

# I Introduction

## I.A General Information

- Addresses are 32-bit.
- Big-endian byte ordering is used.
- Bytes are octets (8 bits).
- Instructions must be aligned to 16 bits, so jump and branch targets must also be aligned to 16 bits.
  - Branch offsets encoded into instructions must be 16-bit aligned, or in other words bit 0 of the branch offset must be **0b0**

## I.B Registers

There are sixteen general-purpose registers (all of which are 32-bit): **r0**, **r1**, **r2**, ..., **r11**, **r12**, **lr** (link register, the return address of **bl** and **jl**), **fp** (frame pointer), and **sp** (stack pointer).

The program counter, **pc**, is 32 bits long, as addresses are 32-bit.

Here are the special-purpose registers:

- **flags**: arithmetic/logic **FLAGS**; (reg encoding: **0x0**)
- **ids**: Interrupt DeStination: the address to jump to upon an interrupt being serviced (also known as the interrupt vector); (reg encoding: **0x1**)
- **ira**: Interrupt Return Address: the address that was jumped from upon an interrupt being serviced; (reg encoding: **0x2**)
- **ie**: IRQ Enable flag: flag indicating whether IRQs are disabled (**0x0**) or enabled (**0x1**); note that this flag starts with a value of **0x0**; (reg encoding: **0x3**)
- **ity**: Interrupt TYpe: flag indicating whether the most recently taken interrupt is an IRQ (**0x0**) or a **swi** (**0x1**) (reg encoding: **0x4**)
- **sty**: Software interrupt TYpe: **swi**'s argument. For **swi rA, #simm**, this is the value **rA + simm** (reg encoding: **0x5**)
- Note: All other encodings for special-purpose registers are reserved.

Here are the bits of **flags**:

- Zero (**Z**): (**flags** bit 0)
- Carry (**C**): (**flags** bit 1)
- oVerflow (**V**): (**flags** bit 2)
- Negative (**N**): (**flags** bit 3)
- Note: All other bit positions of **flags** are reserved.

# II Instruction Set

## II.A Instruction Group 0: **pre** and **lpre**

For **pre**, the following encoding is used, with each character representing one bit:

**0000 iiii iiii iiii**, where

- **i** is a 12-bit constant.

For **lpre**, the following encoding is used, with each character representing one bit:

**0001 0iii iiii iiii iiii iiii iiii iiii**, where

- **i** is a 27-bit constant.

**pre** and **lpre** are mechanisms by which immediates larger than normal can be used, essentially acting like variable width instructions.

There is no mechanism in the assembly language itself to use **pre** or **lpre** as instructions. Instead, it is expected that the assembler or linker will be the one to insert **pre** or **lpre** as needed if an immediate is too large for a particular instruction.

For non-branch instructions:

- If `pre` is used, the immediate field of the `pre` instruction will form bits [16:5] of the immediate of the next non-index instruction. The 17-bit immediate will then be sign-extended to 32 bits. Sign-extension will be performed on the 17-bit immediate even if, had there been no `pre`, the 5-bit immediate would have been zero-extended.
- On the other hand, if `lpre` is used, the immediate field of the `lpre` instruction will form bits [31:5] of the immediate of the next non-index instruction.

For branch instructions (group 3):

- if `pre` is used, the immediate field of the `pre` instruction will form bits [20:9] of the immediate of the next non-index instruction. The 21-bit immediate will then be sign-extended to 32 bits.
- On the other hand, if `lpre` is used, the immediate field of the `lpre` instruction will form bits [31:9] of the immediate of the next non-index instruction.

### II.A.1 Handling of `pre`, `lpre`, and `index`

When a `pre` or `lpre` instruction is found, `pre` or `lpre` will be considered to be “in effect”. This condition lasts for one or two instructions after the `pre` or `lpre` instruction, depending on whether or not `index` was in effect.

`index` is an instruction (defined later) that allows a subsequent load or store instruction to perform `base_reg + index_reg` indexing. When an `index` instruction is found, it is considered to be in effect. Like `pre` and `lpre`, `index` is inserted automatically by the assembler.

`index` can be combined with `pre` or `lpre`, and it does not matter whether `index` or the `pre/lpre` instruction came first.

When `pre`, `lpre`, or `index` is in effect, IRQs will not be serviced.

