

Flare32 CPU

FL4SHK

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# Table of Contents

<b>Table of Contents</b>	<b>1</b>
<b>Introduction</b>	<b>2</b>
2.1 General Information . . . . .	2
2.2 Registers . . . . .	2
<b>Instruction Set</b>	<b>4</b>
3.1 Instruction Group 0: <b>pre</b> and <b>lpre</b> . . . . .	4
3.1.1 Handling of <b>pre</b> , <b>lpre</b> , and <b>index</b> . . . . .	5
3.2 Instruction Group 1 . . . . .	6
3.3 Instruction Group 2 . . . . .	8
3.4 Instruction Group 3: Relative Branches . . . . .	10
3.5 Instruction Group 4 . . . . .	12
3.6 Instruction Group 5: Immediate Indexed Load . . . . .	17
3.7 Instruction Group 6: Immediate Indexed Store . . . . .	17

# Introduction

## 2.1 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`

## 2.2 Registers

There are sixteen general-purpose registers (all of which are 32-bit): `r0`, `r1`, `r2`, ..., `r11`, `r12`, `lr`, `fp` (frame pointer), `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`: Interrupt Enable flag: flag indicating whether interrupts are enabled (`0x1`) or disabled (`0x0`) note that interrupts start off as disabled; (reg encoding `0x3`)
- `hi`: HIgh 32 bits of instructions that produce 64-bit results; (reg encoding `0x4`)
- `lo`: LOw 32 bits of instructions that produce 64-bit results; (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.

## Instruction Set

### 3.1 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 0*iiii* *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.
- 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.

Instructions that use an immediate value, other than **pre**, **lpre**, and relative branches normally have 5-bit immediates. Relative branches normally have 9-bit branch offsets. if **pre** or **lpre** is used with a relative branch, bits [9:5] of the branch offset that is encoded directly into a relative branch instruction will be ignored, and the immediate field of the **pre** or **lpre** instruction will be used to determine bits [9:5] of the branch offset..

### 3.1.1 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, interrupts 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 handle_pre_lpre_index(input in, output out) {
    if (in.instruction.is_pre()) {
        if (in.state.pre.have || in.state.lpre.have) {
            out.state.can_service_interrupts = false;

            // Instruction was a NOP
            out.state.pre.have = false;
            out.state.lpre.have = false;
            out.state.index.have = false;
            out.instruction = nop;
        } else {
            if (in.state.index.have) {
                out.state.can_service_interrupts = false;
            } else {
                out.state.can_service_interrupts = true;
            }
            out.state.pre.set_have(true);
            out.instruction = in.instruction;
        }
    } else if (in.instruction.is_lpre()) {
        if (in.state.pre.have || in.state.lpre.have) {
            out.state.can_service_interrupts = false;

            // Instruction was a NOP
            out.state.pre.have = false;
            out.state.lpre.have = false;
            out.state.index.have = false;
            out.instruction = nop;
        } else {
            if (in.state.index.have) {
                out.state.can_service_interrupts = false;
            }
        }
    }
}
```

```

        } else {
            out.state.can_service_interrupts = true;
        }
        out.state.lpre.set_have(true);
        out.instruction = in.instruction;
    }
} else if (in.instruction.is_index()) {
    if (in.state.index.have) {
        out.state.can_service_interrupts = false;

        // Instruction was a NOP
        out.state.pre.have = false;
        out.state.lpre.have = false;
        out.state.index.have = false;
        out.instruction = nop;
    } else {
        if (in.state.pre.have || in.state.lpre.have) {
            out.state.can_service_interrupts = false;
        } else {
            out.state.can_service_interrupts = true;
        }
        out.state.index.have = true;
        out.instruction = in.instruction;
    }
} else {
    if (
        in.state.pre.have || in.state.lpre.have || in.state.index.have
    ) {
        out.state.can_service_interrupts = false;
    } else {
        out.state.can_service_interrupts = true;
    }
    out.instruction = instruction;

