STUDENTS IDENTIFICATION:

| Number: | Name: |
|------------|---|
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| ist1106180 | Vasco Alexandre Amado Rodrigues |
| ist1107316 | Afonso Maria Pereira Mateus |

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 |

2) clockcycles = 23 Instructions = 10 AVG CPI = <u>23</u> = 21³

B) Num total de 16 iterções programados jaro o cido do programo, exorreram 15 stalls de Bronch Taken e a instrucçõe imedictamente a regerir a "bno", que jó tinho entrodo no pipeline e estoro a meio do suo escerução, é fushed sempre que a brond for taken. Logo estomos ferror umá brondo prediction policy de predict not token".

2.2 Application of data forwarding techniques

| c) | Clock cycles | 797 |
|----|--------------|-------|
| | Instructions | 166 |
| | Average CPI | 1.789 |

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

Exe_time = num_cyclos x eycle-time

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rum_cycloseax cycletime = 797 = 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 | 1,500 |

| Stalls: - Data | H 3 |
|----------------|-----|
| - Structural | 16 |
| - Branch Taken | 25 |

Polo poinmole de aita en 2.2 d), o predap compuedo com 2.1 ó Spardap = 377 - 1,519 249

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, 238 |

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

d)

2.5 Source code optimization: branch delay slot

a) Attach a copy of the new assembly program.

d)

| Clock cycles | 634 |
|--------------|-------|
| Instructions | 166 |
| Average CPI | 1,410 |

| Stalls: - Data | 48 |
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| - Structural | 16 |
| - Branch Taken | Ö |

e)

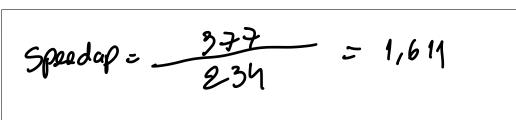


Table 1: Pipeline time diagram, without data forwarding techniques.

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Table 2: Pipeline time diagram, with data forwarding techniques.

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Table 3: Pipeline time diagram, with minimization techniques to reduce the data and structural hazards.

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Table 4: Pipeline time diagram: usage of loop unrolling minimization techniques to reduce the control hazards.

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Table 5: Pipeline time diagram: usage of branch delay slot techniques to reduce the control hazards.

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Code for 2.3

```
loop:
    lw $10, 0($2)
                            # Load A[i] into $10
   lw $11, 0($3)
                            # Load B[i] into $11
    daddi $1, $1, 1
                            # Increment i by 1
    dmul $12, $10, $11
                           # Multiply A[i] and B[i], store result in $12
    daddi $2, $2, 8
                           # Move to the next element in A (increment $2 by 8 bytes)
    daddi $3, $3, 8
                           # Move to the next element in B (increment $3 by 8 bytes)
    dadd $12, $12, $10
                           # Add A[i] to the product (A[i] * B[i] + A[i])
    sw $12, 0($4)
                            # Store the result in C[i] (store $12 at address pointed by $4)
    daddi $4, $4, 8
                            # Move to the next element in C (increment $4 by 8 bytes)
    bne $1, $5, loop
                            # If i \neq N (stored in $5), repeat the loop
halt
                            # Stop execution
```

Code for 2.4

```
loop:
                lw $10, 0($2)
                                         # Load A[i] into $10
                lw $11, 0($3)
                                         # Load B[i] into $11
                                                                                      A[i+1]
                lw $13, 8($2)
                                         # Load A[i·] into $13
                                         # Load B[i ] into $14
                lw $14, 8($3)
                                                                                       B[i+1]
                dmul $12, $10, $11
                                         # Multiply A[i] and B[i], store in $12
                daddi $1, $1, 2
                                         # Increment i by 2
                                         # Multiply A[i+ and B[i- , store in $15
                                                                                      A[i+1] B[i+1]
                dmul $15, $13, $14
                daddi $2, $2, 16
                                         # Move to the next set of elements in A
                daddi $3, $3, 16
                                         # Move to the next set of elements in B
                dadd $12, $12, $10
                                         # Add A[i] to the product, store in $12
                dadd $15, $15, $13
                                         # Add A[i- to the product, store in $15
                                                                                      A[i+1]
                sw $12, 0($4)
                                         # Store result in C[i]
                sw $15, 8($4)
                                         # Store result in C[i+
                                                                                      C[i+1]
                daddi $4, $4, 16
                                         # Move to the next set of elements in C
                bne $1, $5, loop
                                         # If i \neq N, repeat loop
                halt
                                         # Stop execution
```

Code for 2.5

```
loop:
   lw $10, 0($2)
                             # Load A[i] into $10
   lw $11, 0($3)
                             # Load B[i] into $11
   daddi $1, $1, 1
                            # Increment i by 1
   dmul $12, $10, $11
                            # Multiply A[i] and B[i], store result in $12
   daddi $2, $2, 8
                             # Move to the next element in A (increment $2 by 8 bytes)
   daddi $3, $3, 8
                             # Move to the next element in B (increment $3 by 8 bytes)
   dadd $12, $12, $10
                            # Add A[i] to the product (A[i] * B[i] + A[i])
   sw $12, 0($4)
                             # Store the result in C[i] (store $12 at address pointed by $4)
   bne $1, $5, loop
                             # If i \neq N (stored in $5), repeat the loop
   daddi $4, $4, 8
                             # Move to the next element in C (increment $4 by 8 bytes)
   halt
                            # Stop execution
```