STUDENTS IDENTIFICATION:

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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) A política de previsão de desvio utilizada é "predict not taken", uma vez que após a instrução de desvio, é executada a instrução seguinte do programa, e não a que se encontra no destino do desvio. Como a instrução de desvio se situa no fim do ciclo, o salto será feito em todas as iterações, excepto na última, pelo que a instrução "sw" apenas não é anulada nesse caso.

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)

CCold = 377

CCnew = 297

$$\text{Speedup} = \frac{\text{time old}}{\text{time new}} = \frac{\text{CCold} * \text{ClockTime}}{\text{CCnew} * \text{ClockTime}} = \frac{\text{CCold}}{\text{CCnew}} =$$

(mesmo CPU)

$$= \frac{377}{296} = 1.274$$

2.3 Source code optimization: minimization of data and structural hazards

a) Attach a copy of the new assembly program.

c)

Clock cycles	233
Instructions	166
Average CPI	1.404

Stalls:	- Data	32
	- Structural	16
	- Branch Taken	15

**d)**

CCold = 377

CCnew = 233

$$\text{Speedup} = \frac{\text{time old}}{\text{time new}} = \frac{\text{CCold} * \text{ClockTime}}{\text{CCnew} * \text{ClockTime}} = \frac{\text{CCold}}{\text{CCnew}} =$$

(mesmo CPU)

$$= \frac{377}{233} = 1.618$$

2.4 Source code optimization: loop unrolling

a) Attach a copy of the new assembly program.

c)

Clock cycles	185
Instructions	126
Average CPI	1.468

Stalls:	- Data	32
	- Structural	16
	- Branch Taken	7

d)

CCold = 377

CCnew = 185

$$\text{Speedup} = \frac{\text{time old}}{\text{time new}} = \frac{\text{CCold * ClockTime}}{\text{CCnew * ClockTime}} = \frac{\text{CCold}}{\text{CCnew}} =$$

(mesmo CPU)

$$= \frac{377}{185} = 2.038$$

2.5 Source code optimization: branch delay slot

a) Attach a copy of the new assembly program.

d)

Clock cycles	218
Instructions	166
Average CPI	1.313

Stalls:	- Data	32
	- Structural	16
	- Branch Taken	0

e)

CCold = 377

CCnew = 218

$$\text{Speedup} = \frac{\text{time old}}{\text{time new}} = \frac{\text{CCold * ClockTime}}{\text{CCnew * ClockTime}} = \frac{\text{CCold}}{\text{CCnew}} =$$

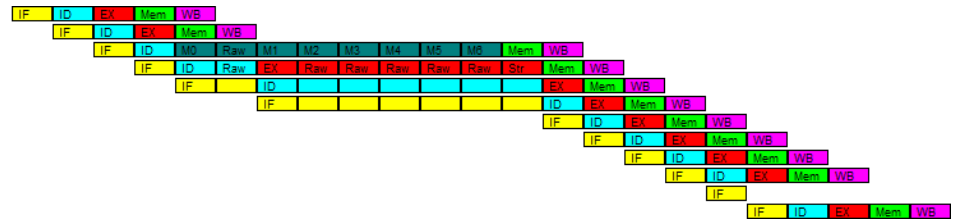(mesmo CPU)

$$= \frac{377}{218} = 1.729$$

2.1. e)

```
lw $10, 0($2)
lw $11, 0($3)
dmul $12, $10, $11
dadd $12, $12, $10
sw $12, 0($4)
daddi $1, $1, 1
daddi $2, $2, 8
daddi $3, $3, 8
daddi $4, $4, 8
bne $1, $5, loop
halt
lw $10, 0($2)
```
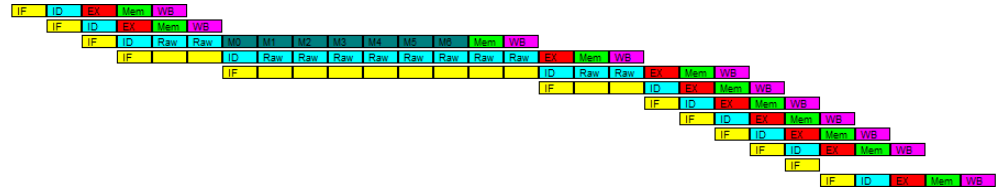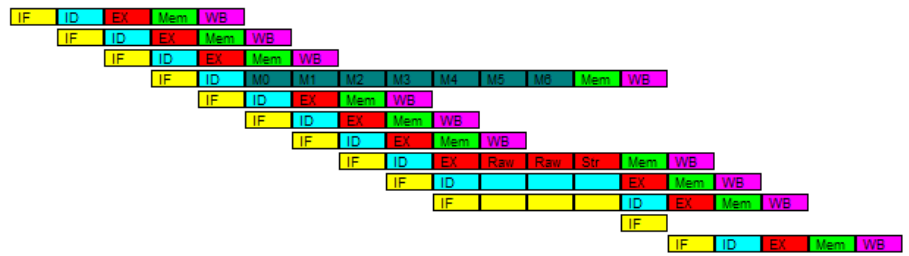
2.2. b)

