INSTITUTO SUPERIOR TÉCNICO

DEPARTAMENTO DE ENGENHARIA INFORMÁTICA

COMPUTER ORGANIZATION

LEIC-A, LEIC-T

Third Lab Assignment: Instruction Level Parallelism

Version 1.0

DUE IN CLASS

STUDENTS IDENTIFICATION:

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|---------|-----------------|
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2.1 Simple execution, without data forwarding techniques

| e) | Clock cycles | 18 | Instructions | 6 | Average CPI | 3,0 | |
|----|--------------|----|--------------|---|-------------|-----|---|
| | | | | | | | - |

| f) | Clock cycles | 174 | Stalls: - Data | 101 |
|----|--------------|-------|----------------|-----|
| | Instructions | 61 | - Structural | 0 |
| | Average CPI | 2,852 | - Branch Taken | 8 |

g) <u>t técnica usada é o static prediction not taken. Les da</u> fetch da instrução BNE, começa-se a dan fetch do instrução SW (durante a saccueção do branch), assumindo que o salto não erealizado. Caso o solto seja realizado, a instrução SW é anulado.

2.2 Application of data forwarding techniques

d)
$$CR = \frac{m^{\frac{\alpha}{2}} \operatorname{ciclor}}{\frac{1}{2}} \qquad CPI = \frac{m^{\frac{\alpha}{2}} \operatorname{ciclor}}{m^{\frac{\alpha}{2}} \operatorname{inst}} \implies t = \frac{CPI. \ m^{\frac{\alpha}{2}} \operatorname{inst}}{CR}$$

$$SPEED VP = \frac{CPI_{2,1} \times \# \operatorname{inst}_{2,1}}{\frac{CPI_{2,1} \times \# \operatorname{inst}_{2,2}}{CR}} = \frac{27852}{27230} = 1,2789$$

2.3 Source code optimization: minimization of data and structural hazards

a) Attach a copy of the new assembly program.

| c) | Clock cycles | 118 |
|------------|--------------|-------|
| | Instructions | 61 |
| | Average CPI | 1,934 |

| Stalls: - Data | 36 |
|----------------|----|
| - Structural | 9 |
| - Branch Taken | 8 |

d)
$$\frac{CPT_{2.7} \times \# inst_{2.1}}{CPT_{2.5} \times \# inst_{2.3}} = \frac{2,852}{1,934} = 1,4747$$

$$\frac{CPT_{2.7} \times \# inst_{2.3}}{CPT_{2.5} \times \# inst_{2.3}} = \frac{1,4747}{1,934} = 1,4747$$

2.4 Source code optimization: loop unrolling

a) Attach a copy of the new assembly program.

| c) | Clock cycles | 103 |
|----|--------------|-------|
| | Instructions | 43 |
| | Average CPI | 2,395 |

| Stalls: - Data | 81 |
|----------------|-------------|
| - Structural | q |
| - Branch Taken | 2 (8/4 = 2) |

SPEED UP = $\frac{t_{old}}{t_{mew}} = \frac{\frac{CPI_{2.1} \times m^{\frac{1}{2}} inst_{2.1}}{CR}}{\frac{CPI_{2.4} \times m^{\frac{1}{2}} inst_{2.4}}{CR}} = \frac{2,852 \times 61}{2,395 \times 43} = 1,6893$

2.5 Source code optimization: branch delay slot

a) Attach a copy of the new assembly program.

| d) | Clock cycles | 101 |
|----|--------------|-------|
| | Instructions | 61 |
| | Average CPI | 1,656 |

| Stalls: | - Data | 2 7 |
|---------|----------------|----------------|
| | - Structural | 9 |
| | - Branch Taken | 0 |

e)
$$SPEED UP = \frac{\frac{CPL_{2.1} \times \# inst_{2.1}}{CR_{2.5}}}{\frac{CPL_{2.5} \times \# inst_{2.5}}{CR_{2.5}}} = \frac{2,852}{1,656} = 1,72212$$

Table 1: Pipeline time diagram, with data forwarding techniques.

| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 38 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 2 | | Ш | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 126 | Ш | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 24 | | Ш | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 19 | | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | | ٤ | | | | | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | 3 | | Ш | | | | | | | | | | | | | | | | | | | | | | |
| 16 | | | | | ≯ | E M W | | ۵ | | | | | | | | | | | | | | | | | | | | | | |
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| 2 | DEM | | Q | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 2 | FDEM | FD | FD | | | | (0) | (1- | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | FDEM | FD | FD | F | 8 | Bop | £ (BO) | (日1) | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | FDEM | FD | FD | F | B1,8 | 5, book | (BO) | 0(#1) | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | FDEM | FD | FD | F | 1, 197, 8 | , #5, book | (BO) | 2,0(41) | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | FDEM | FD | FD | F | B1, B1, 8 | #6, #5, book | 189, mult (160) | \$12,0(41) | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | FDEM | FD | FD | F | di 187, 187, 8 | L #6, #5, Book | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | FDEM | FD | FD | F | laddi 187, 187, 8 | me #6, #5, bop | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 2 | DEM | ۵ | Q | | 5 doddi 187, 187, 8 | 6 Jane #6, #5, Bop | 7 SW B9, mult (BO) | 8 Lw 12,0(47) | 6 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |

