STUDENTS IDENTIFICATION:

Number:	Name:
105901	Francisca Almeida
106943	José Fragão
107245	Patrícia Gameiro

2.1 Simple execution, without data forwarding techniques

f)

Clock cycles	337
Instructions	166
Average CPI	2.271

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

g) The simulator follows a static predict branch not taken policy. This can be easily identified by looking at the instruction that the simulator runs after the branch one. That instruction is always the halt instruction, the one that comes after the branch in the code. We can also note that the policy is static since the simulator keeps missing the prediction (not taking the branch when it should) and yet it does not change its prediction (15 branch (not) taken stalls in 16 iterations).

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) Assuming that the clock rate is the same for both setups (the processor is the same) then the speed up would be the following:

$$\text{speedup} = \frac{\text{CPU Time}_{old}}{\text{CPU Time}_{new}} = \frac{\frac{CPI_{old} \times IC_{old}}{CR}}{\frac{CPI_{new} \times IC_{new}}{CR}} = \frac{CPI_{old} \times IC_{old}}{CPI_{new} \times IC_{new}} = \frac{2.271 \times 166}{1.789 \times 166} = 1.269$$

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	1.5

Stalls:	- Data	48
	- Structural	16
	- Branch Taken	1.5

d) Assuming that the clock rate is the same for both setups (the processor is the same) then the speed up would be the following:

$$\text{speedup} = \frac{\text{CPU Time}_{old}}{\text{CPU Time}_{new}} = \frac{\frac{CPI_{old} \times IC_{old}}{CR}}{\frac{CPI_{new} \times IC_{new}}{CR}} = \frac{CPI_{old} \times IC_{old}}{CPI_{new} \times IC_{new}} = \frac{2.271 \times 166}{1.500 \times 166} = 1.514$$

2.4 Source code optimization: loop unrolling

a) Attach a copy of the new assembly program.

c)

Clock cycles	161
Instructions	126
Average CPI	1.278

Stalls:	- Data	8
	- Structural	16
	- Branch Taken	7

d)

Assuming that the clock rate is the same for both setups (the processor is the same) then the speed up would be the following:

$$\text{speedup} = \frac{\text{CPU time}_{old}}{\text{CPU time}_{new}} = \frac{\frac{CPI_{old} \times IC_{old}}{CR}}{\frac{CPI_{new} \times IC_{new}}{CR}} = \frac{CPI_{old} \times IC_{old}}{CPI_{new} \times IC_{new}} = \frac{2.271 \times 166}{1.278 \times 126} = 2.341$$

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)

Assuming that the clock rate is the same for both setups (the processor is the same) then the speed up would be the following:

$$\text{speedup} = \frac{\text{CPU time}_{old}}{\text{CPU time}_{new}} = \frac{\frac{CPI_{old} \times IC_{old}}{CR}}{\frac{CPI_{new} \times IC_{new}}{CR}} = \frac{CPI_{old} \times IC_{old}}{CPI_{new} \times IC_{new}} = \frac{2.271 \times 166}{1.410 \times 166} = 1.611$$

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	D	D	X	X	X	X	X	X	X	M	W																									
4	dadd $12,$12,$10				F	F	F	D	D	D	D	D	D	D	D	D	X	M	W																						
5	sw $12,0($4)							F	F	F	F	F	F	F	F	F	D	D	D	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														
13																																									
14																																									
15																																									
16																																									
17																																									
18																																									
19																																									
20																																									
21																																									
22																																									
23																																									
24																																									
25																																									
26																																									
27																																									
28																																									
29																																									
30																																									

START OF → THE NEXT ITERATION

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	X	X	X	X	X	X	X	X	M	W																										
4	dadd $12,$12,$10				F	D	D	X	X	X	X	X	X	X	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																			
13																																									
14																																									
15																																									
16																																									
17																																									
18																																									
19																																									
20																																									
21																																									
22																																									
23																																									
24																																									
25																																									
26																																									
27																																									
28																																									
29																																									
30																																									

START OF THE NEXT ITERATION →

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	X	X	X	X	X	X	X	M	W																										
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	X	X	X	X	M	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	haet															F																									
12	lw $10,0($2)																F	D	X																						
13																																									
14																																									
15																																									
16																																									
17																																									
18																																									
19																																									
20																																									
21																																									
22																																									
23																																									
24																																									
25																																									
26																																									
27																																									
28																																									
29																																									
30																																									