Pseudo code for handling the how `pre`, `lpre`, and `index` are to be handled regarding whether or not they are “in effect” is as follows:

```
function handlePreLpreIndex(input in, output out) {
  when (!out.instr.isLpre()) {
    when (in.instr.isPre()) {
      when (
        in.state.pre.haveIt
        || in.state.lpre.haveIt
      ) {
        // invalid instruction
        out.state.pre.haveIt := False
        out.state.lpre.haveIt := False
        out.state.index.haveIt := False
        out.instr := NOP
        out.state.canServiceIrq := True
      } otherwise {
        out.state.pre.haveIt := True
        out.state.pre.data := in.instr[11:0]
        out.instr := in.instr
        out.state.canServiceIrq := False
      }
    } elseif (in.instr.isLpre()) {
      when (
        in.state.pre.haveIt
        || in.state.lpre.haveIt
      ) {
        // invalid instruction
        out.state.pre.haveIt := False
        out.state.lpre.haveIt := False
        out.state.index.haveIt := False
        out.instr := NOP
        out.state.canServiceIrq := True
      } otherwise {
```

```

        out.state.lpre.haveIt := True
        out.instr := in.instr
        out.state.canServiceIrq := False
        out.state.lpre.data[26:16] := in.instr[10:0]
    }
} elseif (in.instr.isIndex()) {
    when (
        in.state.index.haveIt
    ) {
        // invalid instruction
        out.state.pre.haveIt := False
        out.state.lpre.haveIt := False
        out.state.index.haveIt := False
        out.instr := NOP
        out.state.canServiceIrq := True
    } otherwise {
        out.state.index.haveIt := True
        out.instr := in.instr
        out.state.canServiceIrq := False
    }
} otherwise {
    out.state.canServiceIrq := !(
        in.state.pre.haveIt
        || in.state.lpre.haveIt
        || in.state.index.haveIt
    )
    out.instr := instr

    // Whenever we see an instruction other than `pre`, `lpre`, or `index`,
    // that means those instructions stop being "in effect".
    out.state.pre.haveIt := False
    out.state.lpre.haveIt := False
    out.state.index.haveIt := False
}
} otherwise { // when (out.instr.isLpre())
    out.state.lpre.data[15:0] := in.instr
}
}

```

## II.B Instruction Group 1

The following encoding is used, with each character representing one bit:

001i iiii oooo aaaa, where

- **i** is a 5-bit sign-extended or zero-extended immediate, and is denoted **simm** when sign-extended or **imm** when zero-extended. Also, **simm** or **imm** can be expanded with **pre** or **lpre**.
- **a** encodes register **rA**
- **o** is the opcode

Here is a list of instructions from this encoding group.

- Opcode 0x0: add rA, #simm
- Opcode 0x1: add rA, pc, #simm
  - Effect:  $rA \leftarrow pc + simm + 2$ ;
- Opcode 0x2: add rA, sp, #simm
- Opcode 0x3: add rA, fp, #simm
- Opcode 0x4: cmp rA, #simm
  - Effect: Compare rA to simm.
  - Affectable flags: Z, C, V, N
- Opcode 0x5: cpy rA, #simm
  - Effect: Copy an immediate value into rA
- Opcode 0x6: lsl rA, #imm

- Effect: Logical shift left
- Opcode 0x7: lsr rA, #imm
  - Effect: Logical shift right
- Opcode 0x8: asr rA, #imm
  - Effect: Arithmetic shift right
- Opcode 0x9: and rA, #simm
  - Effect: Bitwise AND
- Opcode 0xa: orr rA, #simm
  - Effect: Bitwise OR
- Opcode 0xb: xor rA, #simm
  - Effect: Bitwise XOR
- Opcode 0xc: ze rA, #imm
  - Effect: Set rA[31:imm] to zero.
- Opcode 0xd: se rA, #imm
  - Effect: Sign-extend rA[imm:0] to 32 bits, then copy that value to rA.
- Opcode 0xe: swi rA, #simm
  - Effect: Call software interrupt number rA + simm.
- Opcode 0xf: swi #imm
  - Effect: Call software interrupt number imm.

## II.C Instruction Group 2

The following encoding is used, with each character representing one bit:

010f oooo bbbb aaaa, where

- o is the opcode
- b encodes register rB
- a encodes register rA
- f is encoded as 0 if this instruction cannot affect flags and encoded 1 if this instruction is permitted to affect flags. Note that `cmp` is permitted to affect flags regardless of this bit.

