Boneless-III Architecture Reference Manual

Notice:

This document is a work in progress and subject to change without warning. However, the parts that are *especially* subject to change carry a notice similar to this one.

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1 Introduction

TBD

2 Guide to Instruction Set

This guide first explains how to interpret the notation used in this document. After, it explains the available registers and their behavior.

2.1 Operation Syntax

This document uses the following syntax and operators to describe the operation of each instruction.

2.1.1 Undefined and Unpredictable Behavior

To describe the boundaries of legal program behavior, this document uses the words **UNDEFINED** and **UNPREDICTABLE**.

When execution encounters **UNPREDICTABLE** behavior, the implementation may perform any behavior, including but not limited to hanging and failing to continue execution. The resulting behavior may be different between executions even under the same circumstances.

Certain operations, including any operation with an **UNDEFINED** input, will produce an **UNDEFINED** result. Reading a register whose value is currently **UNDEFINED** may produce any bit pattern. Multiple consecutive reads of such a register may also produce different bit patterns on each read.

2.1.2 Reference Operators

The following operators reference parts of variables or the attached memory.

- opB ← opA: Store opA into opB. If necessary, opA is implicitly zero-extended or truncated to match the length of opB.
- op[b:a]: Reference bits a through b, inclusive, of op. If a is greater than b, the resulting length is zero.
- mem[addr]: Reference memory word at word address addr. The address is implicitly ANDed with **0xffff**.
- ext[addr]: Reference external bus word at word address addr. The address is implicitly ANDed with 0xFFFF.
- {opA, opB}: Concatenate the bits of opA and opB. opA makes the high-order bits of the result and opB makes the low-order bits.
- opB{opA}: Construct the result by repeating opA opB times.

2.1.3 Arithmetic Operators

The arithmetic operators perform arithmetic or bitwise logic between the operands. All operands to these operators are unsigned. If one operand is shorter than the other, it is zero-extended to match the length of the other.

- opA + opB: Add opA and opB. The high bit of the result is a carry bit.
- opA and opB: Perform a bitwise AND between opA and opB.
- opA or opB: Perform a bitwise OR between opA and opB.
- opA xor opB: Perform a bitwise XOR between opA and opB.
- **not op**: Perform a bitwise negation of **op**.

2.1.4 Logical Operators

The logical operators yield 1 if the condition is satisfied and 0 if it is not. If one operand is shorter than the other, it is zero-extended to match the length of the other.

- opA = opB: Satisfied if opA equals opB.
- opA <> opB: Satisfied if opA does not equal opB.

2.1.5 Functions

- sign_extend_16(op): Perform a sign extension of op by replicating the high bit until the total length is 16 bits.
- decode_imm_al(op): Calculate the immediate value of an arithmetic or logical instruction according to the following table.

op	Result
0	0x0000
1	0x0001
2	0008x0
3	TBD
4	0x00FF
5	0xFF00
6	0x7FFF
7	0xFFFF

• decode_imm_sr(op): Calculate the immediate value of a shift or rotate instruction according to the following table.

op	Result
0	8
1	1
2	2
3	3
4	4
5	5
6	6
7	7

2.2 Registers

The CPU contains a number of registers that are used to store data, computation results, and system state. The registers are operated on as described by the operation of each instruction. If a register is not modified by an instruction, its value is preserved, except where noted in this register definition.

2.2.1 Program Counter

The CPU features a 16-bit program counter named PC. All instructions are 16 bit, so all values of PC are valid.

Unless otherwise specified by an instruction's operation, PC \leftarrow PC+1 after each instruction.

The behavior of $PC \leftarrow op$ defines that op is truncated to 16 bits to fit PC. Thus, adjusting PC is defined to wrap.

At reset, PC \leftarrow 0x0000, but this value can be changed by the implementation.

2.2.2 General Purpose Registers and the Window

The CPU has eight 16-bit general purpose (GP) integer registers, named **R0** through **R7**. They are fully interchangeable and can be used as source and/or destination for any instruction which uses a GP register. The register file is windowed: register values are stored in main memory, starting at the window address.

The current window address is stored in a 16-bit register named W. Its value can only be set and/or read by the four window instructions: ADJW, LDW, STW, and XCHW. Setting W logically changes the values of all GP registers simultaneously, enabling fast procedure calls and task switches.

W is added to the number of a GP register to calculate the address where that register is stored. For example, the operation $mem[W+3] \leftarrow mem[W+1]$ sets R3 equal to R1.

The behavior of $W \leftarrow op$ and mem[op] defines that op is truncated to 16 bits to fit W. Thus, adjusting W and calculating GP register addresses are defined to wrap.

At reset, $W \leftarrow 0xFFF8$, but this value can be changed by the implementation.

