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2.1 Simple execution, without data forwarding techniques

f)

Clock cycles	377
Instructions	166
Average CPI	2,271

Stalls:	- Data	192
	- Structural	0
	- Branch Taken	15

g) Predict not taken: No fim da iteração do loop a próxima instrução a tentar ser executada é halt, ou seja a previsão é: "Predict Not Taken". Caso a previsão esteja errada é necessário um flush.

e) 2.3

2.2 Application of data forwarding techniques

c)

Clock cycles	297
Instructions	166
Average CPI	1,789

Stalls:	- Data	112
	- Structural	16
	- Branch Taken	15

d)

$$speedup = \frac{377}{297} = 1,26936$$

2.3 Source code optimization: minimization of data and structural hazards

a) Attach a copy of the new assembly program.

c)

Clock cycles	249
Instructions	166
Average CPI	1,500

Stalls:	- Data	48
	- Structural	16
	- Branch Taken	15

d)

$$speedup = \frac{377}{249} = 1,5140562$$

2.4 Source code optimization: loop unrolling

a) Attach a copy of the new assembly program.

c)

Clock cycles	153
Instructions	126
Average CPI	1.214

Stalls:	- Data	0
	- Structural	16
	- Branch Taken	7

d)

speedup = $\frac{377}{153}$ = 2,464052

2.5 Source code optimization: branch delay slot

a) Attach a copy of the new assembly program.

d)

Clock cycles	234
Instructions	166
Average CPI	1,410

Stalls:	- Data	48
	- Structural	16
	- Branch Taken	0

e)

speedup = $\frac{377}{234}$ = 1,611

Table 1: Pipeline time diagram, without data forwarding techniques.

	INSTRUCTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	lw $10, 0 ($2)	F	D	X	M	W																																			
2	lw $11, 0 ($3)		F	D	X	M	W																																		
3	dmul $12, $10, $11			F	D	Raw	Raw	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M	W																									
4	da dd $12, $12, $10				(F)	(F)	F	D	Raw	Raw	Raw	Raw	Raw	Raw	Raw	Raw	X	M	W																					
5	sw $12, 0 ($4)							(F)	(F)	(F)	(F)	(F)	(F)	(F)	(F)	F	D	Raw	Raw	X	M	W																		
6	daddi $1, $1, 1																(F)	(F)	F	D	X	M	W																	
7	daddi $2, $2, 8																			F	D	X	M	W															
8	daddi $3, $3, 8																				F	D	X	M	W														
9	daddi $4, $4, 8																					F	D	X	M	W													
10	bne $1, $5, loop																						F	D	X	M	W												
11	halt																							F															
12	lw $10, 0 ($2)																								F	D	X	M	W										
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Table 2: Pipeline time diagram, with data forwarding techniques.

	INSTRUCTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	lw $10, 0 ($2)	F	D	X	M	W																																			
2	lw $11, 0 ($3)		F	D	X	M	W																																		
3	dmul $12, $10, $11			F	D	H0	Raw	H1	H2	H3	H4	H5	H6	H	W																										
4	da dd $12, $12, $10				F	D	Raw	X	Raw	Raw	Raw	Raw	Raw	Str	M	W																									
5	sw $12, 0 ($4)					(F)	F	(D)	(D)	(D)	(D)	(D)	(D)	D	X	M	W																							
6	daddi $1, $1, 1							(F)	(F)	(F)	(F)	(F)	(F)	F	D	X	M	W																						
7	daddi $2, $2, 8														F	D	X	M	W																				
8	daddi $3, $3, 8															F	D	X	M	W																		
9	daddi $4, $4, 8																F	D	X	M	W																	
10	bne $1, $5, loop																	F	D	X	M	W																
11	halt																		F																			
12	lw $10, 0 ($2)																			F	D	X	M	W														
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Table 3: Pipeline time diagram, with minimization techniques to reduce the data and structural hazards.

	INSTRUCTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	lw $10, 0($2)	F	D	X	M	W																																			
2	lw $11, 0($3)		F	D	X	M	W																																		
3	daddi $1, $1, 1			F	D	X	M	W																																	
4	dmul $12, $10, $11				F	D	M_0	M_1	M_2	M_3	M_4	M_5	M_6	Mem	WB																										
5	daddi $2, $2, 8					F	D	X	M	W																														
6	daddi $3, $3, 8						F	D	X	M	W																													
7	daddi $12, $12, $10							F	D	X	Raw	Raw	Raw	Str	Mem	W																								
8	sw $12, 0($4)								F	(D)	(D)	(D)	(D)	D	X	M	W																							
9	daddi $4, $4, 8									(F)	(F)	(F)	(F)	F	D	X	M	W																						
10	bne $1, $5, loop														F	D	X	M	W																				
11	halt															F																							
12	lw $10, 0($2)																F	D	X	M	W																		
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Table 4: Pipeline time diagram: usage of loop unrolling minimization techniques to reduce the control hazards.

	INSTRUCTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	lw $10 ,0($2)	F	D	X	M	W																																			
2	lw $11 ,0($3)		F	D	X	M	W																																		
3	lw $13, 8($2)			F	D	X	M	W																																	
4	dmul $12 , $10 , $11				F	D	M0	M1	M2	M3	M4	M5	M6	Mem	W																									
5	lw $14, 8($3)					F	D	X	M	W																														
6	daddi $1,$1, 2						F	D	X	M	W																													
7	dmul $15 , $13, $14							F	D	M0	M1	M2	M3	M4	M5	M6	Mem	W																						
8	daddi $2, $2, 16								F	D	X	M	W																										
9	daddi $3, $3, 16									F	D	X	M	W																									
10	dadd $12, $12, $10										F	D	X	Str	M	W																							
11	sw $12 , 0($4)											F	(D)	D	X	M	W																						
12	daddi $4, $4, 16												(F)	F	D	X	Str	M	W																				
13	dadd $15, $15, $13													·	F	(D)	D	X	M	W																			
14	sw $15, -8($4)															(F)	F	D	X	M	W																		
15	bne $1 , $5, loop																	F	D	X	M	W																	
16	halt																		F																				
17																				F	D	X	M																
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Table 5: Pipeline time diagram: usage of branch delay slot techniques to reduce the control hazards.

	INSTRUCTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	lw $10, 0($2)		F	D	X	M	W																																		
2	lw $11, 0($3)			F	D	X	M	W																																	
3	daddi $1, $1, 1				F	D	X	M	W																																
4	dmul $12, $10, $11					F	D	M_0	M_1	M_2	M_3	M_4	M_5	M_6	Mem	WB																										
5	daddi $2, $2, 8						F	D	X	M	W																														
6	daddi $3, $3, 8							F	D	X	M	W																													
7	dadd $12, $12, $10								F	D	X	Raw	Raw	Raw	Str	Mem	W																								
8	sw $12, 0($4)									F	(D)	(D)	(D)	(D)	D	X	M	W																							
9	bne $1, $5, loop										(F)	(F)	(F)	(F)	F	D	X	M	W																						
10	daddi $4, $4, 8															F	D	X	M	W																				
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