Table 2: Pipeline time diagram, with minimization techniques to reduce the data and structural hazards.

| | INSTR | INSTRUCTIONS | | - | 2 | 3 | 4 | 5 | 9 | 7 | ∞ | 9 | 101 | - | 2 | 3 12 | 41.4 | 5 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 2 | 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 | 6 2 | 7 28 | 3 25 | 30 | 31 | 32 | 33 | 34 | 35 3 | 6 3′ | 7 38 | 39 | 40 |
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| | 1 Lw | 18 12, O(161) | | Ш | ٥ | E | ٤ | € | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | dodoti | B5, B5, 1 | 1 | | 止 | ۵ | Ш | EM W | 3 | | П | \vdash | | \vdash | | | \vdash | \vdash | | | | | | | | | \vdash | \vdash | \vdash | \vdash | | | | | | | | | | |
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| S | 5 dadd | B9, 49, 1372 | 115 | | | | | щ | _ | ш | Ш | W W | 4 | Ш | ШΣ | ∑ ∑ | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | 6 book | \$6, \$5, boop | pool | | | | | | 1 | 0 | ۵ | ٥ | ٥ | 0 | Д | E | > | $\overline{}$ | | | | | | | | | | | _ | _ | | | | | | | | | | |
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| 22 | 6) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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Table 3: Pipeline time diagram: usage of loop unrolling minimization techniques to reduce the control hazards.

| 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 | | | | - 1 | | | | | | | | | | | | | | | | | | | | | | | | |
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| 28 | | | | | | | | M | E | 0 | F | | | | | | | | | | | | | | | | | | |
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| 6 | | | | М3 | ш | D | 17 | | | | | | | | | | | | | | | | | | | | | | |
| ∞ | | | | М2 | Ш | D | Ŧ | | | | | | | | | | | | | | | | | | | | | | |
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Table 4: Pipeline time diagram: usage of branch delay slot techniques to reduce the control hazards.

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| 34 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 98 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 67 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 82 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | - | |
| 92 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5. | H | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 0 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | - | |
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| 12 | | | _ | | | 3 | _ | | | | | | | _ | | | | | | | | | | | | | | | | - |
| 1. | | | 3 | | | ≤ " | ш | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | | | 6 M | | | πı | 0 | | | | | | | | | | | | | | | | | | | | | | | - |
| 47 | | | ₅ μ ₆ | | | T) | ۵ | | | | | | | | | | | | | | | | | | | | | | | _ |
| 17 | | | M2 M3 My M5 | | _ | Ш | ۵ | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | | Y. | , | 3 | 丌 | ۵ | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | | | Σ, | W | ٤ | ш | ۵ | | | | | | | | | | | | | | | | | | | | | | | _ |
| 므 | | | ξ. | Ä | ш | ۵ | ΙL | | _ | | | | | | | | | | | | | | | | | | | | | _ |
| _ | | 3 | Mo M | Ш | ۵ | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | 3 | | _ | D | 4 | | | | | | | | | | | | | | | | | | | | | | | | | |
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| S | ۵ | 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | | _ |
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| _ | ╨ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS | lw #12,0(\$1) | doddi 185,185,1 | droug \$12, \$12, 69 | doddi \$1,81,8 | Sons \$6,85,600 | dodd 89,89,872 | lw \$12,0(\$1) | | | | | | | | | | | | | | | | | | | | | | | |
| | - | 2 | 3 | 4 | 5 | 9 | 7 | ∞ | 6 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| | | | | | | | | | | | | | | | _ | _ | | | | | | | | | | | | | | |

Table 5: Pipeline time diagram, without data forwarding techniques.

