

CSEN 702: Microprocessors Winter 2024

Practice assignment 7

Consider the following code:

```
MUL R3, R1, R2
ADD R5, R3, R4
ADD R7, R2, R6
ADD R10, R8, R9
MUL R11, R7, R10
ADD R5, R5, R11
```

Assume multiplication takes 6 cycles and addition takes 4 cycles, to execute. Both units are pipelined.

a) Consider the regular pipeline with forwarding. Compute the number of cycles needed to execute this code. Show the steps by filling the table.

b) Re-execute this code using Tomasulo using 3 add reservation stations and 2 multiply reservation stations (Assume tomasulo is used for integer instructions) and compute the number of cycles needed. (Show all the steps and consider R1, R2, R4, R6, R8, R9 are available initially)

Also, if two instructions finish in the same cycle, discuss your opinion on who publishes on CDB first.

Solution

A)

| | 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 |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| MUL | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ADD | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ADD | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ADD | | | | | | | | | | | | | | | | | | | | | | | | | | |
| MUL | | | | | | | | | | | | | | | | | | | | | | | | | | |
| ADD | | | | | | | | | | | | | | | | | | | | | | | | | | |

TOTAL=

B) Applying Tomasulo algorithm**Cycle # _____**

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|-----------|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|-----------|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|--------------|----------------|---------------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|-----------|-----------|-----------|-----------|-----------|-----------|-------------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|-----------|-----------|-----------|-----------|-----------|-----------|-------------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|------------|-----------|------------------|--------------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |

| | | | |
|-----|--|--|--|
| R11 | | | |
|-----|--|--|--|

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |

| | | | |
|-----|--|--|--|
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |

| | | | |
|-----|--|--|--|
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |

| | | | |
|-----|--|--|--|
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |

| | | | |
|-----|--|--|--|
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |

| | | | |
|-----|--|--|--|
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |

| | | | |
|-----|--|--|--|
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |

| | | | |
|-----|--|--|--|
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |
| R2 | | | |

| | | | |
|-----|--|--|--|
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|----|----|-----------|-------|
| R1 | | | |

| | | | |
|-----|--|--|--|
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|--|----|-----------|-------|
|--|----|-----------|-------|

| | | | |
|-----|--|--|--|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |

| | | | | | | |
|----|--|--|--|--|--|--|
| M2 | | | | | | |
|----|--|--|--|--|--|--|

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|--|----|----|----|----|----|------|
|--|----|----|----|----|----|------|

| | | | | | | |
|-----------|--|--|--|--|--|--|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|------------|-----------|------------------|--------------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|--------------|----------------|---------------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|-----------|-----------|-----------|-----------|-----------|-----------|-------------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | vj | vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | vj | vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |
| A3 | | | | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |

Cycle # _____

| | Issue | Execute | Write result |
|------------------|-------|---------|--------------|
| MUL R3, R1, R2 | | | |
| ADD R5, R3, R4 | | | |
| ADD R7, R2, R6 | | | |
| ADD R10, R8, R9 | | | |
| MUL R11, R7, R10 | | | |
| ADD R5, R5, R11 | | | |

| | op | Vj | Vk | Qj | Qk | busy |
|----|----|----|----|----|----|------|
| A1 | | | | | | |
| A2 | | | | | | |

| | | | | | | |
|----|--|--|--|--|--|--|
| A3 | | | | | | |
|----|--|--|--|--|--|--|

| | | | | | | |
|----|----|----|----|----|----|------|
| | op | Vj | Vk | Qj | Qk | busy |
| M1 | | | | | | |
| M2 | | | | | | |

| | Qi | Reg value | NOTES |
|-----|----|-----------|-------|
| R1 | | | |
| R2 | | | |
| R3 | | | |
| R4 | | | |
| R5 | | | |
| R6 | | | |
| R7 | | | |
| R8 | | | |
| R9 | | | |
| R10 | | | |
| R11 | | | |