Tutorial - I (Tomasulo's Algorithm)

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	Instructions	Issue	Execute	Write
1	LD F6, 34(R2)			
2	LD F2, 45(R3)			
3	MUL F0, F2, F4			
4	SUB F8, F2, F6			
5	DIV F10, F0, F6			
6	ADD F6, F8, F2			

Consider the above instruction set compromising of 6 instructions. Fill up the table with the cycle number of each operation for all the instructions under the following assumptions.

► The Load, Add/Sub, Mul, Div instructions take 2, 2, 10, 40 cycles respectively. The initial register values of *R*2, *R*3, *F*4 are 100, 200, 2.5 respectively.



- ➤ There are total 3 execution units one for load and store, one for multiplication, and one for addition. The number of reservation stations are 2, 2, 3 for load, multiplication and addition respectively.
- ► The issue is always done in-order and there can be only one issue at a particular clock cycle. Same Cycle ISSUE → DISPATCH is not allowed.



Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation ۷i V_k Qı Busy Disp LD F6. 34(R2) LD1 LD F2. 45(R3) 2 LD2 MUL F0. F2. F4 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 ADD2 ADD F6. F8. F2 6 ADD3 Register Status MUL1 F2 F4 F6 F8 F10 F0 MUL2 Vi: Value for the first operand Vk : Value for the second operand

 \overline{Q}_j : Waiting for the first operand \overline{Q}_k : Waiting for the second operand

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation ۷i V_k Qı Busy Disp LD F6. 34(R2) 1 LD 134 LD1 LD F2. 45(R3) 2 LD2 MUL F0. F2. F4 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 ADD2 ADD F6. F8. F2 6 ADD3 Register Status MUL1 F2 F4 F6 F8 F10 F0 MUL2 LD1 Vi: Value for the first operand

 V_k : Value for the first operand Q_j : Waiting for the first operand Q_k : Waiting for the second operand

Cycle Number

Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Operation

Cycle number of each operation

Reservation Station Table

 V_k

134

245

٧i

Qį

Qk

Disp

	Instructions	Issue	Execute	Write	ſ
1	LD F6, 34(R2)	1	2		ŀ
2	LD F2, 45(R3)	2			ŀ
3	MUL F0, F2, F4				ŀ
4	SUB F8, F2, F6				ļ
5	DIV F10, F0, F6				
6	ADD F6, F8, F2				ŀ
	Regi	ister Status			-

LD1 LD LD LD2 ADD1 ADD2 ADD3 MUL1

MUL2

Busy

				_	
F0	F2	F4	F6	F8	F10
	LD2		LD1		

Vi : Value for the first operand

Vk : Value for the second operand Qi: Waiting for the first operand

Qk : Waiting for the second operand

Reservation Station Table

	Ins	tructi	ons		Issue	I	Execute	Write		Busy	Operation	Vj	V _k	Qj	Qk	Disp	Ì
1	LD	F6, 34	I(R2)		1		2		LD1		LD		134				1
2	LD	F2, 4	(R3)		2				LD2		LD		245				l
3	MUL	. F0, F	2, F4		3	T			LU2		10		240				l
4	SUB	F8, F	2, F6						ADD1								l
5	DIV	F10, F	0, F6						ADD2								1
6	ADD	F6, F	8, F2						ADD3								1
Register Status					MUL1		MUL		2.5	LD2			l				
		F0	F2	F4	F6	F8	F10										ł
		ML1	LD2		LD1		П		MUL2								l

 V_j : Value for the first operand

 V_k : Value for the second operand Q_j : Waiting for the first operand Q_k : Waiting for the second operand



Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Cycle number of each operation

Reservation Station Table

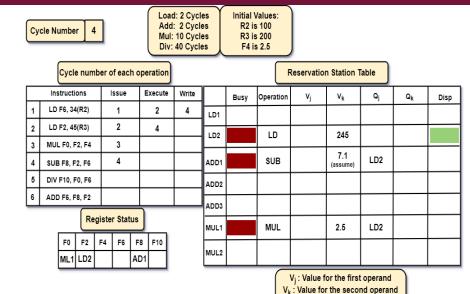
	Ins	tructi	ons		ssue	E	xecute	Write		Busy	Operation	Vj	V _k	Qj	Qk	Disp	
1	LD	F6, 34	I(R2)		1		2		LD1		LD		134				1
2	LD	F2, 45	(R3)		2				LD2		LD		245				l
3	MUL	. F0, F	2, F4	Τ	3	\top			LD2		LU		240				ı
4	SUB	F8, F	2, F6		4				ADD1		SUB			LD2	LD1		ı
5	DIV	F10, F	0, F6						ADD2								l
6	ADD	F6, F	8, F2						ADD3								ı
			D.	:-4-	04-4	$\overline{}$			ADDS								ł
			Re	giste	r Stat	us	_		MUL1		MUL		2.5	LD2			ı
		F0	F2	F4	F6	F8	F10										١
		ML1	LD2		LD1	AD1	П		MUL2								