| 1 1 1 1 1 1 1 1 1 1 | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|----------|-----|---------------|---------------|--------|----------|------------|------------|----------|---|----|---|----|---|--------------|----------|----|----|----|----|----|----------|--------|---|---|----|-----|---|---|-----------|--------------|
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W down & #12 # #12 bodd: #5 #5, #5, 1 sadd: #5 #5, Loop Saw #9, mutt (#0) Lw #12, 0(#1) Lw #12, 0(#1) Lw #12, 0(#1) | 39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W down & #12 # #12 bodd: #5 #5, #5, 1 sadd: #5 #5, Loop Saw #9, mutt (#0) Lw #12, 0(#1) Lw #12, 0(#1) Lw #12, 0(#1) | 38 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 72 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | \vdash | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 33 | | | | | | | | | | | | | | | | | | | | | | _ | | | | | | | ш | ₩ |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 3,5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ш | _ |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 34 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 33 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | - | | | | | | | | | | | | | | | | | | | | | | | | | | | | | \Box | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 0 3 | | | | | | | | | | | | | | _ | | | | | | | | | | | | | | | \vdash | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 3 | | | | | | | | | | | | | | | | | | | | | | _ | | | | | | | \vdash | - |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 53 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ш | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 28 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 27 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 97 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 55 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | \Box | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 4 | | | | | | | | | | | | | | - | \vdash | | | | | | | - | | | | | | | | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 2 | | | | | | | _ | _ | | | | | | | _ | | | | | | _ | _ | | | | | | _ | \vdash | ₩ |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 2 | | | | | | | | - | | | | | | | \vdash | | | | | | | | | | | | | | \square | <u> </u> |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 21 | | | | | | | | Ш | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 20 | | | | | | Σ | | Δ | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 6] | | | | | 3 | | | ᄮ | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | ∞ | | | | `` | | | 11 | | | | | | | | | | | | | | | | | | | | | | \Box | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 1 | | | > | | _ | _ | | | | | | | | _ | \vdash | | | | | | _ | | | | | | | _ | \vdash | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 1, | | | | | | | | | | | | | | | | | | | | | _ | _ | | | | | | _ | \vdash | - |
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| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 4 | | 3 | ۵ | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 13 | | Z | D | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 2 | | مح | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | = | | 72 | _ | | | | | | | | | | | | | | | | | | | | | | | | | | М | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 7 8 9 Lw \$12, 0(\$1) F D X M W danul \$\Phi 12 \text{then } then | 1 | | 2 | | | | | _ | | | | | | | _ | \vdash | | | | | | _ | | | | | | | _ | \vdash | \vdash |
| INSTRUCTIONS 1 2 3 4 5 6 1 w \$12, 0(\$1) F D X M W durul & 12 \ 41 \ 49 \ 49 \ 41 \ 41 \ 41 \ 41 \ 41 | - | | Z. | I | | | | | | | | | | | | | | | | | | | | | | | | | | \vdash | - |
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| INSTRUCTIONS 1 2 3 4 5 6 1 w \$12, 0(\$1) F D X M W durul & 12 \ 41 \ 49 \ 49 \ 41 \ 41 \ 41 \ 41 \ 41 | ∞ | | Æ | Q | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 5 6 1 w \$12, 0(\$1) F D X M W durul & 12 \ 41 \ 49 \ 49 \ 41 \ 41 \ 41 \ 41 \ 41 | - | | M | 0 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |] | |
| INSTRUCTIONS 1 2 3 4 Lw \$12, 0(\$1) F D X M dunul \$12, 0(\$1) F D X M dunul \$12, 0(\$1) F D X M bodd: \$5,\$5,\$1 sadd: \$5,\$5,\$1 Lodd: \$7,\$7 Lodd: \$1,\$1 Lodd: | 9 | | چ | ٥ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 2 3 4 Lw \$12, 0(\$1) F D X M dunul \$12, 0(\$1) F D X M dunul \$12, 0(\$1) F D X M bodd: \$5, \$5, \$1 sadd: \$7, \$1, \$2 Lw \$12, \$0(\$1) Lw \$12, \$0(\$1) Lw \$12, \$0(\$1) Lw \$12, \$0(\$1) Lw \$12, \$12, \$12 Lw \$12, \$12, | S | 3 | ۵ | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | \Box | |
| INSTRUCTIONS 1 2 3 Lw \$12, 0(\$1) F D X durul \$12, 0(\$1) F D X durul \$12, 0(\$1) F D X badd: \$5, \$5, 1 badd: \$7, \$1, \$1, \$8 sur \$6, \$5, \$20 LW \$12, 0(\$1) LW \$12, 0(\$1) | \vdash | | | | | | | | \vdash | | | | | | | | | | | | | | \neg | | | | | | | Н | \vdash |
| INSTRUCTIONS 1 2 Iw \$12, 0(\$1) FD donul #12, 0(\$1) boold #9, #91, #12 bodd: #5, #5, 1007 Sw #9, mult (#0) LW #12, 0(#1) LW #12, 0(#1) | - | | $\overline{}$ | | | | | _ | | | | | | | _ | _ | | | | | | _ | | | | | | | _ | \vdash | \vdash |
| INSTRUCTIONS Iw \$12, 0(\$1) F durul \$12,0(\$1) Acdd \$9, \$99,1 badd: \$5, \$99,1 badd: \$7, \$1,8 Swe \$6, \$5, \$60 LW \$12,0(\$1) LW \$12,0(\$1) | - | | | 4 | | | | | | | | | | | _ | | | | | | | | | | | | | | | | _ |
| INSTRUCTIONS Iw \$12, 0(\$1) dougle \$12,\$149 boold \$9,\$99,1 bodd: \$5,\$5,\$100 Saw \$6,\$5,\$100 LW \$12,0(\$1) LW \$12,0(\$1) | \vdash | | ш | | | | | | | | | | | | | | | | | | | | | | | | | | | \sqcup | \vdash |
| INSTRUCTIONS 1 w \$12, 0 (\$1) down \$6 12, 801, \$9 dodd: \$5, \$9 sw \$6, \$9, mutt (\$0) LW \$11, 0 (\$1) LW \$11, 0 (\$1) | | Ţ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCTIONS 1 \$12, 0(\$1) dougle \$1/\$91/\$1 boold \$9, \$99, 1 bodd: \$5, \$95, 1 bodd: \$7, \$1, 8 Lud \$12, 0(\$1) Lud \$12, 0(\$1) Lud \$12, 0(\$1) | | | # | 4 | | I | ر | Õ | | | | | | | | | | | | | | |] | | | | | | | 1 | |
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| 1W \$12, 0(1W \$12, 0(Jould #1) # Jaddi #5# Sul #9, m Lul #12, 0f. Lul #12, 0f. | S | \$1 | Ð | 9 | , P | 7 | , T | 3 | # | | | | | | | | | | | | | | | | | | | | | | |
| INSTRUCT In \$12, Joodd #9 Sale #6, Sale #9, Au #12, Au #12, | ፬ | 0 | 1 | 22 | プ 神 | Æ. | # 5 | \ \{ | ٥ | | | | | | | | | | | | | | | | | | | | | | |
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2.3 a)

```
2.3.s
                           .word 1, 3, 1, 6, 4
.word 2, 4, 3, 9, 5
                .word
                .code
                           $1, $0, A
$5, $0, 1
$6, $0, 10
$9, 0($1)
                                               ; *A[0]
; $5 = 1 ;; i
; $6 = N ;; N = 10
; $9 = A[0] ;; mult
                daddi
                daddi
                daddi
                daddi
                           $12, 0($1)
$5, $5, 1
$12, $12, $9
$1, $1, 8
               daddi
                                               ; $12 = $12*$9 ;; $12 = A[i]*mult
                dmul
                daddi
                                                ; $9 = $9 + $12 ;; mult = mult + A[i]*mult
                dadd
                           $6, $5, loop ; Exit loop if i == N
     ;; Expected result: mult = f6180 (hex), 1008000 (dec)
```