START OF → THE NEXT ITERATION

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	X	X	X	X	X	X	X	M	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	X	X	X	X	X	X	X	M	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	X	M	W																									
11	dadd $15,$15,$13											F	D	D	X	X	X	M	W																						
12	sw $12,0($4)												F	F	D	D	D	X	M	W																					
13	sw $15,8($4)														F	F	F	D	X	M	W																				
14	daddi $4,$4,16																	F	D	X	M	W																			
15	bne $1,$5,loop																		F	D	X	M	W																		
16	halt																			F																					
17	lw $10,0($2)																				F	D	X																		
18																																									
19																																									
20																																									
21																																									
22																																									
23																																									
24																																									
25																																									
26																																									
27																																									
28																																									
29																																									
30																																									

START OF THE NEXT ITERATION →

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	X	X	X	X	X	X	X	M	W																										
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	X	X	X	X	M	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																						
11	lw $10,0($2)																F	D	X	M																					
12																																									
13																																									
14																																									
15																																									
16																																									
17																																									
18																																									
19																																									
20																																									
21																																									
22																																									
23																																									
24																																									
25																																									
26																																									
27																																									
28																																									
29																																									
30																																									

START OF → THE NEXT ITERATION

2.3.

```
        .data
A:      .word 1,2,3,4,5
        .word 6,7,8,9,10
        .word 11,12,13,14,15
        .word 16
B:      .word 11,22,33,44,55
        .word 66,77,88,99,100
        .word 111,122,133,144,155
        .word 166
C:      .word 0,0,0,0
        .word 0,0,0,0
        .word 0,0,0,0
        .word 0,0,0,0

        .code
        daddi $1, $zero, 0 ; i = 0
        daddi $5, $zero, 16 ; value of N
        daddi $2, $zero, A
        daddi $3, $zero, B
        daddi $4, $zero, C

loop:   lw $10, 0($2)
        lw $11, 0($3)
        daddi $1, $1, 1
        dmul $12, $10, $11
        daddi $2, $2, 8
        daddi $3, $3, 8
        dadd $12, $12, $10
        sw $12, 0($4)
        daddi $4, $4, 8
        bne $1, $5, loop

        halt
```

2.4.

```
        .data
A:      .word 1,2,3,4,5
        .word 6,7,8,9,10
        .word 11,12,13,14,15
        .word 16
B:      .word 11,22,33,44,55
        .word 66,77,88,99,100
        .word 111,122,133,144,155
        .word 166
C:      .word 0,0,0,0
        .word 0,0,0,0
        .word 0,0,0,0
        .word 0,0,0,0

        .code
        daddi $1, $zero, 0 ; i = 0
        daddi $5, $zero, 16 ; value of N
        daddi $2, $zero, A
        daddi $3, $zero, B
        daddi $4, $zero, C

loop:   lw $10, 0($2)
        lw $11, 0($3)
        lw $13, 8($2)
        dmul $12, $10, $11
        lw $14, 8($3)
        daddi $1, $1, 2
        dmul $15, $13, $14
        daddi $2, $2, 16
        daddi $3, $3, 16
        dadd $12, $12, $10
        dadd $15, $15, $13
        sw $12, 0($4)
        sw $15, 8($4)
        daddi $4, $4, 16
        bne $1, $5, loop

        halt
```

2.5.

```
            .data
A:          .word 1,2,3,4,5
            .word 6,7,8,9,10
            .word 11,12,13,14,15
            .word 16
B:          .word 11,22,33,44,55
            .word 66,77,88,99,100
            .word 111,122,133,144,155
            .word 166
C:          .word 0,0,0,0
            .word 0,0,0,0
            .word 0,0,0,0
            .word 0,0,0,0

            .code
            daddi $1, $zero, 0 ; i = 0
            daddi $5, $zero, 16 ; value of N
            daddi $2, $zero, A
            daddi $3, $zero, B
            daddi $4, $zero, C

loop:       lw $10, 0($2)
            lw $11, 0($3)
            daddi $1, $1, 1
            dmul $12, $10, $11
            daddi $2, $2, 8
            daddi $3, $3, 8
            dadd $12, $12, $10
            sw $12, 0($4)
            bne $1, $5, loop
            daddi $4, $4, 8

            halt
```