V_j: Value for the first operand

 V_k : Value for the second operand Q_j : Waiting for the first operand Q_k : Waiting for the second operand

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 4 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Operation ۷i V_k Qi Qı Busy Disp LD F6. 34(R2) 1 2 4 LD 134 LD1 LD F2. 45(R3) 2 4 2 LD 245 LD2 MUL F0. F2. F4 3 3 7.1 LD2 4 SUB SUB F8, F2, F6 ADD1 (assume) DIV F10. F0. F6 5 ADD2 ADD F6. F8. F2 6 ADD3 Register Status MUL1 MUL 2.5 LD2 F2 F6 F8 F10 F0 F4 MUL2 ML1 LD2 LD1 AD1

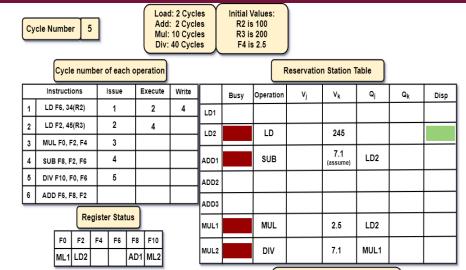
 $\begin{aligned} &V_j: \text{Value for the first operand} \\ &V_k: \text{Value for the second operand} \\ &Q_j: \text{Waiting for the first operand} \\ &Q_k: \text{Waiting for the second operand} \end{aligned}$



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 Q_j : Waiting for the first operand Q_k : Waiting for the second operand



 V_{j} : Value for the first operand V_{k} : Value for the second operand Q_{j} : Waiting for the first operand Q_{k} : Waiting for the second operand

Cycle Number 6

Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Cycle number of each operation

Reservation Station Table

	Ins	tructi	ons	\perp	Issue	E	Execute	Write		Busy	Operation	Vj	V _k	Qj	Qk	Disp
1	LD	F6, 34	(R2)		1		2	4	LD1							
2	LD	F2, 48	(R3)	Т	2		4		1.50		LD		245			
3	MUI	. F0, F	2, F4	T	3	T			LD2		LD		240			
4	SUE	8 F8, F	2, F6	İ	4				ADD1		SUB		7.1 (assume)	LD2		
5	DIV	F10, F	0, F6	\perp	5	\perp			ADD2		ADD			ADD1	LD2	
6	ADD) F6, F	8, F2	\perp	6				ADD3							
			Po	ainta	r Stat											
	Register Status					MUL1		MUL		2.5	LD2					
	F0 F2 F4 F6 F8 F10															
	ML1 LD2 AD2 AD1 ML2					MUL2		DIV		7.1	MUL1					

V_j: Value for the first operand
V_k: Value for the second operand
Q_j: Waiting for the first operand
Q_k: Waiting for the second operand

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 6 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Operation ۷i V_k Qi Qı Busy Disp LD F6. 34(R2) 1 2 4 LD1 LD F2. 45(R3) 2 4 6 2 LD 245 LD2 MUL F0. F2. F4 3 3 -2.5 7.1 4 SUB SUB F8, F2, F6 ADD1 (assume) (assume) DIV F10. F0. F6 5 -2.5 5 ADD1 ADD ADD2 (assume) ADD F6. F8. F2 6 6 ADD3 Register Status -2.5 2.5 MUL1 MUL (assume) F2 F8 F10 F0 F4 F6 DIV 7.1 MUL1

MUL2

AD2 AD1 ML2

Vi: Value for the first operand Vk : Value for the second operand Qi: Waiting for the first operand Qk : Waiting for the second operand