Here is a list of instructions from this encoding group.

- Opcode 0x0: add rA, rB
  - Mnemonic for when flags not affected: `add`
  - Mnemonic for when flags affected: `add.f`
  - Affectable flags: Z, C, V, N
- Opcode 0x1: sub rA, rB
  - Mnemonic for when flags not affected: `sub`
  - Mnemonic for when flags affected: `sub.f`
  - Affectable flags: Z, C, V, N
- Opcode 0x2: add rA, sp, rB
  - Mnemonic for when flags not affected: `add`
  - Mnemonic for when flags affected: `add.f`
  - Affectable flags: Z, C, V, N
- Opcode 0x3: add rA, fp, rB
  - Mnemonic for when flags not affected: `add`
  - Mnemonic for when flags affected: `add.f`
  - Affectable flags: Z, C, V, N
- Opcode 0x4: cmp rA, rB
  - Effect: Compare rA to rB. `cmp` is *always* able to affect flags, independent of the encoded f bit of the instruction.
  - Affectable flags: Z, C, V, N
- Opcode 0x5: cpy rA, rB
  - Mnemonic for when flags not affected: `cpy`
  - Mnemonic for when flags affected: `cpy.f`

- Effect: Copy `rB` into `rA`
- Affectable flags: `Z`, `N`
- Opcode `0x6`: `lsl rA, rB`
  - Mnemonic for when flags not affected: `lsl`
  - Mnemonic for when flags affected: `lsl.f`
  - Effect: Logical shift left
  - Affectable flags: `Z`, `N`
- Opcode `0x7`: `lsr rA, rB`
  - Mnemonic for when flags not affected: `lsr`
  - Mnemonic for when flags affected: `lsr.f`
  - Effect: Logical shift right
  - Affectable flags: `Z`, `N`
- Opcode `0x8`: `asr rA, rB`
  - Mnemonic for when flags not affected: `asr`
  - Mnemonic for when flags affected: `asr.f`
  - Effect: Arithmetic shift right
  - Affectable flags: `Z`, `N`
- Opcode `0x9`: `and rA, rB`
  - Mnemonic for when flags not affected: `and`
  - Mnemonic for when flags affected: `and.f`
  - Effect: Bitwise AND
  - Affectable flags: `Z`, `N`
- Opcode `0xa`: `orr rA, rB`
  - Mnemonic for when flags not affected: `orr`
  - Mnemonic for when flags affected: `orr.f`
  - Effect: Bitwise OR
  - Affectable flags: `Z`, `N`
- Opcode `0xb`: `xor rA, rB`
  - Mnemonic for when flags not affected: `xor`
  - Mnemonic for when flags affected: `xor.f`
  - Effect: Bitwise XOR
  - Affectable flags: `Z`, `N`
- Opcode `0xc`: `adc rA, rB`
  - Mnemonic for when flags not affected: `adc`
  - Mnemonic for when flags affected: `adc.f`
  - Effect: Add with Carry, using the formula  $rA + rB + \text{flags.C}$  to compute the value that will be written into `rA`.
  - Affectable flags: `Z`, `C`, `V`, `N`
- Opcode `0xd`: `sbc rA, rB`
  - Mnemonic for when flags not affected: `sbc`
  - Mnemonic for when flags affected: `sbc.f`
  - Effect: Subtract with Borrow, using the formula  $rA + (\sim rB) + \text{flags.C}$  to compute the value that will be written into `rA`.
  - Affectable flags: `Z`, `C`, `V`, `N`
- Opcode `0xe`: `cmpbc rA, rB`
  - Effect: Compare `rA` to `rB`, but with carry-in and a different effect for setting the `flags.Z`. `cmpbc` is *always* able to affect `flags`, independent of the encoded `f` bit of the instruction.
  - Note: this instruction acts much like `sbc rA, rB`, but without storing the subtraction's result into `rA`. However, this instruction sets the `Z` flag to `prev(flags.Z) AND ((rA + (~rB) + flags.C) == 0)`
  - Affectable flags: `Z`, `C`, `V`, `N`

## II.D Instruction Group 3: Relative Branches

The following encoding is used, with each character representing one bit:

011i iiii iiii oooo, where

- i is a 9-bit sign-extended immediate, which can be expanded by `pre` or `lpre`, and is denoted `simm`
- o is the opcode

Here is a list of instructions from this encoding group.