2.2.3 Result Flags

The CPU has four result flags to describe the result of ALU computations. The flags are updated by most ALU instructions. The CPU can act on the result of the flags by executing a conditional jump which transfers control if the flags are in the desired state. The exact contents of each flag after an instruction executes are explained in the instruction's operation, but the general purpose and behavior of each flag are explained below.

The Z (Zero) flag is set to 1 if the low 16 bits of the result of the operation were zero, and 0 otherwise.

The S (negative) flag is set to the 15th bit of the result of the operation.

The C (Carry) flag is set to the 16th bit of the result of an arithmetic operation, or UNDEFINED if the operation was logical.

The **V** (oVerflow) flag is set if the arithmetic operation encountered two's complement overflow, or **UNDEFINED** if the operation was logical.

2.2.4 Extended Immediate

The CPU has two registers that help build a 16-bit immediate value.

The **EXTI** instruction sets the **ext13** register to its 13-bit immediate and the **has_ext13** register to 1.

Generally, if an instruction can use an immediate and has_ext13 is 1, the instruction will use ext13 as the high 13 bits of the the immediate value and take the low 3 bits from the instruction itself. The exact behavior of an instruction with regards to has_ext13 and ext13 is specified in the instruction's operation.

Except for after EXTI, ext13 \leftarrow UNDEFINED and has_ext13 \leftarrow 0 after every instruction, even those which do not use either register.

3 List of Instructions

The following pages provide a detailed description of instructions, arranged in alphabetical order.

Executing any instruction with an encoding not present on the following pages has ${f UNPREDICTABLE}$ behavior.

3.1 ADC

Add Register with Carry

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
ADC		0	0001	0			Rd			Ra		0	1		Rb	

Assembly:

Purpose:

To add 16-bit integers in registers, with carry input.

Restrictions:

None.

Operation:

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← opA + opB + C
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← res[16]
V ← (opA[15] = opB[15]) and (opA[15] <> res[15])
```

Remarks:

A 32-bit addition with both operands in registers can be performed as follows:

```
; Perform {R1, R0} \leftarrow {R3, R2} + {R5, R4} ADD R0, R2, R4 ADC R1, R3, R5
```

3.2 ADCI

Add Immediate with Carry

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ADCI	00011						Rd			Ra		0	1	i	mm	3

Encoding (long form):

	F	E	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	t13						
ADCI		0	0001	1			Rd			Ra		0	1	iı	mm	3

Assembly:

ADCI Rd, Ra, imm

Purpose:

To add a constant to a 16-bit integer in a register, with carry input.

Restrictions:

None.

Operation:

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_al(imm3)
res ← opA + opB + C
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← res[16]
V ← (opA[15] = opB[15]) and (opA[15] <> res[15])
```

Remarks:

A 32-bit addition with a register and an immediate operand can be performed as follows:

```
; Perform {R1, R0} \leftarrow {R3, R2} + 0x40001 ADDI R0, R2, 1 ADCI R1, R3, 4
```

3.3 ADD Add Register

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ADD		0	0001			Rd			Ra		0	0		Rb		

Assembly:

ADD Rd, Ra, Rb

Purpose:

To add 16-bit integers in registers.

Restrictions:

None.

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← opA + opB
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← res[16]
V ← (opA[15] = opB[15]) and (opA[15] <> res[15])
```

3.4 ADDI Add Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ADDI		0	0001			Rd			Ra		0	0	- 11	mm	3	

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
ADDI	00011						Rd			Ra		0	0	iı	mm	3

Assembly:

ADDI Rd, Ra, imm

Purpose:

To add a constant to a 16-bit integer in a register.

Restrictions:

None.

3.5 ADJW

Adjust Window Address

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ADJW		1	010			000			010			i	mm	5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	110 ext13															
ADJW		1	010	0			000			010			iı	nm	5	

Assembly:

ADJW imm

Purpose:

To increase or decrease the address of the register window.

Restrictions:

If imm contains a value that is not a multiple of 8, the behavior is UNPREDICTABLE. If the long form is used, and imm5[4:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then imm \( \infty \{ \text{ext13, imm5[2:0]} \}
else imm \( \infty \text{sign_extend_16(imm5)} \)
\( \infty \infty \text{W} + \text{imm} \)
```

Remarks:

This instruction may be used in a function prologue or epilogue.

Notice:

The interpretation of the immediate field of this instruction is not final.

3.6 AND

Bitwise AND with Register

Encoding:

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
AND		0	0000	0			Rd			Ra		0	0		Rb	

Assembly:

AND Rd, Ra, Rb

Purpose:

To perform bitwise AND between 16-bit integers in registers.