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

2.3. b)

```
lw $10, 0($2)
lw $11, 0($3)
daddi $1, $1, 1
dmul $12, $10, $11
daddi $2, $2, 8
daddi $3, $3, 8
daddi $4, $4, 8
dadd $12, $12, $10
sw $12, -8($4)
bne $1, $5, loop
halt
lw $10, 0($2)
```
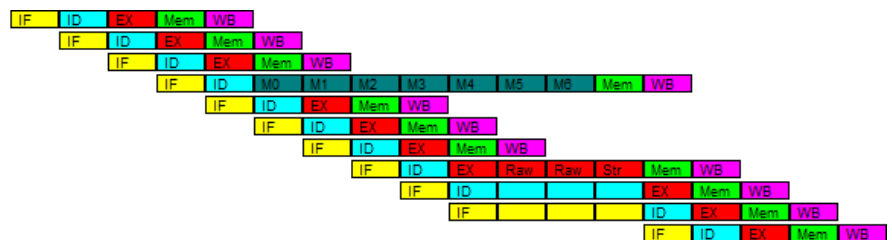
2.4. b)

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

2.5. c)

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

2.3. a)

```
1    .data
     11 references
2  v A:              .word 1,2,3,4,5
3                    .word 6,7,8,9,10
4                    .word 11,12,13,14,15
5                    .word 16
     9 references
6  v B:              .word 11,22,33,44,55
7                    .word 66,77,88,99,100
8                    .word 111,122,133,144,155
9                    .word 166
     9 references
10 v C:              .word 0,0,0,0
11                   .word 0,0,0,0
12                   .word 0,0,0,0
13                   .word 0,0,0,0
14
15   .code
16                   daddi $1, $zero, 0 ; i = 0
17                   daddi $5, $zero, 16 ; value of N
18                   daddi $2, $zero, A
19                   daddi $3, $zero, B
20                   daddi $4, $zero, C
21
     15 references
22 v loop:           lw $10, 0($2)
23                   lw $11, 0($3)
24                   daddi $1, $1, 1
25                   dmul $12, $10, $11
26                   daddi $2, $2, 8
27                   daddi $3, $3, 8
28                   daddi $4, $4, 8
29
30                   dadd $12, $12, $10
31                   sw $12, -8($4)
32
33                   bne $1, $5, loop
34
35                   halt
```

2.4. a)

```
 1    .data
      11 references
 2  ∨ A:            .word 1,2,3,4,5
 3    │  │  │       .word 6,7,8,9,10
 4    │  │  │       .word 11,12,13,14,15
 5    │  │  │       .word 16
      9 references
 6  ∨ B:            .word 11,22,33,44,55
 7    │  │  │       .word 66,77,88,99,100
 8    │  │  │       .word 111,122,133,144,155
 9    │  │  │       .word 166
      9 references
10  ∨ C:            .word 0,0,0,0
11    │  │  │       .word 0,0,0,0
12    │  │  │       .word 0,0,0,0
13    │  │  │       .word 0,0,0,0
14
15    .code
16    │  │  │       daddi $1, $zero, 0 ; i = 0
17    │  │  │       daddi $5, $zero, 16 ; value of N
18    │  │  │       daddi $2, $zero, A
19    │  │  │       daddi $3, $zero, B
20    │  │  │       daddi $4, $zero, C
21
      15 references
22  ∨ loop:
23    │  │  │       lw $10, 0($2)
24    │  │  │       lw $11, 0($3)
25    │  │  │       lw $13, 8($2)
26    │  │  │       lw $14, 8($3)
27
28    │  │  │       dmul $12, $10, $11
29    │  │  │       dmul $15, $13, $14
30
31    │  │  │       dadd $12, $12, $10
32    │  │  │       dadd $15, $15, $13
33
34    │  │  │       sw $12, 0($4)
35    │  │  │       sw $15, 8($4)
36
37    │  │  │       daddi $1, $1, 2
38    │  │  │       daddi $2, $2, 16
39    │  │  │       daddi $3, $3, 16
40    │  │  │       daddi $4, $4, 16
41
42    │  │  │       bne $1, $5, loop
43
44    │  │  │       halt
```

2.5. a)

```
1    .data
     11 references
2  ∨ A:              .word 1,2,3,4,5
3    |     |     |   .word 6,7,8,9,10
4    |     |     |   .word 11,12,13,14,15
5    |     |     |   .word 16
     9 references
6  ∨ B:              .word 11,22,33,44,55
7    |     |     |   .word 66,77,88,99,100
8    |     |     |   .word 111,122,133,144,155
9    |     |     |   .word 166
     9 references
10 ∨ C:              .word 0,0,0,0
11   |     |     |   .word 0,0,0,0
12   |     |     |   .word 0,0,0,0
13   |     |     |   .word 0,0,0,0
14
15   .code
16                   daddi $1, $zero, 0 ; i = 0
17                   daddi $5, $zero, 16 ; value of N
18                   daddi $2, $zero, A
19                   daddi $3, $zero, B
20                   daddi $4, $zero, C
21
     15 references
22 ∨ loop:           lw $10, 0($2)
23   |     |     |   lw $11, 0($3)
24   |     |     |   daddi $1, $1, 1
25   |     |     |   dmul $12, $10, $11
26   |     |     |   daddi $2, $2, 8
27   |     |     |   daddi $3, $3, 8
28   |     |     |   daddi $4, $4, 8
29   |     |     |   dadd $12, $12, $10
30
31                   bne $1, $5, loop
32                   sw $12, -8($4)
33
34                   halt
```