    // Whenever we see an instruction other than pre, lpre, or index,
    // that means that those instructions stop being "in effect".
    out.state.pre.have = false;
    out.state.lpre.have = false;
    out.state.index.have = false;
}
}

```

### 3.2 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 immediate, and is denoted `simm`
- `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`
- Opcode 0x2: `add rA, sp, #simm`
- Opcode 0x3: `add rA, fp, #simm`
- Opcode 0x4: `cmp rA, #simm`
  - Note: Compare `rA` to `simm`.
  - Affectable flags: Z, C, V, N
- Opcode 0x5: `cpy rA, #simm`
  - Note: Copy an immediate value into `rA`
- Opcode 0x6: `lsl rA, #simm`
  - Note: Logical shift left
- Opcode 0x7: `lsr rA, #simm`
  - Note: Logical shift right
- Opcode 0x8: `asr rA, #simm`
  - Note: Arithmetic shift right
- Opcode 0x9: `and rA, #simm`
  - Note: Bitwise AND
- Opcode 0xa: `orr rA, #simm`
  - Note: Bitwise OR
- Opcode 0xb: `xor rA, #simm`
  - Note: Bitwise XOR
- Opcode 0xc: `zeb rA`
  - Effect: Set `rA[31:8]` to zero.



- Opcode 0xd: **zeh** *rA*
  - Effect: Set *rA*[31:16] to zero.
- Opcode 0xe: **seb** *rA*
  - Effect: Sign-extend *rA*[7:0] to 32 bits, then copy that value to *rA*
- Opcode 0xf: **seh** *rA*
  - Effect: Sign-extend *rA*[15:0] to 32 bits, then copy that value to *rA*

### 3.3 Instruction Group 2

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

010f oooo cccc aaaa, where

- o is the opcode
- c encodes register *rC*
- 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*, *rC*
  - Mnemonic for when flags not affected: **add**
  - Mnemonic for when flags affected: **add.f**
  - Affectable flags: Z, C, V, N
- Opcode 0x1: **sub** *rA*, *rC*
  - 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*, *rC*
  - Mnemonic for when flags not affected: **add**
  - Mnemonic for when flags affected: **add.f**
  - Affectable flags: Z, C, V, N

- Opcode 0x3: **add rA, rC**
  - Mnemonic for when flags not affected: **add**
  - Mnemonic for when flags affected: **add.f**
  - Affectable flags: Z, C, V, N
- Opcode 0x4: **cmp rA, rC**
  - Note: Compare **rA** to **rC**. **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, rC**
  - Mnemonic for when flags not affected: **cpy**
  - Mnemonic for when flags affected: **cpy.f**
  - Note: Copy **rC** into **rA**
  - Affectable flags: Z, N
- Opcode 0x6: **lsl rA, rC**
  - Mnemonic for when flags not affected: **lsl**
  - Mnemonic for when flags affected: **lsl.f**
  - Note: Logical shift left
  - Affectable flags: Z, N
- Opcode 0x7: **lsr rA, rC**
  - Mnemonic for when flags not affected: **lsr**
  - Mnemonic for when flags affected: **lsr.f**
  - Note: Logical shift right
  - Affectable flags: Z, N
- Opcode 0x8: **asr rA, rC**
  - Mnemonic for when flags not affected: **asr**
  - Mnemonic for when flags affected: **asr.f**
  - Note: Arithmetic shift right
  - Affectable flags: Z, N
- Opcode 0x9: **and rA, rC**
  - Mnemonic for when flags not affected: **and**
  - Mnemonic for when flags affected: **and.f**
  - Note: Bitwise AND

- Affectable flags: Z, N
- Opcode 0xa: **orr rA, rC**
  - Mnemonic for when flags not affected: **orr**
  - Mnemonic for when flags affected: **orr.f**
  - Note: Bitwise OR
  - Affectable flags: Z, N
- Opcode 0xb: **xor rA, rC**
  - Mnemonic for when flags not affected: **xor**
  - Mnemonic for when flags affected: **xor.f**
  - Note: Bitwise XOR
  - Affectable flags: Z, N
- Opcode 0xc: **adc rA, rC**
  - Mnemonic for when flags not affected: **adc**
  - Mnemonic for when flags affected: **adc.f**
  - Note: Add with Carry
  - Affectable flags: Z, C, V, N
- Opcode 0xd: **sbc rA, rC**
  - Mnemonic for when flags not affected: **sbc**
  - Mnemonic for when flags affected: **sbc.f**
  - Note: Subtract with Borrow
  - Affectable flags: Z, C, V, N

### 3.4 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, 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
  - In-Depth Effect:  $1r \leq pc + 2; pc \leq pc + simm + 2;$
- Opcode 0x1: **bra** *simm*
  - Name: BRanch Always
  - Description: Relative branch always
  - Effect:  $pc \leq pc + simm + 2;$
- Opcode 0x2: **beq** *simm*
  - Name: Branch if EQual
  - Effect:  $if (flags.Z) pc \leq pc + simm + 2;$
- Opcode 0x3: **bne** *simm*