ML1

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 6 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Operation ۷i V_k Qi Qı Busy Disp LD F6. 34(R2) 1 2 4 LD1 LD F2. 45(R3) 2 4 6 2 LD2 MUL F0. F2. F4 3 3 -2.5 7.1 4 SUB SUB F8, F2, F6 ADD1 (assume) (assume) DIV F10. F0. F6 5 -2.5 5 ADD1 ADD ADD2 (assume) ADD F6. F8. F2 6 6 ADD3 Register Status -2.5 2.5 MUL1 MUL (assume) F2 F8 F10 F0 F4 F6 MUL2 DIV 7.1 MUL1

> V_j: Value for the first operand V_k: Value for the second operand Q_j: Waiting for the first operand Q_k: Waiting for the second operand

ML1

AD2 AD1 ML2

Cycle Number

Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles

Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Operation

SUB

ADD

Busy

LD1 LD2

ADD1

Cycle number of each operation

Reservation Station Table

 V_k

7.1

(assume) -2.5

Q

ADD1

 Q_k

Disp

 V_{i}

-2.5

(assume)

	Instructions	Issue	Execute	Write
1	LD F6, 34(R2)	1	2	4
2	LD F2, 45(R3)	2	4	6
3	MUL F0, F2, F4	3	7	
4	SUB F8, F2, F6	4	7	
5	DIV F10, F0, F6	5		
6	ADD F6, F8, F2	6		
	Regi	ister Status	1	

ADD2
ADD3
MUL1
MUL2

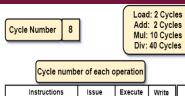
F0	F2	F4	F6	F8	F10
ML1			AD2	AD1	ML2

П				(assume)			
	ADD3						
	MUL1	MUL	-2.5 (assume)	2.5			17
	MUL2	DIV		7.1	MUL1		

Vi : Value for the first operand

Vk: Value for the second operand

Qi: Waiting for the first operand Qk : Waiting for the second operand



Initial Values: R2 is 100 R3 is 200 F4 is 2.5

r of each o	peration							
Issue	Execute	Write	Γ					
1	2	4	┢					
2	4	6	ŀ					
3	7		L					
4	7		4					
5			1					
6			ŀ					
ter Status								
			ľ					

듸		Busy	Operation	Vj	V _k	Qj	Q _k	Disp	
4	LD1								
\dashv	LD2								
	ADD1		SUB	-2.5 (assume)	7.1 (assume)				9
\dashv	ADD2		ADD		-2.5 (assume)	ADD1			
	ADD3								
	MUL1		MUL	-2.5 (assume)	2.5				17
	MUL2		DIV		7.1	MUL1			
							$\overline{}$		

Register Status

F0 F2 F4 F6 F8 F10 ML1 AD2 AD1 ML2

Vi : Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Q_k: Waiting for the second operand

LD F6, 34(R2)

MUL F0, F2, F4 SUB F8, F2, F6 DIV F10, F0, F6

ADD F6. F8. F2

2

5

6

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Operation Busy LD1

	Instructions	Issue	Execute	Write			
1	LD F6, 34(R2)	1	2	4			
2	LD F2, 45(R3)	2	4	6			
3	MUL F0, F2, F4	3	7				
4	SUB F8, F2, F6	4	7	9			
5	DIV F10, F0, F6	5					
6	ADD F6, F8, F2	6					
Register Status							

F0	F2	F4	F6	F8	F10
ML1			AD2		ML2

	1552						
	ADD1	SUB	-2.5	7.1			9
4	ADD2	ADD	-9.6	-2.5			
	ADD3						
	MUL1	MUL	-2.5	2.5			17
	MUL2	DIV		7.1	MUL1		

 V_k

Q

 Q_k

Disp

 V_{i}

Vi: Value for the first operand

Vk : Value for the second operand Qi: Waiting for the first operand

Qk: Waiting for the second operand

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Instructions Issue Execute Write LD F6. 34(R2) 2

7

7

6

9

	Reservation Station Table										
		Busy	Operation	Vj	V _k	Qj	Qk	Disp			
╛	LD1										
\dashv	LD2										
	ADD1										
4	ADD2		ADD	-9.6	-2.5						
	ADD3										
	MUL1		MUL	-2.5	2.5				17		
	MUL2		DIV		7.1	MUL1					

Register Status

2

3

4

5

6

F0	F2	F4	F6	F8	F10
ML1			AD2		ML

 V_j : Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Q_k: Waiting for the second operand

LD F2. 45(R3)

