STUDENTS IDENTIFICATION:

Number:	Name:
89455	Henrique Dias
89466	Isabel Soares
89535	Rodrigo Sousa

2.1 Simple execution, without data forwarding techniques

f)

Clock cycles	174
Instructions	61
Average CPI	2.852

Stalls: - Data	101+0+0=101
- Structural	0
- Branch Taken	8+~~[illegible]~~

g) Branch not taken, visto que é sempre realizado o fetch da instrução SW $9, mult($0), mesmo quando o branch é realizado.

2.2 Application of data forwarding techniques

c)

Clock cycles	136
Instructions	61
Average CPI	2.230

Stalls: - Data	63+0+0=63
- Structural	9
- Branch Taken	8+~~[illegible]~~

d)

$$\text{SpeedUp} = \frac{2.852 \times \cancel{61}}{2.230 \times \cancel{61}} \simeq 1.2789$$

Houve uma melhoria em termos de performance.

2.3 Source code optimization: minimization of data and structural hazards

a) Attach a copy of the new assembly program. Código em anexo (Prog3)

c)

Clock cycles	~~[illegible]~~ 127
Instructions	61
Average CPI	~~[illegible]~~ 2.082

Stalls: - Data	45+0+0=45
- Structural	9
- Branch Taken	8

d)

$$\text{SpeedUp} = \frac{2.852 \times \cancel{61}}{2.082 \times \cancel{61}} \simeq 1.3698$$

Houve uma melhoria face ao anterior.

2.4 Source code optimization: loop unrolling

a) Attach a copy of the new assembly program. Código em anexo (Prog4)

c)

Clock cycles	97
Instructions	43
Average CPI	2.256

Stalls:	- Data	69+0+0=69
	- Structural	9
	- Branch Taken	2

d)

$$SpeedUp = \frac{2.852 \times 61}{2.256 \times 43} \simeq 1.7934$$

Houve uma melhoria a qualquer outro anterior

2.5 Source code optimization: branch delay slot

a) Attach a copy of the new assembly program. Código em anexo (Prog5)

d)

Clock cycles	110
Instructions	61
Average CPI	1.803

Stalls:	- Data	36+0+0=36
	- Structural	9
	- Branch Taken	0

e)

$$SpeedUp = \frac{2.852 \times \cancel{61}}{1.803 \times \cancel{61}} \simeq 1.5818$$

Houve uma melhoria em relação ao 2.1 e 2.2. Contudo, é mais eficiente fazendo loop unrolling.

Table 1: 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 $12, 0($1)	F	D	X	M	W										F																									
2	dmul $12, $12, $9		F	D	X	X	X	X	X	X	X	X	M	W																											
3	dadd $9, $9, $12			F	D	D	X	X	X	X	X	X	X	M	W																										
4	daddi $5, $5, 1				F	F	D	D	D	D	D	D	D	X	M	W																									
5	daddi $1, $1, 8						F	F	F	F	F	F	F	D	X	M																									
6	bne $6, $5, loop													F	D	X																									
7	sw $9, mult($9)														F																										
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Table 2: 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 $12, 0($1)	F	D	X	M	N									F																										
2	daddi $5, $5, 1		F	D	X	M	W																																		
3	daddi $1, $1, 8			F	D	X	M	W																																	
4	dmul $12, $12, $9				F	D	X	X	X	X	X	X	X	M	W																										
5	dadd $9, $9, $12					F	D	X							M																										
6	bne $6, $5, loop						F	D							X																										
7	sw $9, mult($6)							F																																	
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Table 3: 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 $12, 0($1)	F	D	X	M	W																									F										
2	daddi $5,$5,3		F	D	X	M	W																																		
3	daddi $1,$1,24			F	D	X	M	W																																	
4	dmul $12,$12,$5				F	D	X	X	X	X	X	X	X	M	W																										
5	lw $13, -16($1)					F	D	X	M	W																															
6	dadd $9,$9,$12						F	D	X						M	W																									
7	dmul $13,$13,$9							F	D						X	X	X	X	X	X	X	M	W																		
8	lw $14, -8($1)								F						D	X	M	W																							
9	dadd $9,$9,$13														F	D	X						M	W																	
10	dmul $14,$14,$9															F	D						X	X	X	X	X	X	X	M	W										
11	dadd $9,$9,$14																F						D	X							M										
12	bne $6,$5,loop																						F	D							X										
13	sw $9, mult($0)																							F																	
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Table 4: 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 $12, 0($1)	F	D						X	M	W		F	D						X	M																				
2	daddi $5, $5, 1		F						D	X	M	W		F						D	X																				
3	daddi $1, $1, 8								F	D	X	M	W							F	D																				
4	dmul $12, $12, $9									F	D	X	X	X	X	X	X	X	M	W	F																				
5	bne $6, $5, loop										F	D	X	M	W																										
6	dadd $9, $9, $12											F	D	X						M	W																				
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