CMPE 110: Computer Architecture Out-of-Order Execution

Jishen Zhao (http://users.soe.ucsc.edu/~jzhao/)

[Adapted in part from Jose Renau, Mary Jane Irwin, Joe Devietti, Onur Mutlu, and others]

Tomasulo's Algorithm

- If reservation station available before renaming
 - Instruction + renamed operands (registers) inserted into the reservation station
 - Only rename if reservation station is available
- Else stall
- While in reservation station, each instruction:
 - Watches common data bus (CDB) for tag of its sources
 - When tag seen, grab value for the source and keep it in the reservation station
 - When both operands available, instruction ready to be dispatched
- Dispatch instruction to the Functional Unit when instruction is ready

Tomasulo's Algorithm Con't

- After instruction finishes in the Functional Unit
 - Arbitrate for CDB
 - Put tagged value onto CDB (tag broadcast)
 - Register file is connected to the CDB
 - Register contains a tag indicating the latest writer to the register
 - If the tag in the register file matches the broadcast tag, write broadcast value into register (and set valid bit)
 - Reclaim rename tag
 - no valid copy of tag in system!

Put it all together: An Exercise

```
MUL R3 \leftarrow R1, R2

ADD R5 \leftarrow R3, R4

ADD R7 \leftarrow R2, R6

ADD R10 \leftarrow R8, R9

MUL R11 \leftarrow R7, R10

ADD R5 \leftarrow R5, R11
```

- F, D, X, W, i.e., 4-stage pipeline
 - Assume ADD (4 cycle pipelined execute, i.e., X takes 4 cycles), MUL (6 cycle pipelined execute, i.e., X takes 6 cycles)
 - Assume one adder and one multiplier

•

- How many cycles
 - In a pipelined machine without bypassing (forwarding) →stall on data hazards (Answer: 28 cycles, Quiz 1 question 2)
 - In a pipelined machine with bypassing (Answer: 25 cycles)
 - In an out-of-order dispatch pipelined with forwarding

Cycle: 1 SRC1 SRC2 tag value V tag value tag value valid? Α R1 В R2 R3 3 D R4 4 ADD R5 5 SRC1 SRC2 R6 6 value V value tag tag X R7 Y R8 8 Z R9 9 R10 10 1 R11

MUL

					V	tag	value	V	tag	value
	tag	value	valid?	Α						
R1		1	1	В						
R2		2	1							
R3	X	3	0	С						
R4		4	1	D						
R5		5	1			2724	\ /	DD /	-	
R6		6	1		V	SRC1 tag	value	V	tag	RC2 value
R7		7	1	X	1	-	1	1	-	2
R8		8	1	Y						
R9		9	1	Z						
R10		10	1	Т						
R11		11	1				MU	L/		<u> </u>

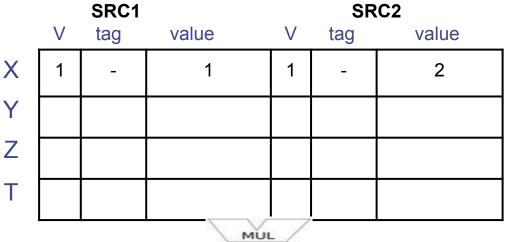
SRC1

SRC2

	tag	value v	'alid'	?
R1 [1	1	
R2		2	1	
R3	X	3	0	
R4		4	1	
R5	Α	5	0	
R6		6	1	
R7		7	1	
R8		8	1	
R9		9	1	
R10		10	1	
R11		11	1	

B

		SRC1			SR	C2
_	V	tag	value	V	tag	value
	0	Х	-	1	1	4
			A	DD /		



	tag	value	valid?
R1		1	1
R2		2	1
R3	X	3	0
R4		4	1
R5	Α	5	0
R6		6	1
R7	В	7	0
R8		8	1
R9		9	1
R10		10	1
R11		11	1