2.4 a)

```
.word
         .code
                   $1, $0, A
$5, $0, 1
                                    ; *A[0]
; $5 = 1 ;; i
         daddi
         daddi
                  $6, $0, 10
$9, 0($1)
$1, $1, 8
                                    ; $6 = N ;; N = 10
; $9 = A[0] ;; mult
         daddi
         daddi
                   $12, 0($1)
$13, 8($1)
$14, 16($1)
                                    ; $12 = A[i]
; $13 = A[i+1]
loop:
                                     ; $14 = A[i+2]
                   $12, $12, $9 ; $12 = $12*$9 ;; $12 = A[i]*mult
         dmul
         dadd
                   $9, $9, $12 ; $9 = $9 + $12 ;; mult = mult + A[i]*mult
         dmul
         dadd
                   $9, $9, $13
         dmul
         dadd
                   $5, $5, 3
$1, $1, 24
         daddi
                                    ; i+=3
         daddi
                   $6, $5, loop
                                    ; Exit loop if i == N
         halt
;; Expected result: mult = f6180 (hex), 1008000 (dec)
```

2.5 a)

```
.data
                .word
                .word 2, 4, 3, 9, 5
mult:
        .word
                0
        .code
        daddi
                $1, $0, A
                               ; *A[0]
        daddi
                $5, $0, 1
                $6, $0, 10
        daddi
                               ; $6 = N ;; N = 10
                $9, 0($1)
                               ; $9 = A[0] ;; mult
        daddi
                $1, $1, 8
                $12, 0($1)
loop:
                               ; $12 = A[i]
        daddi
        dmul
                $12, $12, $9
                               ; $12 = $12*$9 ;; $12 = A[i]*mult
        daddi
                $6, $5, loop
$9, $9, $12
        bne
                               ; Exit loop if i == N
        dadd
                               ; $9 = $9 + $12 ;; mult = mult + A[i]*mult
        SW
                $9, mult($0)
                               ; Store result
        halt
;; Expected result: mult = f6180 (hex), 1008000 (dec)
```