- Opcode 0x0: `bl simm`
  - Name: Branch and Link
  - Description: Relative call
  - Effect: `lr <= pc + 2; pc <= pc + simm + 2;`
- Opcode 0x1: `bra simm`
  - Name: BRanch Always
  - Description: Unconditional relative branch
  - Effect: `pc <= pc + simm + 2;`
- Opcode 0x2: `beq simm`
  - Name: Branch if EQual
  - Effect: `if (flags.Z) pc <= pc + simm + 2;`
- Opcode 0x3: `bne simm`
  - Name: Branch if Not Equal
  - Effect: `if (!flags.Z) pc <= pc + simm + 2;`
- Opcode 0x4: `bmi simm`
  - Name: Branch if MInus
  - Effect: `if (flags.N) pc <= pc + simm + 2;`
- Opcode 0x5: `bpl simm`
  - Name: Branch if PPlus
  - Effect: `if (!flags.N) pc <= pc + simm + 2;`
- Opcode 0x6: `bvs simm`
  - Name: Branch if oVerflow Set
  - Effect: `if (flags.V) pc <= pc + simm + 2;`
- Opcode 0x7: `bvc simm`
  - Name: Branch if oVerflow Clear
  - Effect: `if (!flags.V) pc <= pc + simm + 2;`
- Opcode 0x8: `bgeu simm`
  - Name: Branch if Greater than or Equal Unsigned
  - Effect: `if (flags.C) pc <= pc + simm + 2;`
- Opcode 0x9: `bltu simm`
  - Name: Branch if Less Than Unsigned
  - Effect: `if (!flags.C) pc <= pc + simm + 2;`
- Opcode 0xa: `bgtu simm`
  - Name: Branch if Greater Than Unsigned
  - Effect: `if (flags.C AND !flags.Z) pc <= pc + simm + 2;`
- Opcode 0xb: `bleu simm`
  - Name: Branch if Less than or Equal Unsigned
  - Effect: `if (!flags.C OR flags.Z) pc <= pc + simm + 2;`
- Opcode 0xc: `bges simm`
  - Name: Branch if Greater than or Equal Signed
  - Effect: `if (!(flags.N XOR flags.V)) pc <= pc + simm + 2;`
- Opcode 0xd: `blts simm`
  - Name: Branch if Less Than Signed
  - Effect: `if (flags.N XOR flags.V) pc <= pc + simm + 2;`
- Opcode 0xe: `bgtS simm`
  - Name: Branch if Greater Than Signed

- Effect:
 

```
if (!(flags.N XOR flags.V) AND !flags.Z)
    pc <= pc + simm + 2;
```
- Opcode 0xf: bles simm
  - Name: Branch if Less than or Equal Signed
  - Effect:
 

```
if ((flags.N XOR flags.V) OR flags.Z)
    pc <= pc + simm + 2;
```

## II.E Instruction Group 4

The following encoding is used, with each character representing one bit:

100o oooo bbbb aaaa, where

- o is the opcode
- b encodes register rB or register sC, where sC is one of the special-purpose registers
- a encodes register rA or register sA, where sA is one of the special-purpose registers

Here is a list of instructions from this encoding group.

- Opcode 0x0: jl rA
  - Effect: lr <= pc + 2; pc <= rA;
- Opcode 0x1: jmp rA
  - Effect: pc <= rA;
- Opcode 0x2: jmp ira
  - Effect: pc <= ira;
- Opcode 0x3: reti
  - Effect: enables IRQs (by copying 0x1 into ie) and performs pc <= ira;
- Opcode 0x4: ei
  - Effect: copy 1 into ie.
- Opcode 0x5: di
  - Effect: copy 0 into ie.
- Opcode 0x6: push rA, rB
  - Effect: pushes rA onto the stack, using rB as the stack pointer, post-decrementing rB.
  - This instruction does nothing when rA is the same register as rB.
  - Note: As a pseudo instruction, omitting “ , rB” will automatically select sp as the particular stack pointer.
- Opcode 0x7: push sA, rB
  - Effect: pushes sA onto the stack, using rB as the stack pointer, post-decrementing rB.
  - Note that sA is considered to be 32-bit for the purpose of the store to memory and decrementing rB, even if sA is flags or ie.
  - Note: As a pseudo instruction, omitting “ , rB” will automatically select sp as the particular stack pointer.
- Opcode 0x8: pop rA, rB
  - Effect: pops rA off the stack, using rB as the stack pointer, pre-incrementing rB.
  - This instruction does nothing when rA is the same register as rB.
  - Note: As a pseudo instruction, omitting “ , rB” will automatically select sp as the particular stack pointer.
- Opcode 0x9: pop sA, rB
  - Effect: pops sA off the stack, using rB as the stack pointer, pre-incrementing rB.
  - Note that sA is considered to be 32-bit for the purpose of the load from memory and incrementing rB, even if sA is flags or ie.
  - Note: As a pseudo instruction, omitting “ , rB” will automatically select sp as the particular stack pointer.
- Opcode 0xa: pop pc, rB
  - Effect: pops pc off the stack, using rB as the stack pointer, pre-incrementing rB.