  - Name: Branch if Not Equal
  - Effect:  $if (!flags.Z) pc \leq pc + simm + 2;$
- Opcode 0x4: **bmi** *simm*
  - Name: Branch if MInus
  - Effect:  $if (flags.N) pc \leq pc + simm + 2;$
- Opcode 0x5: **bpl** *simm*
  - Name: Branch if PLus
  - Effect:  $if (!flags.N) pc \leq pc + simm + 2;$
- Opcode 0x6: **bvs** *simm*
  - Name: Branch if oVerflow Set
  - Effect:  $if (flags.V) pc \leq pc + simm + 2;$
- Opcode 0x7: **bvc** *simm*
  - Name: Branch if oVerflow Clear
  - Effect:  $if (!flags.V) pc \leq pc + simm + 2;$
- Opcode 0x8: **bgeu** *simm*
  - Name: Branch if Greater than or Equal Unsigned
  - Effect:  $if (flags.C) pc \leq pc + simm + 2;$
- Opcode 0x9: **bltu** *simm*
  - Name: Branch if Less Than Unsigned

- Effect: if ( $\neg \text{flags.C}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xa: **bgtu** *sim*
  - Name: Branch if Greater Than Unsigned
  - Effect: if ( $\text{flags.C AND } \neg \text{flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xb: **bleu** *sim*
  - Name: Branch if Less than or Equal Unsigned
  - Effect: if ( $\neg \text{flags.C OR flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xc: **bges** *sim*
  - Name: Branch if Greater than or Equal Signed
  - Effect: if ( $\neg (\text{flags.N XOR flags.V})$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xd: **blts** *sim*
  - Name: Branch if Less Than Signed
  - Effect: if ( $\text{flags.N XOR flags.V}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xe: **bgts** *sim*
  - Name: Branch if Greater Than Signed
  - Effect: if ( $\neg (\text{flags.N XOR flags.V}) \text{ AND } \neg \text{flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;
- Opcode 0xf: **bles** *sim*
  - Name: Branch if Less than or Equal Signed
  - Effect: if ( $(\text{flags.N XOR flags.V}) \text{ OR flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim} + 2$ ;

### 3.5 Instruction Group 4

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

100o oooo cccc aaaa, where

- o is the opcode
- c encodes register **rC** or register **sC**, where **sC** is one of **hi**, **lo**, **flags**, **ira**, **ids**, or **ie**
- a encodes register **rA** or register **sA**, where **sA** is one of **hi**, **lo**, **flags**, **ira**, **ids**, or **ie**

Here is a list of instructions from this encoding group.

- Opcode 0x0: **j1 rA**
  - Effect:  $lr \leq pc + 2$ ;  $pc \leq rA$ ;
- Opcode 0x1: **jmp rA**
  - Effect:  $pc \leq rA$ ;
- Opcode 0x2: **jmp rA, rC**
  - Effect:  $pc \leq (rA + rC)$ ;
- Opcode 0x3: **jmp ira**
  - Effect:  $pc \leq ira$ ;
- Opcode 0x4: **reti**
  - Effect: enables interrupts (by copying 1 into **ie**) and performs  $pc \leq ira$ ;
- Opcode 0x5: **cpy rA, sC**
  - Effect:  $rA \leq sC$ ;
- Opcode 0x6: **cpy sA, rC**
  - Effect:  $sA \leq rC$ ;
- Opcode 0x7: **ei**
  - Effect: copy 1 into **ie**.
- Opcode 0x8: **di**
  - Effect: copy 0 into **ie**.
- Opcode 0x9: **push rA, rC**
  - Effect: pushes **rA** onto the stack, using **rC** as the stack pointer, post-decrementing **rC**.
  - This instruction does nothing when **rA** is the same register as **rC**.
- Opcode 0xa: **pop rA, rC**
  - Effect: pops **rA** off the stack, using **rC** as the stack pointer, pre-incrementing **rC**.
  - This instruction does nothing when **rA** is the same register as **rC**.
- Opcode 0xb: **push sA, rC**

- Effect: pushes **sA** onto the stack, using **rC** as the stack pointer, post-decrementing **rC**.
  - Note that **sA** is considered to be 32-bit for the purpose of the store to memory and decrementing **rC**, even if **sA** is **flags** or **ie**.
- Opcode 0xc: **pop sA, rC**
  - Effect: pops **sA** off the stack, using **rC** as the stack pointer, pre-incrementing **rC**.
  - Note that **sA** is considered to be 32-bit for the purpose of the load from memory and incrementing **rC**, even if **sA** is **flags** or **ie**.
- Opcode 0xd: **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.
  - Note: Any time **index** stops being in effect, **pre** will stop being in effect as well.
- Opcode 0xe: **mul rA, rC**
  - Effect: `rA <= rA * rC;`
- Opcode 0xf: **udiv rA, rC**
  - Effect: `rA <= u32(rA) / u32(rC);`
- Opcode 0x10: **sdiv rA, rC**
  - Effect: `rA <= s32(rA) / s32(rC);`
