Instruction Set

6 Jan. 2021

32-bit instruction format

31:29	28	27:24	23:16	15:8	7:0
opcode	en	raddr2 (s3)	raddr1 (s2)	raddr0 (s1)	waddr (dst)

opcode: complex operation code
en: twiddle factor enable signal
raddr2: read address 2 of the data memory (4-bit ROM [0:15])
raddr1: read address 1 of the data memory (8-bit BRAM [0:255])
raddr0: read address 0 of the data memory (8-bit BRAM [0:255])
waddr: write address of the data memory (8-bit BRAM [80:255])

Opcode (All of these are complex operations. e.g. MULADD: (a+jb) + (Wi+jWq)*(c+jd))

~~000~~	001	010	100	101	110	111
~~LOAD~~	ADD	SUB	MUL	MULADD	MULSUB	MAX

Examples in RISC-V fashion: OPCODE $DST, ($S3), $S2, $S1

Assembly	Operation	Instructions in Hex
ADD $128, $16, $48	R128 = R16 + R48	32'h20_30_10_80
MUL $129, $17, $49	R129 = R17 + R49	32'h80_31_11_81
MULADD $130, $18, $50, $0	R130 = R18 + R0 * R50	32'hB0_32_12_82
MULSUB $131, $129, $128, $1	R131 = R129 - R1 * R128	32'hD1_80_81_83

Assuming the overlay is comprised of an array of 256 PEs and each PE has 4 DSP blocks. The instruction schedule can be found as follows (if running at 500MHz, 1 cycle = 2ns):

Cycle	Operation	Instruction
256*32	***Load input data***[1]	**Nil**
1*32	*Complex multiplication*	(a+jb)*(c+jd) → a' + jb'
1*80 1*80	*FFT*	a' + jb' + W_N(c'+jd') → a'' + jb'' a' + jb' - W_N(c'+jd') → c'' + jd''
1*16	~~*Output half values*~~	Add a few cycles to compute partial alpha profiles
32	*Shift internal data*[2]	Can this step multiplex with PE computation?
1*32	*Complex multiplication*	(a+jb)*(c+jd) → a' + jb'; c' + jd'
1*80 1*80	*FFT*	a' + jb' + W_N(c'+jd') → a'' + jb'' a' + jb' - W_N(c'+jd') → c'' + jd''
1*16	*Output half values*	Nil
32	*Shift data*	Nil
…	…	…
256*32	***Fetch output data***	**Nil**

[1,2]*Load input data*, *Shift internal data* and *Fetch output data* do not require instructions. They are handled by the SIPO and PISO modules.

Latency = (256*32 + (32+2*80+16) + 255*(32+32+2*80+16) + 256*32) * 2ns = 0.156 ms

Q. How to do a MAX operation among all the outputs of the 256 PEs (after square operation)? Add logic fabrics after the 256 PEs?
Alpha profile should be done in the current PE and keep forward to the next PE.