Restrictions:

None.

Operation:

 $\begin{array}{lll} opA & \leftarrow & mem[W+Ra] \\ opB & \leftarrow & mem[W+Rb] \\ res & \leftarrow & opA \ and \ opB \\ mem[W+Rd] & \leftarrow & res \\ Z & \leftarrow & res[15:0] = 0 \\ S & \leftarrow & res[15] \\ C & \leftarrow & UNDEFINED \\ V & \leftarrow & UNDEFINED \end{array}$

3.7 ANDI

Bitwise AND with Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ANDI	00001						Rd			Ra		0	0	i	mm	3

Encoding (long form):

	F	F E D 110 0000		С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
ANDI		0	0000	1			Rd			Ra		0	0	iı	mm	3

Assembly:

ANDI Rd, Ra, imm

Purpose:

To perform bitwise AND between a 16-bit integer in a register and a constant.

Restrictions:

None.

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_al(imm3)
res ← opA and opB
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
CMP		0	0000	0		(000			Ra		1	1		Rb	

Assembly:

Purpose:

To compare 16-bit two's complement integers in registers.

Restrictions:

None.

Operation:

```
\begin{array}{l} opA \leftarrow mem[W+Ra] \\ opB \leftarrow mem[W+Rb] \\ res \leftarrow opA + \textbf{not} \ opB + 1 \\ Z \leftarrow res[15:0] = 0 \\ S \leftarrow res[15] \\ C \leftarrow res[16] \\ V \leftarrow (opA[15] = \textbf{not} \ opB[15]) \ \textbf{and} \ (opA[15] \Leftrightarrow res[15]) \end{array}
```

Remarks:

This instruction behaves identically to SUB, with the exception that it discards the computed value.

3.9 CMPI

Compare to Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
CMPI		0	0000	1			000			Ra		1	1	i	mm	3

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI	. 110 EX112															
CMPI		0	0000	1			000			Ra		1	1	iı	mm	3

Assembly:

CMPI Rd, Ra, imm

Purpose:

To compare a two's complement constant to a 16-bit two's complement integer in a register.

Restrictions:

None.

Operation:

Remarks:

This instruction behaves identically to SUBI, with the exception that it discards the computed value.

3.10 EXTI

Extend Immediate

Encoding:

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							im	m1	3					

Assembly:

EXTI imm

Purpose:

To extend the range of immediate in the following instruction.

Restrictions:

None.

Operation:

 $ext13 \leftarrow imm13$ $has_ext13 \leftarrow 1$

Remarks:

This instruction is automatically emitted by the assembler while translating other instructions. As it changes both the meaning of and the constraints placed on the immediate field in the following instruction, placing it manually may lead to unexpected results.

3.11 J Jump

Encoding (short form):

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
J		10	11			111	11					of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	L 110 ext13															
J	1011 1111											of	f8			

Assembly:

J label

Purpose:

To unconditionally transfer control.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \( \infty \) {ext13, off8[2:0]}
else off \( \infty \) sign_extend_16(off8)
PC \( \infty \) PC + 1 + off
```

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JAL		1	010	1			Rd					of.	f 8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
JAL		1	010	1			Rd					of	f8			

Assembly:

JAL Rd, label

Purpose:

To transfer control to a subroutine.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off8[2:0]}
else off \leftarrow sign_extend_16(off8)
mem[W+Rd] \leftarrow PC + 1
PC \leftarrow PC + 1 + off
```

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JC		10	11			101	10					of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110	. 0 ext13													
JC		110 ext13 1011 1010 off8														

Assembly:

JC label

Purpose:

To transfer control if an arithmetic operation resulted in unsigned overflow.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (C)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JUGE.

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JE		10	11			100	00					of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13												
JE		10	ext13 011 1000 off8													

Assembly:

JE label

Purpose:

To transfer control after a \mbox{CMP} Ra, Rb instruction if Ra is equal to Rb.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (Z)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JZ.

3.15 JN Jump Never

Encoding (short form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JN		10	11			011	11					of	f8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
JN		10	11			013	11					-0t	f 8			

Assembly:

JN label

Purpose:

To serve as a placeholder for a jump instruction.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

 $PC \leftarrow PC + 1$

Remarks:

The JN instruction has no effect. It may be used as a placeholder for a different jump instruction with a predefined offset when the exact condition is unknown, such as in certain self-modifying code.

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JNC		10	11			00	10					_ ot	f 8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13												
JNC		10	11			00	10					of	f8			

Assembly:

JNC label

Purpose:

To transfer control if an arithmetic operation did not result in unsigned overflow.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not C)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JULT.

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JNE		10	11			000	00					_of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13												
JNE		10	11	ext13												

Assembly:

JNE label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is not equal to Rb.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not Z)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JNZ.