MUL F0. F2. F4

SUB F8, F2, F6 DIV F10, F0, F6

ADD F6. F8. F2

2

3

5

6

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 10 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation V_i ٧k Qk Disp Busy LD F6. 34(R2) 2 4 LD1 LD F2. 45(R3) 2 2 4 6 LD2 7 MUL F0. F2. F4 3 3 7 9 4 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 5 -2.5 12 ADD -9.6 ADD2 10 ADD F6. F8. F2 6 6 ADD3 Register Status 17 2.5 MUL1 MUL -2.5 F0 F2 F4 F6 F8 F10

DIV

MUL2

 V_j : Value for the first operand V_K : Value for the second operand Q_j : Waiting for the first operand Q_k : Waiting for the second operand

7.1

ML1

AD2

ML2

MUL1

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 11 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation V_i ٧k Qk Disp Busy LD F6. 34(R2) 2 4 LD1 LD F2. 45(R3) 2 2 4 6 LD2 7 MUL F0. F2. F4 3 3 7 9 4 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 5 -2.5 12 ADD -9.6 ADD2 10 ADD F6. F8. F2 6 6 ADD3 Register Status 17 2.5 MUL1 MUL -2.5 F0 F2 F4 F6 F8 F10

DIV

MUL2

 V_j : Value for the first operand V_k : Value for the second operand Q_i : Waiting for the first operand

7.1

Q_k : Waiting for the second operand

IML1

AD2

ML2

MUL1



Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Cycle number of each operation

Reservation	Station	Table
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	Instructions	Issue	Execute	Write				
1	LD F6, 34(R2)	1	2	4				
2	LD F2, 45(R3)	2	4	6				
3	MUL F0, F2, F4	3	7					
4	SUB F8, F2, F6	4	7	9				
5	DIV F10, F0, F6	5						
6	ADD F6, F8, F2	6	10	12				
	Register Status							

F0	F2	F4	F6	F8	F10
ML1					ML

\dashv		Dusy	Operation	¥J	*K	۳	□ QK	DISP	
4	LD1								
\dashv	LD2								
+	ADD1								
	ADD2		ADD	-9.6	-2.5				12
	ADD3								
	MUL1		MUL	-2.5	2.5				17
	MUL2		DIV		7.1	MUL1			
			$\overline{}$				$\overline{}$		

V_j: Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Q_k: Waiting for the second operand

Cycle Number 12

Load: 2 Cycles
Add: 2 Cycles
Mul: 10 Cycles
Div: 40 Cycles
Div: 40 Cycles

Cycle number of each operation

Cycle number of each operation

Instructions
Issue
Execute
Write
Busy
Operation

	Instructions	Issue	Execute	Write				
1	LD F6, 34(R2)	1	2	4				
2	LD F2, 45(R3)	2	4	6				
3	MUL F0, F2, F4	3	7					
4	SUB F8, F2, F6	4	7	9				
5	DIV F10, F0, F6	5						
6	ADD F6, F8, F2	6	10	12				

Register Status

F0	F2	F4	F6	F8	F10
ML1					ML2

4		Busy	Operation	Vj	V _k	Qj	Q _k	Disp	ı
4	LD1								
$\frac{1}{2}$	LD2								
1	ADD1								
$\frac{1}{2}$	ADD2								
	ADD3								
	MUL1		MUL	-2.5	2.5				17
	MUL2		DIV		7.1	MUL1			

Reservation Station Table

 V_j : Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Q_k: Waiting for the second operand

Cycle Number 17

Load: 2 Cycles
Add: 2 Cycles
Mul: 10 Cycles
Div: 40 Cycles

Cycle number of each operation

Instructions Issue Execute Write

Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Reservation	Station	Table
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	Instructions	Issue	Execute	Write
1	LD F6, 34(R2)	1	2	4
2	LD F2, 45(R3)	2	4	6
3	MUL F0, F2, F4	3	7	17
4	SUB F8, F2, F6	4	7	9
5	DIV F10, F0, F6	5		
6	ADD F6, F8, F2	6	10	12
			$\overline{}$	

$\overline{}$		Dusy	Operation	• 1	ı v	 ⊸K.	ا الموام ا	
4	LD1							
6	LD2							
17								
9	ADD1							
	ADD2							
12	ADD3							
	MUL1		MUL	-2.5	2.5			17
	MUL2		DIV	-6.25	7.1			