Instructions for SCD kernel:

```
# 8 element-wise complex multiplications
MUL $80, $16, $48
MUL $81, $17, $49
MUL $82, $18, $50
MUL $83, $19, $51
MUL $84, $20, $52
MUL $85, $21, $53
MUL $86, $22, $54
MUL $87, $23, $55

# 8-point FFT (bit-reverse order)
# stage 1
MULADD $88, $80, $84, $0
MULSUB $89, $80, $84, $0
MULADD $90, $82, $86, $0
MULSUB $91, $82, $86, $0
MULADD $92, $81, $85, $0
MULSUB $93, $81, $85, $0
MULADD $94, $83, $87, $0
MULSUB $95, $83, $87, $0
# stage 2
MULADD $96, $88, $90, $0
MULSUB $98, $88, $90, $0
MULADD $97, $89, $91, $2
MULSUB $99, $89, $91, $2
MULADD $100, $92, $94, $0
MULSUB $102, $92, $94, $0
MULADD $101, $93, $95, $2
MULSUB $103, $93, $95, $2
# stage 3
MULADD $104, $96, $100, $0
MULSUB $108, $96, $100, $0
MULADD $105, $98, $102, $1
MULSUB $109, $98, $102, $1
MULADD $106, $97, $101, $2
MULSUB $110, $97, $101, $2
MULADD $107, $99, $103, $3
MULSUB $111, $99, $103, $3
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# 32 element-wise complex multiplications
MUL $80, $16, $48
MUL $81, $17, $49
MUL $82, $19, $50
MUL $83, $20, $51
MUL $84, $21, $52
MUL $85, $22, $53
MUL $86, $23, $54
MUL $87, $24, $55
MUL $88, $25, $56
MUL $89, $26, $57
MUL $90, $27, $58
MUL $91, $28, $59
MUL $92, $29, $60
MUL $93, $30, $61
MUL $94, $31, $62
MUL $95, $32, $63
MUL $96, $33, $64
MUL $97, $34, $65
MUL $98, $35, $66
MUL $99, $36, $67
MUL $100, $37, $68
MUL $101, $38, $69
MUL $102, $39, $70
MUL $103, $40, $71
MUL $104, $41, $72
MUL $105, $42, $73
MUL $106, $43, $74
MUL $107, $44, $75
MUL $108, $45, $76
MUL $109, $46, $77
MUL $110, $47, $78
MUL $111, $48, $79

# 32-point FFT (bit-reverse order)
# stage 1
MULADD $112, $80, $96, $0
MULSUB $113, $80, $96, $0
MULADD $114, $88, $104, $0
MULSUB $115, $88, $104, $0
MULADD $116, $84, $100, $0
MULSUB $117, $84, $100, $0
MULADD $118, $92, $108, $0
MULSUB $119, $92, $108, $0
MULADD $120, $82, $98, $0
MULSUB $121, $82, $98, $0
MULADD $122, $90, $106, $0
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MULSUB $123, $90, $106, $0
MULADD $124, $86, $102, $0
MULSUB $125, $86, $102, $0
MULADD $126, $94, $110, $0
MULSUB $127, $94, $110, $0
MULADD $128, $81, $97, $0
MULSUB $129, $81, $97, $0
MULADD $130, $89, $105, $0
MULSUB $131, $89, $105, $0
MULADD $132, $85, $101, $0
MULSUB $133, $85, $101, $0
MULADD $134, $93, $109, $0
MULSUB $135, $93, $109, $0
MULADD $136, $83, $99, $0
MULSUB $137, $83, $99, $0
MULADD $138, $91, $107, $0
MULSUB $139, $91, $107, $0
MULADD $140, $87, $103, $0
MULSUB $141, $87, $103, $0
MULADD $142, $95, $111, $0
MULSUB $143, $95, $111, $0

# stage 2
MULADD $80, $112, $114, $0
MULSUB $82, $112, $114, $0
MULADD $81, $113, $115, $8
MULSUB $83, $113, $115, $8
MULADD $84, $116, $118, $0
MULSUB $86, $116, $118, $0
MULADD $85, $117, $119, $8
MULSUB $87, $117, $119, $8
MULADD $88, $120, $122, $0
MULSUB $90, $120, $122, $0
MULADD $89, $121, $123, $8
MULSUB $91, $121, $123, $8
MULADD $92, $124, $126, $0
MULSUB $94, $124, $126, $0
MULADD $93, $125, $127, $8
MULSUB $95, $125, $127, $8
MULADD $96, $128, $130, $0
MULSUB $98, $128, $130, $0
MULADD $97, $129, $131, $8
MULSUB $99, $129, $131, $8
MULADD $100, $132, $134, $0