- Note that `pc` is considered to be 32-bit for the purpose of the load from memory and incrementing `rB`, even if `pc` is `flags` or `ie`.
- Note: As a pseudo instruction, omitting “`, rB`” will automatically select `sp` as the particular stack pointer.
- Opcode `0xb`: `mul rA, rB`
  - Effect: `rA <= rA * rB`;
- Opcode `0xc`: `udiv rA, rB`
  - Effect: `rA <= u32(rA) / u32(rB)`;
- Opcode `0xd`: `sdiv rA, rB`
  - Effect: `rA <= s32(rA) / s32(rB)`;
- Opcode `0xe`: `umod rA, rB`
  - Effect: `rA <= u32(rA) \\/ u32(rB)`;
- Opcode `0xf`: `smod rA, rB`
  - Effect: `rA <= s32(rA) \\/ s32(rB)`;
- Opcode `0x10`: `lumul rA, rB`
  - Effect: This instruction multiplies `rA` by `rB`, performing an unsigned 32-bit by 32-bit -> 64-bit multiply, storing result in `concat{r0, r1}`.
- Opcode `0x11`: `lsmul rA, rB`
  - Effect: This instruction multiplies `rA` by `rB`, performing a signed 32-bit by 32-bit -> 64-bit multiply, storing result in `concat{r0, r1}`.
- Opcode `0x12`: `udiv64 rA, rB`
  - Effect: performs a 64-bit by 64-bit unsigned division of `concat{rA, r{A + 1}}` by `concat{rB, r{B + 1}}`, storing 64-bit result in `concat{rA, r{A + 1}}`.
  - Note: This instruction operates as if `rA` were encoded with (`A[0x0] == 0b0`) and `rB` were encoded with (`B[0x0] == 0b0`),
  - Note: This instruction executes more quickly if `rB`'s value is `0x00000000`, i.e. if the operation is actually a 64-bit by 32-bit -> 64-bit unsigned divide.
- Opcode `0x13`: `sdiv64 rA, rB`
  - Effect: performs a 64-bit by 64-bit signed division of `concat{rA, r{A + 1}}` by `concat{rB, r{B + 1}}`, storing 64-bit result in `concat{rA, r{A + 1}}`.
  - Note: This instruction operates as if `rA` were encoded with (`A[0x0] == 0b0`) and `rB` were encoded with (`B[0x0] == 0b0`),
  - Note: This instruction executes more quickly if `rB` is equal to bits `[63:32]` of `s64(r{B+1})`.
- Opcode `0x14`: `umod64 rA, rB`
  - Effect: performs a 64-bit by 64-bit unsigned modulo of `concat{rA, r{A + 1}}` by `concat{rB, r{B + 1}}`, storing 64-bit result in `concat{rA, r{A + 1}}`.
  - Note: This instruction operates as if `rA` were encoded with (`A[0x0] == 0b0`) and `rB` were encoded with (`B[0x0] == 0b0`),
  - Note: This instruction executes more quickly if `rB`'s value is `0x00000000`, i.e. if the operation is actually a 64-bit by 32-bit -> 64-bit unsigned modulo.
- Opcode `0x15`: `smod64 rA, rB`
  - Effect: performs a 64-bit by 64-bit signed modulo of `concat{rA, r{A + 1}}` by `concat{rB, r{B + 1}}`, storing 64-bit result in `concat{rA, r{A + 1}}`.
  - Note: This instruction operates as if `rA` were encoded with (`A[0x0] == 0b0`) and `rB` were encoded with (`B[0x0] == 0b0`),
  - Note: This instruction executes more quickly if `rB` is equal to bits `[63:32]` of `s64(r{B+1})`.
- Opcode `0x16`: `ldub rA, [rB]`
  - Effect: Load an 8-bit value from memory at address computed as `rB + index_reg`, zero-extend the 8-bit value to 32 bits, then put the zero-extended 32-bit value into `rA`.
  - The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
  - Shorthand for having the assembler insert an `index rC` instruction before this one: `ldub rA, [rB, rC]`
- Opcode `0x17`: `ldsb rA, [rB]`