- Opcode 0x11: **umod rA, rC**
  - Effect: `rA <= u32(rA) % u32(rC);`
- Opcode 0x12: **smod rA, rC**
  - Effect: `rA <= s32(rA) % s32(rC);`

- Opcode 0x13: **lumul rA, rC**
  - Effect: This instruction multiplies **rA** by **rC**, performing an unsigned 32-bit by 32-bit -> 64-bit multiply, storing result in {hi, lo}.
- Opcode 0x14: **lsmul rA, rC**
  - Effect: This instruction multiplies **rA** by **rC**, performing a signed 32-bit by 32-bit -> 64-bit multiply, storing result in {hi, lo}.
- Opcode 0x15: **ludiv rA, rC**
  - Effect: performs a 64-bit by 64-bit unsigned division of {hi, lo} by {rA, rC}, storing 64-bit result in {hi, lo}.
  - Note: This instruction executes more quickly if **rA**'s value is 0x00000000, i.e. if the operation is actually a 64-bit by 32-bit -> 64-bit unsigned divide.
- Opcode 0x16: **lsdiv rA, rC**
  - Effect: performs a 64-bit by 64-bit signed division of {hi, lo} by {rA, rC}, storing 64-bit result in {hi, lo}.
  - Note: This instruction executes more quickly if **rA** is equal to bits [63:32] of **sign\_extend\_to\_64(rC)**.
- Opcode 0x17: **lumod rA, rC**
  - Effect: performs a 64-bit by 64-bit unsigned modulo of {hi, lo} by {rA, rC}, storing 64-bit result in {hi, lo}.
  - Note: This instruction executes more quickly if **rA**'s value is 0x00000000, i.e. if the operation is actually a 64-bit by 32-bit -> 64-bit unsigned modulo.
- Opcode 0x18: **lsmod rA, rC**
  - Effect: performs a 64-bit by 64-bit signed modulo of {hi, lo} by {rA, rC}, storing 64-bit result in {hi, lo}.
  - Note: This instruction executes more quickly if **rA** is equal to bits [63:32] of **sign\_extend\_to\_64(rC)**.
- Opcode 0x19: **ldub rA, [rC]**
  - Effect: Load an 8-bit value from memory at address computed as **rC** + <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 rB** instruction before this one: **ldub rA, [rC, rB]**



- Opcode 0x1a: **ldsb** rA, [rC]
  - Effect: Load an 8-bit value from memory at address computed as rC + <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** rB instruction before this one: **ldsb** rA, [rC, rB]
- Opcode 0x1b: **lduh** rA, [rC]
  - Effect: Load a 16-bit value from memory at address computed as rC + <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** rB instruction before this one: **lduh** rA, [rC, rB]
- Opcode 0x1c: **ldsh** rA, [rC]
  - Effect: Load a 16-bit value from memory at address computed as rC + <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** rB instruction before this one: **ldsh** rA, [rC, rB]
- Opcode 0x1d: **stb** rA, [rC]
  - Effect: Store rA[7:0] to memory at the address computed as rC + <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** rB instruction before this one: **stb** rA, [rC, rB]
- Opcode 0x1e: **sth** rA, [rC]
  - Effect: Store rA[15:0] to memory at the address computed as rC + <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** rB instruction before this one: **sth** rA, [rC, rB]

### 3.6 Instruction Group 5: Immediate Indexed Load

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

101*i* *iiii* *cccc* *aaaa*, where

- *i* is a 5-bit sign-extended immediate, which can be expanded by **pre**, and is denoted **simm**
- *c* encodes register **rC**
- *a* encodes register **rA**

The one instruction from this encoding group is **ldr rA, [rC, #simm]**. This is a 32-bit load into **rA**, where the effective address to load from is computed as **rC + <index\_reg> + simm**, using the sign-extended form of **simm**.

The **<index\_reg>** value is guaranteed to be zero unless an **index** is in effect.

Shorthand for having the assembler insert an **index rB** instruction before this one: **ldr rA, [rC, rB, #simm]**

### 3.7 Instruction Group 6: Immediate Indexed Store

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

110*i* *iiii* *cccc* *aaaa*, where

- *i* is a 5-bit sign-extended immediate, which can be expanded by **pre**
- *c* encodes register **rC**
- *a* encodes register **rA**

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

The **<index\_reg>** value is guaranteed to be zero unless an **index** is in effect.

Shorthand for having the assembler insert an **index rB** instruction before this one: **str rA, [rC, rB, #simm]**