

Flare32 CPU

FL4SHK

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# Introduction

## 2.1 Registers

There are sixteen general-purpose registers: **r0**, **r1**, **r2**, . . . , **r11**, **r12**, **lr**, **fp**, **sp**. Each register is 32 bits long. For special purpose registers, there are also **pc**, the program counter (which is 32 bits long), and the **flags**. Also there are the interrupts-related registers: **ids** (the destination to go to upon an interrupt happening), **ira** (the program counter value to return to after an interrupt) and **ie** (whether or not interrupts are enabled). Two more registers are **hi** and **lo**, which are used as the high 32 bits and low 32 bits of the result of a 32 by 32 -> 64 multiplication, or as the high 32 bits and low 32 bits of the result of a 64 by 64 -> 64 division. Here are the flags:

Table 1: The Flags

Zero (Z)	Carry (C)	oVerflow (V)	Negative (N)
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## 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.

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.

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, fp, 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

- o is the opcode
- i is a 9-bit sign-extended immediate, which can still be affected by **pre**, but when **pre** is the instruction before this one, only bits [4:0] of the immediate value encoded into this instruction will be used by the hardware, with the remaining bits of the immediate coming from however many **pre** instructions were used. Multiple **pre** instructions can still form larger than 18-bit branch offsets. This immediate is denoted **simm**.

Here is a list of instructions from this encoding group.

- Opcode 0x0: **bl** **simm**
  - Effect:  $lr \leq pc + 2$ ;  $pc \leq pc + simm + 2$ ;
- Opcode 0x1: **bra** **simm**
  - Effect:  $pc \leq pc + simm + 2$ ;
- Opcode 0x2: **bne** **simm**
  - Effect: if (!flags.Z)  $pc \leq pc + simm + 2$ ;
- Opcode 0x3: **beq** **simm**
  - Effect: if (flags.Z)  $pc \leq pc + simm + 2$ ;
- Opcode 0x4: **bpl** **simm**
  - Effect: if (!flags.N)  $pc \leq pc + simm + 2$ ;
- Opcode 0x5: **bmi** **simm**
  - Effect: if (flags.N)  $pc \leq pc + simm + 2$ ;
- Opcode 0x6: **bvc** **simm**
  - Effect: if (!flags.V)  $pc \leq pc + simm + 2$ ;
- Opcode 0x7: **bvs** **simm**
  - Effect: if (flags.V)  $pc \leq pc + simm + 2$ ;
- Opcode 0x8: **bgeu** **simm**
  - Effect: if (flags.C)  $pc \leq pc + simm + 2$ ;

- Opcode 0x9: **bltu** *sim*m  
 – Effect: if ( $\neg \text{flags.C}$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xa: **bgtu** *sim*m  
 – Effect: if ( $\text{flags.C AND } (\neg \text{flags.Z})$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xb: **bleu** *sim*m  
 – Effect: if ( $(\neg \text{flags.C}) \text{ OR } \text{flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xc: **bges** *sim*m  
 – Effect: if ( $\neg (\text{flags.N XOR flags.V})$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xd: **blts** *sim*m  
 – Effect: if ( $\text{flags.N XOR flags.V}$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xe: **bgts** *sim*m  
 – Effect: if ( $(\neg (\text{flags.N XOR flags.V})) \text{ AND } (\neg \text{flags.Z})$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;
- Opcode 0xf: **bles** *sim*m  
 – Effect: if ( $(\text{flags.N XOR flags.V}) \text{ OR } \text{flags.Z}$ )  $\text{pc} \leq \text{pc} + \text{sim}m + 2$ ;

### 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:  $\text{lr} \leq \text{pc} + 2$ ;  $\text{pc} \leq \text{rA}$ ;

- 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  $\langle \text{index\_reg} \rangle \leftarrow \text{rA}$ ; 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:  $\text{rA} \leftarrow \text{rA} * \text{rC}$ ;
- Opcode 0xf: **udiv rA, rC**
  - Effect:  $\text{rA} \leftarrow \text{u32}(\text{rA}) / \text{u32}(\text{rC})$ ;
- Opcode 0x10: **sdiv rA, rC**
  - Effect:  $\text{rA} \leftarrow \text{s32}(\text{rA}) / \text{s32}(\text{rC})$ ;
- Opcode 0x11: **umod rA, rC**
  - Effect:  $\text{rA} \leftarrow \text{u32}(\text{rA}) \% \text{u32}(\text{rC})$ ;
- Opcode 0x12: **smod rA, rC**
  - Effect:  $\text{rA} \leftarrow \text{s32}(\text{rA}) \% \text{s32}(\text{rC})$ ;
- Opcode 0x13: **lumul rA, rC**
  - Effect: This instruction multiplies **rA** by **rC**, performing an unsigned 32-bit by 32-bit  $\rightarrow$  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:

101i 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:

110i 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]**