- Effect: Load an 8-bit value from memory at address computed as  $rB + \text{index\_reg}$ , sign-extend the 8-bit value to 32 bits, then put the sign-extended 32-bit value into  $rA$ .
- The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
- Shorthand for having the assembler insert an `index rC` instruction before this one: `ldsb rA, [rB, rC]`
- Opcode 0x18: `lduh rA, [rB]`
  - Effect: Load a 16-bit value from memory at address computed as  $rB + \text{index\_reg}$ , zero-extend the 16-bit value to 32 bits, then put the zero-extended 32-bit value into  $rA$ .
  - The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
  - Shorthand for having the assembler insert an `index rC` instruction before this one: `lduh rA, [rB, rC]`
- Opcode 0x19: `ldsh rA, [rB]`
  - Effect: Load a 16-bit value from memory at address computed as  $rB + \text{index\_reg}$ , sign-extend the 16-bit value to 32 bits, then put the zero-extended 32-bit value into  $rA$ .
  - The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
  - Shorthand for having the assembler insert an `index rC` instruction before this one: `ldsh rA, [rB, rC]`
- Opcode 0x1a: `stb rA, [rB]`
  - Effect: Store  $rA[7:0]$  to memory at the address computed as  $rB + \text{index\_reg}$ .
  - The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
  - Shorthand for having the assembler insert an `index rC` instruction before this one: `stb rA, [rB, rC]`
- Opcode 0x1b: `sth rA, [rB]`
  - Effect: Store  $rA[15:0]$  to memory at the address computed as  $rB + \text{index\_reg}$ .
  - The `index_reg` value is guaranteed to be zero unless an `index` is in effect.
  - Shorthand for having the assembler insert an `index rC` instruction before this one: `sth rA, [rB, rC]`
- Opcode 0x1c: `cpy rA, sB`
  - Effect:  $rA \leq sB$ ;
- Opcode 0x1d: `cpy sA, rB`
  - Effect:  $sA \leq rB$ ;
- Opcode 0x1e: `cpy sA, sB`
  - Effect:  $sA \leq sB$ ;
- Opcode 0x1f: `index rA`
  - Effect: Performs `index_reg <= rA`; and stores that `index` is in effect.
  - Note: If `index` is in effect and the current instruction is `index`, the current instruction will be treated as a NOP, and `index` will stop being in effect.
  - Note: `pre` and `index` can be combined with one another (though this is only useful for `ldr` and `str`).
  - Note: A non-`pre` instruction following `index` will store that that `index` is not in effect any more. (It will also store that `pre` is not in effect any more).
  - Note: If `index` is in effect, the current instruction cannot be interrupted by an IRQ.
  - Note: Any time `index` stops being in effect, `pre` will stop being in effect as well.

## II.F Instruction Group 5: Immediate Indexed Load

The following encoding is used, with each character representing one bit:

101i iiii bbbb aaaa, where

- `i` is a 5-bit sign-extended immediate, which can be expanded by `pre` or `lpre`, and is denoted `simm`
- `b` encodes register  $rB$
- `a` encodes register  $rA$

The one instruction from this encoding group is `ldr rA, [rB, #simm]`. This is a 32-bit load into  $rA$ , where the effective address to load from is computed as  $rB + \langle \text{index\_reg} \rangle + \text{simm}$ , using the sign-extended form of `simm`.

The `<index_reg>` value is guaranteed to be zero unless an `index` is in effect.