		SRC1			SR	C2
_	V	tag	value	V	tag	value
	0	Х	-	1	1	4
	1	-	2	1	-	6
			A	DD /		

	SRC1			SR	C2
V	tag	value	V	tag	value
1	-	1	1	1	2
		MUI	_/		

	7		
	tag	value	valid?
R1		1	1
R2		2	1
R3	X	3	0
R4		4	1
R5	Α	5	0
R6		6	1
R7	В	7	0
R8		8	1
R9		9	1
R10	С	10	0
211		11	1

		SRC1			SR	C2
_	V	tag	value	V	tag	value
	0	Х	-	1	-	4
	1	ı	2	1	ı	6
	1	ı	8	1	ı	9
			A	DD /		

		SRC1			SR	C2
_	V	tag	value	V	tag	value
	1	-	1	1	1	2
•			MU	L /		

	tag	value v	/alid?
R1		1	1
R2		2	1
R3	X	3	0
R4		4	1
R5	Α	5	0
R6		6	1
R7	В	7	0
R8		8	1
R9		9	1
210	С	10	0
211	Υ	11	0

		SRC1			SR	C2
	V	tag	value	V	tag	value
	0	Х	1	1	1	4
	1	-	2	1	ı	6
	1	-	8	1	ı	9
•			A	DD /		

	SRC1			SR	C2
V	tag	value	V	tag	value
1	-	1	1	1	2
0	В	-	0	С	-
		MUI	_/		

		-	
	tag	value	valid?
R1		1	1
R2		2	1
R3	X	3	0
R4		4	1
R5	D	5	0
R6		6	1
R7	В	7	0
R8		8	1
R9		9	1
10	С	10	0
11	Υ	11	0

	SRC1		SRC2				
V	tag	value	V	tag	value		
0	X	-	1	1	4		
1	ı	2	1	ı	6		
1	ı	8	1	ı	9		
0	Α	-	0	Y	-		
ADD							

	SRC1		SRC2				
V	tag	value	V	tag	value		
1	_	1	1	1	2		
0	В	-	0	С	-		
		MUI	_/				

	tag	value \	/alid?
R1		1	1
R2		2	1
R3	X	2	1
R4		4	1
R5	D	5	0
R6		6	1
R7	В	8	1
R8		8	1
R9		9	1
10	С	10	0
11	Υ	11	0

		SRC1		SRC2				
	V	tag	value	V	tag	value		
	1	X	2	1	1	4		
	1	ı	2	1	ı	6		
	1	ı	8	1	ı	9		
	0	Α	-	0	Y	1		
•	ADD							

	SRC1		SRC2			
V	tag	value	V	tag	value	
1	ı	1	1	ı	2	
1	В	8	0	С	-	
		MUI	_/			

	tag	value \	valid?
2 1		1	1
R2		2	1
₹3	X	2	1
₹4		4	1
R 5	D	5	0
₹6		6	1
₹7	В	8	1
₹8		8	1
₹9		9	1
10	С	17	1
11	V	11	

		SRC1		SRC2			
	V	tag	value	V	tag	value	
	1	X	2	1	1	4	
	1	I	8	1	-	9	
	0	Α	-	0	Y	-	
•	ADD						

		SRC1		SRC2					
\	V	tag	value	V	tag	value			
	1	В	8	1	С	17			
			MUI	_/					

	, 0.0.				V	tag	value	V	tag	value
	tag	value	valid?	٨	1	X	2	1		4
R1		1	1	A	'			'		-
R2		2	1	В						
R3	X	2	1	C						
R4		4	1	D	0	Α	-	0	Y	-
R5	D	5	0			2724	A	DD /		
						SRC1				C2
R6		6	1		V	tag	value	V	tag	value
R6 R7	В	6 8	1	X	V	tag	value	V	tag	value
	В		-	X Y	1	tag B	value 8	1	tag	value 17
R7	В	8	1							
R7 R8	В	8	1	Υ						