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JNO		10	11			001	11					_of	f8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
JNO		11					-ct	f 8								

Assembly:

JNO label

Purpose:

To transfer control if an arithmetic operation did not result in signed overflow.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not V)
then PC ← PC + 1 + off
else PC ← PC + 1
```

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JNS		10	11			000	01					_of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110 ext13														
JNS	1011 0001											of	f8			

Assembly:

JNS label

Purpose:

To transfer control if an arithmetic or shift operation produced a non-negative result.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not S)
then PC ← PC + 1 + off
else PC ← PC + 1
```

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JNZ		10	11			000	00					_of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110	10 ext13													
JNZ		10	11			000	90					of	f 8			

Assembly:

JNZ label

Purpose:

To transfer control if an arithmetic or shift operation produced a non-zero result.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not Z)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JNE.

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JO		10	11			101	11					of	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	L 110 EXT13															
JO		10	11			10	11					of	f8			

Assembly:

JO label

Purpose:

To transfer control if an arithmetic operation resulted in signed overflow.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (V)
then PC ← PC + 1 + off
else PC ← PC + 1
```

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JR		1	010	0			Rs			100				off5		

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
JR		1	010	0			Rs			100				off5		

Assembly:

JR Rs, off

Purpose:

To transfer control to a variable absolute address contained in a register, with a constant offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \( \) {ext13, off5[2:0]}
else off \( \) sign_extend_16(off5)
PC \( \) mem[\( \) +Ra] + off
```

3.23 JRAL

Jump to Register and Link

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JRAL		1	010	0			Rd			101		0	0		Rb	

Assembly:

JRAL Rd, Rb

Purpose:

To transfer control to a subroutine whose variable absolute address is contained in a register.

Restrictions:

None.

```
\begin{array}{l} \text{addr} \leftarrow \text{mem[W+Rb]} \\ \text{mem[W+Rd]} \leftarrow \text{PC} + 1 \\ \text{PC} \leftarrow \text{addr} \end{array}
```

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JS		10	11			100	01					of	f8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
JS		10	11			100	01					-0t	f 8			

Assembly:

JS label

Purpose:

To transfer control if an arithmetic or shift operation produced a negative result.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (S)
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.25 **JSGE**

Jump if Signed Greater or Equal

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JSGE		10	11			010	01					Ot.	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	110 ext13															
JSGE		10	11			010	01					of	f8			

Assembly:

JSGE label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is greater than or equal to Rb when interpreted as signed integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not (S xor V))
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.26 **JSGT**

Jump if Signed Greater Than

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JSGT	1011			0110				off8								

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	110			ext13												
JSGT	1011					off8										

Assembly:

JSGT label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is greater than to Rb when interpreted as signed integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not ((S xor V) or Z))
then PC ← PC + 1 + off
else PC ← PC + 1
```

Encoding (short form):

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JSLE		10	11			111	10					of	f8			

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110														
JSLE	1011 1110 off8															

Assembly:

JSLE label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is less than or equal to Rb when interpreted as signed integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (((S xor V) or Z))
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.28 JSLT

Jump if Signed Less Than

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JSLT		10	11			110	01					Ot.	f8			

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110 ext13														
JSLT																

Assembly:

JSLT label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is less than Rb when interpreted as signed integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if ((S xor V))
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.29 JST

Jump through Switch Table

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JST		1	010	0			Rs			111				off5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
JST		1	010	0			Rs			111				off5		

Assembly:

JST Rs, off

Purpose:

To transfer control to an address contained in a jump table at a variable offset, where the address is relative to the location of the table.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off5[2:0]}
else off ← sign_extend_16(off5)
table ← PC + 1 + off
entry ← mem[W+Rs]
addr ← mem[table + entry]
PC ← table + addr
```

3.30 JUGE

Jump if Unsigned Greater or Equal

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JUGE		10	11			101	10					Ot.	f 8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110	ext13 011 1010 off8													
JUGE						of	f8									

Assembly:

JUGE label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is greater than or equal to Rb when interpreted as unsigned integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (C)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JC.