The following pseudo instructions exist within the assembler for this encoding group:

- `ldr rA, [rB]`
  - This pseudo instruction assembles to the following:
    - `ldr rA, [rB, #0x0]`
- `ldr rA, [rB, rC]`
  - This pseudo instruction assembles to the following:
    - `index rC`
    - `ldr rA, [rB, #0x0]`
- `ldr rA, [rB, rC, #simm]`
  - This pseudo instruction assembles to the following:
    - `index rC`
    - `ldr rA, [rB, #simm]`

## II.G Instruction Group 6: Immediate Indexed Store

The following encoding is used, with each character representing one bit:

110i iiii bbbb aaaa, where

- `i` is a 5-bit sign-extended immediate, which can be expanded by `pre` or `lpre`, and is denoted `simm`
- `b` encodes register `rB`
- `a` encodes register `rA`

The one instruction from this encoding group is `str rA, [rB, #simm]`. This is a 32-bit store of `rA`, where the effective address to store to is computed as `<index_reg> + rB + simm`, using the sign-extended form of `simm`.

The `<index_reg>` value is guaranteed to be zero unless an `index` is in effect.

The following pseudo instructions exist within the assembler for this encoding group:

- `str rA, [rB]`
  - This pseudo instruction assembles to the following:
    - `str rA, [rB, #0x0]`
- `str rA, [rB, rC]`
  - This pseudo instruction assembles to the following:
    - `index rC`
    - `str rA, [rB, #0x0]`
- `str rA, [rB, rC, #simm]`
  - This pseudo instruction assembles to the following:
    - `index rC`
    - `str rA, [rB, #simm]`

## II.H Instruction Group 7, Subgroup 0b00:

Extra 8-bit and 16-bit Ops} The following encoding is used, with each character representing one bit:

1110 0woo bbbb aaaa, where

- `w` is the operation width
  - When `0b0`: 8-bit operation
  - When `0b1`: 16-bit operation
- `o` is the opcode
- `b` encodes register `rB`
- `a` encodes register `rA`

Here is a list of instructions from this encoding group.

- Opcode `0x0`:
  - `w` value `0b0`: `cmpb rA, rB`
    - Effect: Compare `rA[7:0]` to `rB[7:0]`
    - Affectable flags: `Z`, `C`, `V`, `N`

- w value 0b1: cmph rA, rB
  - Effect: Compare rA[15:0] to rB[15:0]
  - Affectable flags: Z, C, V, N
- Opcode 0x1:
  - w value 0b0: lsrB rA, rB
    - Effect: Logical shift right rA[7:0] by rB
  - w value 0b1: lsrh rA, rB
    - Effect: Logical shift right rA[15:0] by rB
- Opcode 0x2:
  - w value 0b0: asrb rA, rB
    - Effect: Arithmetic shift right rA[7:0] by rB
  - w value 0b1: asrh rA, rB
    - Effect: Arithmetic shift right rA[15:0] by rB

## II.I Instruction Group 7, Subgroup 0b010: Extra load/store instructions

The following encoding is used, with each character representing one bit:

1110 10oo bbbb aaaa, where

- o is the opcode
- b encodes register rB or sB
- a encodes register sA

Here is a list of instructions from this encoding group.

- Opcode 0x0: ldr sA, [rB]
  - Effect: 32-bit load of sA from memory at address held in rB.
- Opcode 0x1: ldr sA, [sB]
  - Effect: 32-bit load of sA from memory at address held in sB.
- Opcode 0x2: str sA, [rB]
  - Effect: 32-bit store of sA to memory at address held in rB.
- Opcode 0x3: str sA, [sB]
  - Effect: 32-bit store of sA to memory at address held in sB.

## II.J Instruction Group 7, Subgroup 0b0110: Icache Reload Instruction

The following encoding is used, with each character representing one bit:

1110 110i iiii aaaa, where

- i is a 5-bit sign-extended immediate, which can be expanded by pre or lpre, and is denoted `simm`.
- a encodes register rA

The one instruction from this encoding group is `icreload [rA, #simm]`. This instruction forcibly reloads the icache line at an effective address computed as `<index_reg> + rA + simm`, using the sign-extended form of `simm`. As a side note, this instruction will attempt to read the data from dcache, and will only read from memory if dcache doesn't have that data. Icache lines and dcache lines are the same length, 64 bytes.

The `<index_reg>` value is guaranteed to be zero unless an `index` is in effect.

The following pseudo instructions exist within the assembler for this encoding group:

- `icreload [rA]`
  - This pseudo instruction assembles to the following:
    - `icreload [rA, #0x0]`
- `icreload [rA, rC]`
  - This pseudo instruction assembles to the following:
    - `index rC`
    - `icreload [rA, #0x0]`
- `icreload [rA, rC, #simm]`
  - This pseudo instruction assembles to the following:

- index rC
- icreload [rA, #simm]