)
      - **ins64** dA, dB, simm16
        - Opcode: 0x7

- Note: signed 64-bit integer(s)
- **inf16** dA, dB, simm16
  - Opcode: 0x8
  - Note: BFloat16 format floating point number.
- **out** (actual mnemonics below)
  - Opcode: 0x9
    - **outs** dA, dB, simm16
      - t : 0
      - Note: dA.sdata is simply sent to the output data bus.
    - **outv** dA, dB, simm16
      - t : 1
      - Note: The type of dA is ignored for this operation as the entirety of the LAR is sent to the port.