3.31 JUGT

Jump if Unsigned Greater Than

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JUGT		10	11			01	10					Ot.	f8			

Encoding (long form):

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13												
JUGT	1011 0110											of	f8			

Assembly:

JUGT label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is greater than to Rb when interpreted as unsigned integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not ((not C) or V))
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.32 JULE

Jump if Unsigned Less or Equal

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JULE		1011				111	10					Ot.	f 8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13												
JULE	1011 1110											of	f8			

Assembly:

JULE label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is less than or equal to Rb when interpreted as unsigned integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if ((not C) or V)
then PC ← PC + 1 + off
else PC ← PC + 1
```

3.33 JULT

Jump if Unsigned Less Than

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
JULT		10	11			001	10					-0t	f8			

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13 off8												
JULT						of	f8									

Assembly:

JULT label

Purpose:

To transfer control after a CMP Ra, Rb instruction if Ra is less than Rb when interpreted as unsigned integer.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (not C)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JNC.

3.34 JVT

Jump through Virtual Table

Encoding (short form):

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JVT		1	010	0			Rs			110				off5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
JVT		1	010	0			Rs			110				off5		

Assembly:

JVT Rs, off

Purpose:

To transfer control to an address contained in a jump table at a constant offset, where the address is relative to the location of the table.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off5[2:0]}
else off ← sign_extend_16(off5)
table ← mem[W+Rs]
addr ← mem[table + off]
PC ← table + addr
```

Encoding (short form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
JZ		10	11			100	00					of	f8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110		ext13 1000 off8												
JZ						of	f8									

Assembly:

JZ label

Purpose:

To transfer control if an arithmetic or shift operation produced a zero result.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

Operation:

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
if (Z)
then PC ← PC + 1 + off
else PC ← PC + 1
```

Remarks:

This instruction has the same encoding as JE.

3.36 LD Load

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
LD		01000					Rd			Ra				off5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	L 110 ext13															
LD		0	100	0			Rd			Ra				off5		

Assembly:

LD Rd, Ra, off

Purpose:

To load a word from memory at a variable address, with a constant offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off5[2:0]}
else off ← sign_extend_16(off5)
addr ← mem[W+Ra] + off
data ← mem[addr]
mem[W+Rd] ← data
```

3.37 LDR

Load PC-relative

Encoding (short form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
LDR		0	100	1			Rd			Ra				off5		

Encoding (long form):

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	. 110 ext13															
LDR		0	100	1			Rd			Ra				off5		

Assembly:

LDR Rd, Ra, off

Purpose:

To load a word from memory at a constant PC-relative address, with a variable offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off5[2:0]}
else off \leftarrow sign_extend_16(off5)
addr \leftarrow PC + 1 + off + mem[W+Ra]
data \leftarrow mem[addr]
mem[W+Rd] \leftarrow data
```

3.38 LDW

Adjust and Load Window Address

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
LDW		1	010	0			Rd			011			i	mm	5	

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	t13						
LDW		1	010	0			Rd			011			iı	nm	5	

Assembly:

LDW Rd, imm

Purpose:

To increase or decrease the address of the register window, and retrieve the prior address of the register window.

Restrictions:

If imm contains a value that is not a multiple of 8, the behavior is **UNPREDICTABLE**. If the long form is used, and imm5[4:3] are non-zero, the behavior is **UNPREDICTABLE**.

Operation:

```
if (has_ext13)
then imm ← {ext13, imm5[2:0]}
else imm ← sign_extend_16(imm5)
old ← W
W ← W + imm
mem[W+Rd] ← old
```

Remarks:

See also STW. This instruction may be used in a function prologue, where Rd is any register chosen to act as a frame pointer.

Notice:

The interpretation of the immediate field of this instruction is not final.

3.39 LDX Load External

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
LDX		0	110	0			Rd			Ra				off5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
LDX		0	110	0			Rd			Ra				off5		

Assembly:

LDX Rd, Ra, off

Purpose:

To complete a load cycle on external bus at a variable address, with a constant offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off5[2:0]}
else off \leftarrow sign_extend_16(off5)
addr \leftarrow mem[W+Ra] + off
data \leftarrow ext[addr]
mem[W+Rd] \leftarrow data
```

3.40 LDXA

Load External Absolute

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
LDXA		0	110	1			Rd					of	f8			

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI	110 ext13															
LDXA		0	110	1			Rd					of	f8			

Assembly:

LDXA Rd, off

Purpose:

To complete a load cycle on external bus at a constant absolute address.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off8[2:0]}
else off \leftarrow sign_extend_16(off8)
data \leftarrow ext[off]
mem[W+Rd] \leftarrow data
```

3.41 MOV Move

Assembly:

MOV Rd, Rs

Purpose:

To move a value from register to register.

Restrictions:

None.

Remarks:

The assembler does not translate any instructions for MOV with identical Rd and Rs, and translates MOV with any other register combination to

AND Rd, Rs, Rs

3.42 MOVI

Move Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
IVOM		1	000	0			Rd					im	m8			

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
IVOM		1	000	0			Rd					im	m8			

Assembly:

MOVI Rd, imm

Purpose:

To load a register with a constant.

Restrictions:

If the long form is used, and imm8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
\begin{tabular}{ll} \textbf{if} & (has\_ext13) \\ \textbf{then} & imm &\leftarrow \{ext13, imm8[2:0]\} \\ \textbf{else} & imm &\leftarrow sign\_extend\_16(imm8) \\ mem[W+Rd] &\leftarrow imm \\ \end{tabular}
```