Register Status

	$\overline{}$			_	
F0	F2	F4	F6	F8	F10
					ML:

V_i: Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Q_k: Waiting for the second operand

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 Cycle Number 17 Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation ٧i V_k Qı Busy Disp LD F6. 34(R2) 2 4 LD1 LD F2. 45(R3) 2 4 6 2 LD2 7 17 MUL F0. F2. F4 3 4 7 9 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 5 ADD2 10 ADD F6. F8. F2 6 12 6 ADD3 Register Status MUL1 F2 F4 F6 F8 F10 F0 -6.257.1 MUL2 DIV

 V_{j} : Value for the first operand V_{k} : Value for the second operand Q_{j} : Waiting for the first operand Q_{k} : Waiting for the second operand

ML2

Load: 2 Cycles Initial Values: Add: 2 Cycles R2 is 100 18 Cycle Number Mul: 10 Cycles R3 is 200 Div: 40 Cycles F4 is 2.5 Cycle number of each operation Reservation Station Table Instructions Issue Execute Write Qi Operation V_i ٧k Qk Disp Busy LD F6. 34(R2) 2 4 LD1 LD F2. 45(R3) 2 2 4 6 LD2 7 17 MUL F0. F2. F4 3 3 7 9 4 SUB F8, F2, F6 ADD1 DIV F10. F0. F6 5 18 5 ADD2 10 ADD F6. F8. F2 6 12 6 ADD3 Register Status MUL1

MUL2

ML2

 \boldsymbol{V}_j : Value for the first operand \boldsymbol{V}_k : Value for the second operand

7.1

-6.25

DIV

 \mathbf{Q}_{j} : Waiting for the first operand \mathbf{Q}_{k} : Waiting for the second operand

F0 | F2 | F4 | F6 | F8 | F10

58



Load: 2 Cycles Add: 2 Cycles Mul: 10 Cycles Div: 40 Cycles Initial Values: R2 is 100 R3 is 200 F4 is 2.5

Cycle number of each operation

Reservation Station Table

	Instructions	Issue	Execute	Write
1	LD F6, 34(R2)	1	2	4
2	LD F2, 45(R3)	2	4	6
3	MUL F0, F2, F4	3	7	17
4	SUB F8, F2, F6	4	7	9
5	DIV F10, F0, F6	5	18	58
6	ADD F6, F8, F2	6	10	12

, LO, L	о, г2		0			\perp	12
	Re	giste	r Stat	us			
F0	F2	F4	F6	F8	F10		

e		Busy	Operation	Vj	V _k	Qj	Qk	Disp	
╝	LD1								1
	LD2								l
									ŀ
	ADD1								
╝	ADD2								
╝	ADD3								1
									l
	MUL1								l
	MUL2		DIV	-6.25	7.1				58
							=		4

V_j: Value for the first operand

V_k: Value for the second operand Q_i: Waiting for the first operand

Qk: Waiting for the second operand

Су	cle N	umbe	r 5	8			Ad Mu	ad: 2 Cycl ld: 2 Cycl ıl: 10 Cycl v: 40 Cycl	es es	R2 i:	Values: s 100 s 200 s 2.5	$\bigg)$				F0 F2 F6	-6.25 -2.5 -12.1
		Cycl	e nun	nber o	of eac	h ope	eration					Re	eservation	n Station 1	Table	F8 F10	-9.6 -0.88
	Ins	tructi	ons		Issue	E	xecute	Write		Busy	Operatio	n	Vj	V _k	Qj	Qk	Disp
1	LD	F6, 34	4(R2)		1		2	4	LD1			T					
2	LD	F2, 48	5(R3)		2		4	6	LD2			$^{+}$					+
3	MUI	_ F0, F	2, F4		3		7	17	LD2			+					
4	SUE	3 F8, F	2, F6		4		7	9	ADD1								
5	DIV	F10, F	0, F6		5		18	58	ADD2			T					
6	ADE) F6, F	8, F2		6		10	12	ADD3			+					+
			_	giste	r Stat	_			MUL1			\dagger					+
		F0	F2	F4	F6	F8	F10		MUL2								

 V_j : Value for the first operand V_k : Value for the second operand Q_j : Waiting for the first operand Q_k : Waiting for the second operand

Thank You 1

¹Most of the material are taken from the famous book on Comp Arch by Hen/Pat, Comp Arch course by Milos Prvulovic for teaching purposes

