

Pipelined processors

Example 1

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Example 1

Considering the following pseudo-code:

```
for (i = 0; i < 100; i++) {  
     $Y[i] = X[i]^2 + X[i] / Z[i]$   
}
```

Suppose that vectors $X[i]$ and $Z[i]$ contain 100 FP numbers, were previously saved in memory, and $Z[i] \neq 0$.

Assume the RISC-V processor RV32G with single-precision FP operations presented below:

- Integer ALU: 1 clock cycle
- Data memory: 1 clock cycle
- FP multiplier unit: pipelined 4 stages
- FP arithmetic unit: pipelined 2 stages
- FP divider unit: not pipelined unit, requiring 4 clock cycles
- branch delay slot: 2 clock cycle (disabled)
- forwarding is enabled.

Example 1 – [cont]

- 1. Write an assembly program for the architecture RISC-V RV32G with FP extensions able to perform the previously presented pseudo-code**
- 2. show the timing of the developed loop-based program and compute how many cycles does this program take to execute**
- 3. using all the static optimization techniques, re-write the developed code in order to eliminate the most data hazards**
- 4. show the timing development of the new optimized program and compute how many clock cycles does this program take to execute.**

1. Write an assembly program for the architecture RISC-V RV32G with FP extensions able to perform the previously presented pseudo-code

```
#***** RISC-V RV32G PROGRAM *****  
#-----  
# STATIC OPTIMIZATION EXAMPLE  
# The code implements the following algorithm  
# for (i = 0; i < 100; i++) {  
#   Y[i] = x[i]^2 + x[i] /z[i]  
#   Z[i] ≠ 0 }  
#-----  
    .data  
vect1: .word 1, 2, 3, 4, 5, 6, 7, 8, 9, 10...  
vect2: .word 1, 2, 3, 4, 5, 6, 7, 8, 9, 10...  
vect3: .word 1, 2, 3, 4, 5, 6, 7, 8, 9, 10...
```

1)

	.text	CC
MAIN:	addi x1, x0, 100	
	la x2, vect1	
	la x3, vect2	
	la x4, vect3	
loop:	flw f1, 0(x2)	
	flw f2, 0(x3)	
	fmul.s f3, f1, f1	
	fdiv.s f4, f1, f2	
	fadd f5, f3, f4	
	fsw f5, 0(x4)	
	addi x2, x2, 4	
	addi x3, x3, 4	
	addi x4, x4, 4	
	addi x1, x1, -1	
	bnez x1, loop	
	nop	

2)

	.text	CC
MAIN:	addi x1, x0, 100	5
	la x2, vect1	2
	la x3, vect2	2
	la x4, vect3	2

	.text	CC
MAIN:	addi x1, x0, 100	5
	auipc X2, 0x10000	1
	addi x2, x2, -4	1
	auipc x3, 0x10000	1
	addi x3, x3, 338	1
	auipc x4, 0x10000	1
	addi x4, x4, 780	1

2)

[illegible]

2)

	.text	CC
MAIN:	addi x1, x0, 100	5
	la x2, vect1	2
	la x3, vect2	2
	la x4, vect3	2
loop:	flw f1, 0(x2)	1
	flw f2, 0(x3)	1
	fmul.s f3, f1, f1	4
	fdiv.s f4, f1, f2	1
	fadd.s f5, f3, f4	2
	fsw f5, 0(x4)	1
	addi x2, x2, 4	1
	addi x3, x3, 4	1
	addi x4, x4, 4	1
	addi x1, x1, -1	1
	bnez x1, loop	2+1
	nop	1

2)

	.text	CC
MAIN:	addi x1, x0, 100	5
	la x2, vect1	2
	la x3, vect2	2
	la x4, vect3	2
loop:	flw f1, 0(x2)	1
	flw f2, 0(x3)	1
	fmul.s f3, f1, f1	4
	fdiv.s f4, f1, f2	1
	fadd.s f5, f3, f4	2
	fsw f5, 0(x4)	1
	addi x2, x2, 4	1
	addi x3, x3, 4	1
	addi x4, x4, 4	1
	addi x1, x1, -1	1
	bnez x1, loop	2+1
	nop	

2)

11

11
+

17 x 99

17

2)

	.text	CC
MAIN:	addi x1, x0, 100	5
	la x2, vect1	2
	la x3, vect2	2
	la x4, vect3	2
loop:	flw f1, 0(x2)	1
	flw f2, 0(x3)	1
	fmul.s f3, f1, f1	4
	fdiv.s f4, f1, f2	1
	fadd.s f5, f3, f4	2
	fsw f5, 0(x4)	1
	addi x2, x2, 4	1
	addi x3, x3, 4	1
	addi x4, x4, 4	1
	addi x1, x1, -1	1
	bnez x1, loop	2
	nop	1

2)

11

16

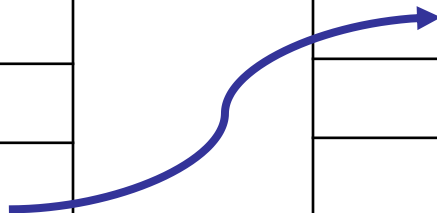
1

$$\begin{array}{r}
 11 \\
 + \\
 17 \times 99 \\
 + \\
 16 \\
 + \\
 1 \\
 \hline
 1710
 \end{array}$$