3.43 MOVR

Move PC-relative Address

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
MOVR		1	000	1			Rd					of	f8			

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
MOVR		1	000	1			Rd					of	f 8			

Assembly:

MOVR Rd, off

Purpose:

To load a register with an address relative to PC with a constant offset.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off8[2:0]}
else off \leftarrow sign_extend_16(off8)
mem[W+Rd] \leftarrow PC + 1 + off
```

3.44 OR

Bitwise OR with Register

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
OR		0	000	0			Rd			Ra		0	1		Rb	

Assembly:

OR Rd, Ra, Rb

Purpose:

To perform bitwise OR between 16-bit integers in registers.

Restrictions:

None.

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← opA or opB
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

3.45 ORI

Bitwise OR with Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ORI		0	000	1			Rd			Ra		· (1)	1	iı	mm	3

Encoding (long form):

	F	E	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	L 110 61112															
ORI		0	0000	1			Rd			Ra		0	1	iı	mm	3

Assembly:

ORI Rd, Ra, imm

Purpose:

To perform bitwise OR between a 16-bit integer in a register and a constant.

Restrictions:

None.

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_al(imm3)
res ← opA or opB
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

3.46 ROL Rotate Left

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ROL		0	010	0			Rd			Ra		0	1		Rb	

Assembly:

Purpose:

To perform a left rotate of a 16-bit integer in a register by a variable bit amount.

Restrictions:

If Rb contains a value greater than 15, the behavior is UNPREDICTABLE.

```
\begin{array}{l} opA \;\leftarrow\; mem[W+Ra] \\ opB \;\leftarrow\; mem[W+Rb] \\ res \;\leftarrow\; \{opA[15-opB:0], \; opA[15:16-opB]\} \\ mem[W+Rd] \;\leftarrow\; res \\ Z \;\leftarrow\; res[15:0] \;=\; 0 \\ S \;\leftarrow\; res[15] \\ C \;\leftarrow\; \textbf{UNDEFINED} \\ V \;\leftarrow\; \textbf{UNDEFINED} \end{array}
```

3.47 ROLI

Rotate Left Immediate

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
ROLI		0	010	1			Rd			Ra		0	1	i	mm	3

Assembly:

ROLI Rd, Ra, amount

Purpose:

To perform a left rotate of a 16-bit integer in a register by a constant bit amount.

Restrictions:

The amount may be between 0 and 15, inclusive.

3.48 RORI

Rotate Right Immediate

Assembly:

RORI Rd, Ra, amount

Purpose:

To perform a right rotate of a 16-bit integer in a register by a constant bit amount.

Restrictions:

The amount may be between 0 and 15, inclusive.

Remarks:

The assembler translates RORI with amount of 0 to

ROLI Rd, Ra, 0

and RORI with any other amount to

ROLI Rd, Ra, (16 - amount)

3.49 SBB

Subtract Register with Borrow

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SBB		0	0001	0			Rd			Ra		1	1		Rb	

Assembly:

Purpose:

To subtract 16-bit two's complement integers in registers, with borrow input.

Restrictions:

None.

Operation:

```
\begin{array}{l} opA \leftarrow mem[W+Ra] \\ opB \leftarrow mem[W+Rb] \\ res \leftarrow opA + \textbf{not} \ opB + C \\ mem[W+Rd] \leftarrow res \\ Z \leftarrow res[15:0] = 0 \\ S \leftarrow res[15] \\ C \leftarrow res[16] \\ V \leftarrow (opA[15] = \textbf{not} \ opB[15]) \ \textbf{and} \ (opA[15] <> res[15]) \end{array}
```

Remarks:

A 32-bit subtraction with both operands in registers can be performed as follows:

```
; Perform {R1, R0} \leftarrow {R3, R2} - {R5, R4} SUB R0, R2, R4 SBB R1, R3, R5
```

3.50 SBBI

Subtract Immediate with Borrow

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SBBI	00011						Rd			Ra		1	1		mm	3

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13		•				
SBBI		0	0001	1			Rd			Ra		1	1	iı	mm	3

Assembly:

SBBI Rd, Ra, imm

Purpose:

To subtract a two's complement constant from a 16-bit two's complement integer in a register, with borrow input.

Restrictions:

None.

Operation:

Remarks:

A 32-bit subtraction with a register and an immediate operand can be performed as follows:

```
; Perform {R1, R0} \leftarrow {R3, R2} - 0x40001 SUBI R0, R2, 1 SBBI R1, R3, 4
```

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SLL		0	010	0			Rd			Ra		0	0		Rb	

Assembly:

Purpose:

To perform a left logical shift of a 16-bit integer in a register by a variable bit amount.

Restrictions:

If Rb contains a value greater than 15, the behavior is UNPREDICTABLE.

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← {opA[15-opB:0], opB{0}}
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

3.52 SLLI

Shift Left Logical Immediate

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SLLI	00101						Rd			Ra		0	0	iı	mm	3

Assembly:

SLLI Rd, Ra, amount

Purpose:

To perform a left logical shift of a 16-bit integer in a register by a constant bit amount.

Restrictions:

The amount may be between 0 and 15, inclusive.

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_sr(imm3)
res ← {opA[15-opB:0], opB{0}}
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SRA		0	010	0			Rd			Ra		1	1		Rb	

Assembly:

Purpose:

To perform a right arithmetical shift of a 16-bit integer in a register by a variable bit amount.

Restrictions:

If Rb contains a value greater than 15, the behavior is UNPREDICTABLE.

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← {opB{opA[15]}, opA[15:opB]}
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

3.54 SRAI

Shift Right Arithmetical Immediate

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
SRAI		0	010	0			Rd			Ra		1	1	i	mm	3

Assembly:

SRAI Rd, Ra, amount

Purpose:

To perform a right arithmetical shift of a 16-bit integer in a register by a constant bit amount.

Restrictions:

The amount may be between 0 and 15, inclusive.

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SRL		0	010	0			Rd			Ra		1	0		Rb	

Assembly:

Purpose:

To perform a right logical shift of a 16-bit integer in a register by a variable bit amount.

Restrictions:

If Rb contains a value greater than 15, the behavior is UNPREDICTABLE.

```
opA ← mem[W+Ra]
opB ← mem[W+Rb]
res ← {opB{0}, opA[15:opB]}
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

3.56 SRLI

Shift Right Logical Immediate

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SRLI		0	010	1			Rd			Ra		1	0	iı	mm	3

Assembly:

SRLI Rd, Ra, amount

Purpose:

To perform a right logical shift of a 16-bit integer in a register by a constant bit amount.

Restrictions:

The amount may be between 0 and 15, inclusive.

3.57 ST Store

Encoding (short form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
ST		0	101	0			Rs			Ra				off5		

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
ST		0	101	0			Rs			Ra				off5		

Assembly:

ST Rs, Ra, off

Purpose:

To store a word to memory at a variable address, with a constant offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off5[2:0]}
else off ← sign_extend_16(off5)
addr ← mem[W+Ra] + off
data ← mem[W+Rs]
mem[addr] ← data
```

Encoding (short form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
STR		0	101	1			Rs			Ra				off5		

Encoding (long form):

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI	110 ext13															
STR		0	101	1			Rs			Ra				off5		

Assembly:

STR Rs, Ra, off

Purpose:

To store a word to memory at a constant PC-relative address, with a variable offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off \leftarrow {ext13, off5[2:0]}
else off \leftarrow sign_extend_16(off5)
addr \leftarrow PC + 1 + off + mem[W+Ra]
data \leftarrow mem[W+Rs]
mem[addr] \leftarrow data
```

3.59 STW

Store to Window Address

Encoding:

	F	Ε	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
STW		1	010	0			000			000		0	0		Rb	

Assembly:

STW Rb

Purpose:

To arbitrarily change the address of the register window.

Restrictions:

If **Rb** contains a value that is not a multiple of 8, the behavior is **UNPREDICTABLE**.

Operation:

 $W \leftarrow mem[W+Rb]$

Remarks:

See also LDW. This instruction may be used in a function epilogue, where Rb is any register chosen to act as a frame pointer.

3.60 STX Store External

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
STX		0	111	0			Rs			Ra				off5		

Encoding (long form):

	F	E	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	t13						
STX		0)111	0			Rs			Ra				off5		

Assembly:

STX Rs, Ra, off

Purpose:

To complete a store cycle on external bus at a variable address, with a constant offset.

Restrictions:

If the long form is used, and off5[4:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off5[2:0]}
else off ← sign_extend_16(off5)
addr ← mem[W+Ra] + off
data ← mem[W+Rs]
ext[addr] ← data
```

3.61 STXA

Store External Absolute

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
STXA		0)111	1			Rs					Ot.	f8			

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
STXA		0	111	1			Rs					-0t	f 8			

Assembly:

STXA Rs, off

Purpose:

To complete a store cycle on external bus at a constant absolute address.

Restrictions:

If the long form is used, and off8[7:3] are non-zero, the behavior is UNPREDICTABLE.