MULSUB $102, $132, $134, $0
MULADD $101, $133, $135, $8
MULSUB $103, $133, $135, $8
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MULADD $104, $136, $138, $0
MULSUB $106, $136, $138, $0
MULADD $105, $137, $139, $8
MULSUB $107, $137, $139, $8
MULADD $108, $140, $142, $0
MULSUB $110, $140, $142, $0
MULADD $109, $141, $143, $8
MULSUB $111, $141, $143, $8

# stage 3
MULADD $112, $80, $84, $0
MULSUB $116, $80, $84, $0
MULADD $113, $81, $85, $4
MULSUB $117, $81, $85, $4
MULADD $114, $82, $86, $8
MULSUB $118, $82, $86, $8
MULADD $115, $83, $87, $12
MULSUB $119, $83, $87, $12
MULADD $120, $88, $92, $0
MULSUB $124, $88, $92, $0
MULADD $121, $89, $93, $4
MULSUB $125, $89, $93, $4
MULADD $122, $90, $94, $8
MULSUB $126, $90, $94, $8
MULADD $123, $91, $95, $12
MULSUB $127, $91, $95, $12
MULADD $128, $92, $96, $0
MULSUB $132, $92, $96, $0
MULADD $129, $93, $97, $4
MULSUB $133, $93, $97, $4
MULADD $130, $94, $98, $8
MULSUB $134, $94, $98, $8
MULADD $131, $95, $99, $12
MULSUB $135, $95, $99, $12
MULADD $136, $96, $100, $0
MULSUB $140, $96, $100, $0
MULADD $137, $97, $101, $4
MULSUB $141, $97, $101, $4
MULADD $138, $98, $102, $8
MULSUB $142, $98, $102, $8
MULADD $139, $99, $103, $12
MULSUB $143, $99, $103, $12

# stage 4
MULADD $80, $112, $120, $0
MULSUB $88, $112, $120, $0
MULADD $81, $113, $121, $2
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MULSUB $89, $113, $121, $2
MULADD $82, $114, $122, $4
MULSUB $90, $114, $122, $4
MULADD $83, $115, $123, $6
MULSUB $91, $115, $123, $6
MULADD $84, $116, $124, $8
MULSUB $92, $116, $124, $8
MULADD $85, $117, $125, $10
MULSUB $93, $117, $125, $10
MULADD $86, $118, $126, $12
MULSUB $94, $118, $126, $12
MULADD $87, $119, $127, $14
MULSUB $95, $119, $127, $14
MULADD $96, $128, $136, $0
MULSUB $104, $128, $136, $0
MULADD $97, $129, $137, $2
MULSUB $105, $129, $137, $2
MULADD $98, $130, $138, $4
MULSUB $106, $130, $138, $4
MULADD $99, $131, $139, $6
MULSUB $107, $131, $139, $6
MULADD $100, $132, $140, $8
MULSUB $108, $132, $140, $8
MULADD $101, $133, $141, $10
MULSUB $109, $133, $141, $10
MULADD $102, $134, $142, $12
MULSUB $110, $134, $142, $12
MULADD $103, $135, $143, $14
MULSUB $111, $135, $143, $14

# stage 5
MULADD $80, $112, $128, $0
MULSUB $96, $112, $128, $0
MULADD $81, $113, $129, $1
MULSUB $97, $113, $129, $1
MULADD $82, $114, $130, $2
MULSUB $98, $114, $130, $2
MULADD $83, $115, $131, $3
MULSUB $99, $115, $131, $3
MULADD $84, $116, $132, $4
MULSUB $100, $116, $132, $4
MULADD $85, $117, $133, $5
MULSUB $101, $117, $133, $5
MULADD $86, $118, $134, $6
MULSUB $102, $118, $134, $6
MULADD $87, $119, $135, $7
MULSUB $103, $119, $135, $7
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MULADD $88, $120, $136, $8
MULSUB $104, $120, $136, $8
MULADD $89, $121, $137, $9
MULSUB $105, $121, $137, $9
MULADD $90, $122, $138, $10
MULSUB $106, $122, $138, $10
MULADD $91, $123, $139, $11
MULSUB $107, $123, $139, $11
MULADD $92, $124, $140, $12
MULSUB $108, $124, $140, $12
MULADD $93, $125, $141, $13
MULSUB $109, $125, $141, $13
MULADD $94, $126, $142, $14
MULSUB $110, $126, $142, $14
MULADD $95, $127, $143, $15
MULSUB $111, $127, $143, $15