3)

	.text
MAIN:	addi x1, x0, 100
	la x2, vect1
	la x3, vect2
	la x4, vect3
loop:	flw f1, 0(x2)
	flw f2, 0(x3)
	fmul.s f3, f1, f1
	fdiv.s f4, f1, f2
	fadd.s f5, f3, f4
	fsw f5, 0(x4)
	addi x2, x2, 4
	addi x3, x3, 4
	addi x4, x4, 4

	.text
MAIN:	addi x1, x0, 100
	la x2, vect1
	la x3, vect2
	la x4, vect3
loop:	flw f1, 0(x2)
	flw f2, 0(x3)
	fmul.s f3, f1, f1
	fdiv.s f4, f1, f2
	addi x2, x2, 4
	fadd.s f5, f3, f4
	fsw f5, 0(x4)
	addi x3, x3, 4
	addi x4, x4, 4



3)

																					cc
loop:	flw	f1, 0(x2)	F	D	E	M	W														1
	flw	f2, 0(x3)		F	D	E	M	W													1
	fmul.s	f3, f1, f1			F	D	X	X	X	X	M	W									4
	fdiv.s	f4, f1, f2				F	D	d	d	d	d	M	W								1
	addi	x2, x2, 4					F	D	E	M	W										0
	fadd.s	f5, f3, f4						F	D	s	s	A	A	M	W						2
	fsw	f5, 0(x4)							F	s	s	D	E	s	M	W					1
	addi	x3, x3, 4										F	D	s	E	M	W				1
	addi	x4, x4, 4											F	s	D	E	M	W			1

12

4)

	.text		CC
MAIN:	addi	x1, x0, 25	5
	la	x2, vect1	2
	la	x3, vect2	2
	la	x4, vect3	2
loop:	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 4	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	addi	x3, x3, 4	1
	addi	x4, x4, 4	1
	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 4	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	addi	x3, x3, 4	1
	addi	x4, x4, 4	1

11

12

12

	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 4	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	addi	x3, x3, 4	1
	addi	x4, x4, 4	1
	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 4	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	addi	x3, x3, 4	1
	addi	x1, x1, -1	1
	addi	x4, x4, 4	1
	bnez	x1,loop	1+1
	nop		1

12

15

1

4)

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+
51 x 24
+
51

1286

4+)

	.text		CC
MAIN:	addi	x1, x0, 25	5
	la	x2, vect1	2
	la	x3, vect2	2
	la	x4, vect3	2
loop:	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1

	.text		CC
MAIN:	addi	x1, x0, 25	5
	la	x2, vect1	2
	la	x3, vect2	2
	la	x4, vect3	2
loop:	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	flw	f1, 4(x2)	1
	flw	f2, 4(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 4(x4)	1
	flw	f1, 8(x2)	1
	flw	f2, 8(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 8(x4)	1

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	flw	f1, 12(x2)	1
	flw	f2, 12(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 16	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 12(x4)	1
	addi	x3, x3, 16	1
	addi	X1, x1, -1	1
	addi	x4, x4, 16	1
	bnez	x1,loop	1+1
	nop		1

15

1

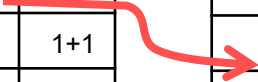
$11 + (45 \times 24) + 45$
1136

4+) Enabling Branch delay slot

	.text		CC
MAIN:	addi	x1, x0, 25	5
	la	x2, vect1	2
	la	x3, vect2	2
	la	x4, vect3	2
loop:	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	flw	f1, 4(x2)	1
	flw	f2, 4(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 4(x4)	1
	flw	f1, 8(x2)	1
	flw	f2, 8(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 8(x4)	1

	flw	f1, 12(x2)	1
	flw	f2, 12(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 16	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 12(x4)	1
	addi	x3, x3, 16	1
	addi	x1, x1, -1	1
	addi	x4, x4, 16	1
	bnez	x1,loop	1+1
	nop		1

	flw	f1, 12(x2)	1
	flw	f2, 12(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 16	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 12(x4)	1
	addi	x1, x1, -1	1
	addi	x3, x3, 16	1
	bnez	x1,loop	1
	addi	x4, x4, 16	1
	nop		1



4+) Enabling Branch delay slot

	.text		CC
MAIN:	addi	x1, x0, 25	5
	la	x2, vect1	2
	la	x3, vect2	2
	la	x4, vect3	2
loop:	flw	f1, 0(x2)	1
	flw	f2, 0(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 0(x4)	1
	flw	f1, 4(x2)	1
	flw	f2, 4(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 4(x4)	1
	flw	f1, 8(x2)	1
	flw	f2, 8(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	fadd.s	f5, f3, f4	2
	fsw	f5, 8(x4)	1

11

10

10

10

	flw	f1, 12(x2)	1
	flw	f2, 12(x3)	1
	fmul.s	f3, f1, f1	4
	fdiv.s	f4, f1, f2	1
	addi	x2, x2, 16	0
	fadd.s	f5, f3, f4	2
	fsw	f5, 12(x4)	1
	addi	x1, x1, -1	1
	addi	x3, x3, 16	1
	bnez	x1,loop	1
	addi	x4, x4, 16	1
	nop		1

14

1

11 + (44 x 25) + 1

1112