SRC1

SRC2

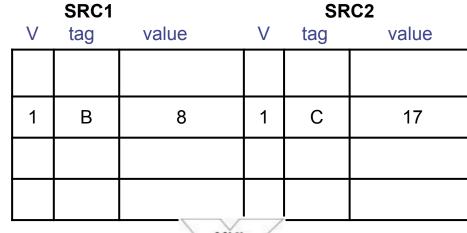
	, 0.0.				V	tag	value	V	tag	value
	tag	value	valid?	٨	1	X	2	1	10.9	4
R1		1	1	A	'			'		
R2		2	1	В				_		
R3	X	2	1	С						
R4		4	1	D	1	Α	6	0	Υ	-
R5	D	5	0					ADD /		
R6		6	1		V	SRC1 tag	value	V	tag	value
R7	В	8	1	X						
R8		8	1	Υ	1	В	8	1	С	17
R9		9	1	Z						
R10	С	17	1	Т						
R11	Υ	11	0				MU	L/		

SRC1

SRC2

	ton	value	valid0		V	tag	value
	tag	value	valid?	Α			
R1		1	1	В			
R2		2	1	С			
R3	Х	2	1				
R4		4	1	D	1	Α	6
R5	D	5	0			SRC1	
R6		6	1		V	tag	value
R7	В	8	1	X			
R8		8	1	Υ	1	В	8
R9		9	1	Z			
R10	С	17	1	Т			
R11	Υ	11	0				

	SRC1			SR	C2
V	tag	value	V	tag	value
1		0			
1	Α	6	0	Y	-
		A	DD /		



	tag	value	valid?
R1		1	1
R2		2	1
R3	X	2	1
R4		4	1
R5	D	5	0
R6		6	1
R7	В	8	1
R8		8	1
R9		9	1
R10	С	17	1
R11	Υ	136	1

Α

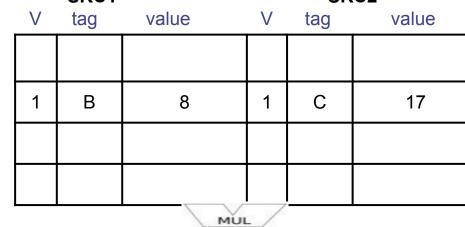
В

X

Y

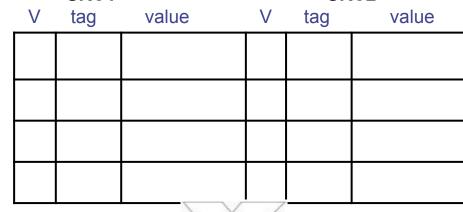
Z

		SRC1			SR	C2
	V	tag	value	V	tag	value
	1	А	6	1	Y	136
•			A	DD /		
		SRC1			SR	C2



	tag	value	/alid?
R1		1	1
R2		2	1
R3	X	2	1
R4		4	1
R5	D	5	0
R6		6	1
R7	В	8	1
R8		8	1
R9		9	1
10	С	17	1
11	Υ	136	1

		SRC1		SRC2 V tag value		
	V	tag	value	V	tag	value
	1	Α	6	1	Y	136
•			\ A	DD /		
		SRC1			SR	C2
	V	tag	value	V	tag	value



	, 0.0.				V	tag	value	V	tag	value
	tag	value	valid?	٨		10.9			<u></u>	
R1		1	1	A						
R2		2	1	В						
R3	X	2	1	С						
R4		4	1	D						
R5	D	142	1			CDC4	/	ADD /	0.5	000
R6		6	1		V	SRC1 tag	value	V	tag	RC2 value
R7	В	8	1	X						
R8		8	1	Υ						
R9		9	1	Z						
R10	С	17	1	Т						
R11	Υ	136	1			<u> </u>		NUL /		

SRC1

SRC2

Instruction	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MUL R3 ← R1, R2	F	D	X1	X2	x 3	X4	X5	X6	W											
ADD R5 ← R3, R4		F	D						X1	X2	X3	X4	W							
ADD R7 ← R2, R6			F	D	X1	X2	X3	X4	W											
ADD R10 ← R8, R9				F	D	X1	X2	X3	X4	W										
MUL R11 ← R7, R10					F	D				X1	X2	X3	X4	X5	X6	W				
ADD R5 ← R5, R11						F	D									X1	X2	X3	X4	W