```
if (has_ext13)
then off ← {ext13, off8[2:0]}
else off ← sign_extend_16(off8)
data ← mem[W+Rs]
ext[off] ← data
```

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SUB		0	0001	0			Rd			Ra		1	0		Rb	

Assembly:

SUB Rd, Ra, Rb

Purpose:

To subtract 16-bit two's complement integers in registers.

Restrictions:

None.

```
\begin{array}{l} opA \leftarrow mem[W+Ra] \\ opB \leftarrow mem[W+Rb] \\ res \leftarrow opA + \textbf{not} \ opB + 1 \\ mem[W+Rd] \leftarrow res \\ Z \leftarrow res[15:0] = 0 \\ S \leftarrow res[15] \\ C \leftarrow res[16] \\ V \leftarrow (opA[15] = \textbf{not} \ opB[15]) \ \textbf{and} \ (opA[15] \Leftrightarrow res[15]) \end{array}
```

Subtract Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
SUBI		0	0001	1			Rd			Ra		1	0	iı	nm	3

Encoding (long form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	xt13						
SUBI		0	0001	1			Rd			Ra		1	0	iı	mm	3

Assembly:

SUBI Rd, Ra, imm

Purpose:

To subtract a two's complement constant from a 16-bit two's complement integer in a register.

Restrictions:

None.

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_al(imm3)
res ← opA + not opB + 1
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← res[16]
V ← (opA[15] = not opB[15]) and (opA[15] <> res[15])
```

3.64 XCHG

Exchange Registers

Assembly:

XCHG Ra, Rb

Purpose:

To exchange the values of two registers.

Restrictions:

None.

Remarks:

The assembler does not translate any instructions for XCHG with identical Ra and Rb, and translates XCHG with any other register combination to

XOR Ra, Ra, Rb

XOR Rb, Rb, Ra

XOR Ra, Ra, Rb

3.65 XCHW

Exchange Window Address

Encoding:

	F	Е	D	С	В	Α	9	8	7	6	5	4	3	2	1	0
XCHW		1	010	0			Rd			001		0	0		Rb	

Assembly:

XCHW Rd, Rb

Purpose:

To exchange the address of the register window with a register.

Restrictions:

If **Rb** contains a value that is not a multiple of 8, the behavior is **UNPREDICTABLE**.

Operation:

```
\begin{array}{l} \text{old} \; \leftarrow \; \texttt{W} \\ \texttt{W} \; \leftarrow \; \texttt{mem[W+Rb]} \\ \texttt{mem[W+Rd]} \; \leftarrow \; \texttt{old} \end{array}
```

Remarks:

This instruction may be used in a context switch routine. For example, if multiple register windows are set up such that each contains the address of the next one in R7, the following code may be used to switch contexts:

yield:

```
XCHW R7, R7
JR R0
; Elsewhere:
JALR R0, yield
```

3.66 XOR

Bitwise XOR with Register

Encoding:

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
XOR		0	0000	0			Rd			Ra		1	0		Rb	

Assembly:

XOR Rd, Ra, Rb

Purpose:

To perform bitwise XOR between 16-bit integers in registers.

Restrictions:

None.

Operation:

 $\begin{array}{lll} opA & \leftarrow & mem[W+Ra] \\ opB & \leftarrow & mem[W+Rb] \\ res & \leftarrow & opA & xor & opB \\ mem[W+Rd] & \leftarrow & res \\ Z & \leftarrow & res[15:0] = 0 \\ S & \leftarrow & res[15] \\ C & \leftarrow & UNDEFINED \\ V & \leftarrow & UNDEFINED \end{array}$

3.67 XORI

Bitwise XOR with Immediate

Encoding (short form):

	F	Ε	D	С	В	A	9	8	7	6	5	4	3	2	1	0
XORI		0	0000	1			Rd			Ra		1	0	iı	mm	3

Encoding (long form):

	F	Е	D	С	В	A	9	8	7	6	5	4	3	2	1	0
EXTI		110							ех	ct13						
XORI		0	0000	1			Rd			Ra		1	0	iı	mm	3

Assembly:

XORI Rd, Ra, imm

Purpose:

To perform bitwise XOR between a 16-bit integer in a register and a constant.

Restrictions:

None.

```
opA ← mem[W+Ra]
if (has_ext13)
then opB ← {ext13, imm3}
else opB ← decode_imm_al(imm3)
res ← opA xor opB
mem[W+Rd] ← res
Z ← res[15:0] = 0
S ← res[15]
C ← UNDEFINED
V ← UNDEFINED
```

4	List	of	Assembly	Directives
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TBD

5 Function Calling Sec

TBD