POLITECNICO DI MILANO

μ-LAB

High Performance Processors and Systems

Dynamic Scheduling

- Scoreboard exercise -

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HPPS

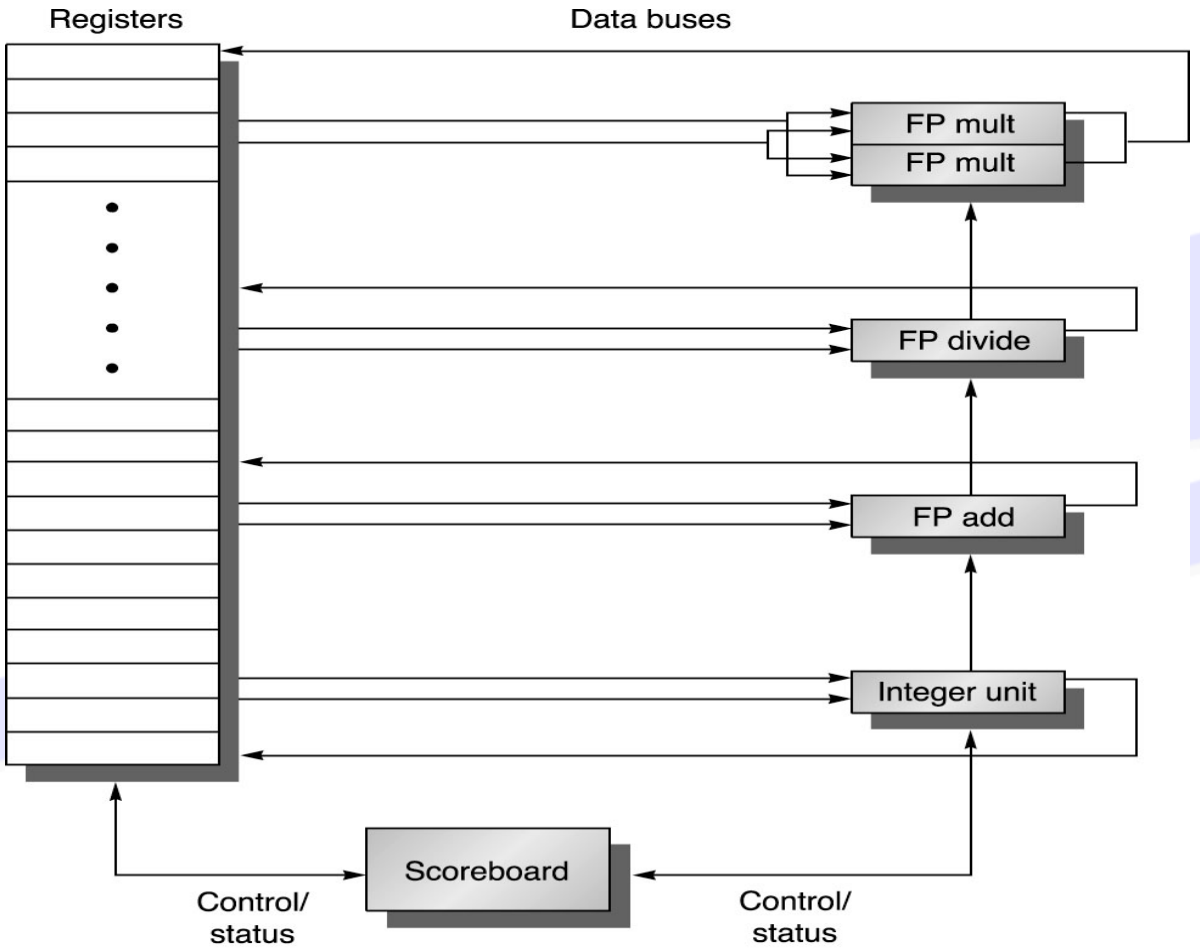
Outline

- Dynamic Scheduling: just a brief remind
- Scorebord
  - Exercise
  - Open issues…

Dynamic Scheduling

- Scheduling separates dependent instructions
  - Static – performed by the compiler
  - Dynamic – performed by the hardware
- Advantages of dynamic scheduling
  - Handles dependences unknown at compile time
  - Simplifies the compiler
  - Optimization is done at run time
- Disadvantages
  - Can not eliminate true data dependences

MIPS with Scoreboard



Scoreboard Operation

- Scoreboard centralizes hazard management
  - Every instruction goes through the scoreboard
  - Scoreboard determines when the instruction can read its operands and begin execution
  - Monitors changes in hardware and decides when an stalled instruction can execute
  - Controls when instructions can write results

- New pipeline

ID		EX	WB
Issue	Read Regs	Execution	Write

Execution Process

- Issue
  - Functional unit is free (structural)
  - Active instructions do not have same Rd (WAW)
- Read Operands
  - Checks availability of source operands
  - Resolves RAW hazards dynamically (out-of-order execution)
- Execution
  - Functional unit begins execution when operands arrive
  - Notifies the scoreboard when it has completed execution
- Write result
  - Scoreboard checks WAR hazards
  - Stalls the completing instruction if necessary

Scoreboard Data Structure

- Instruction status – indicates pipeline stage

- Functional unit status
  - Busy – functional unit is busy or not
  - Op – operation to perform in the unit (+, -, etc.)
  - Fi – destination register
  - Fj, Fk – source register numbers
  - Qj, Qk – functional unit producing Fj, Fk
  - Rj, Rk – flags indicating when Fj, Fk are ready

- Register result status – FU that will write registers

Exercise

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Scoreboard - Clk=1

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1													addd	1			
mult2													multd				
Add1	YES	ADD	F0	F2	F4			YES	YES		S1		multd				
Add2													addd				
F0	F2	F4	F6	F8	F10	F12	F14										
ADD1																	

Scoreboard - Clk=2

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	YES	MULT	F2	F6	F8			YES	YES		S2		**addd**	1	2		
mult2	NO												**multd**	2			
Add1	YES	ADD	F0	F2	F4			YES	YES	2	S1		**multd**				
Add2	NO												**addd**				
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
ADD1	MULT1																

Scoreboard - Clk=3

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	YES	MULT	F2	F6	F8			YES	YES	4	S2		**addd**	1	2		
mult2	YES	MULT	F10	F0	F2	ADD1	MULT1	NO	NO		S3		**multd**	2	3		
Add1	YES	ADD	F0	F2	F4			NO	NO	1	S1		**multd**	3			
Add2	NO												**addd**				
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
ADD1	MULT1				MULT2												

Scoreboard - Clk=4

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	YES	MULT	F2	F6	F8			NO	NO	3	S2
mult2	YES	MULT	F10	F0	F2	ADD1	MULT1	NO	NO		S3
Add1	YES	ADD	F0	F2	F4			NO	NO	0	S1
Add2	NO										

F0	F2	F4	F6	F8	F10	F12	F14
ADD1	MULT1				MULT2		

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	
multd	2	3		
multd	3			
addd				

WAW

Scoreboard - Clk=5

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	YES	MULT	F2	F6	F8			NO	NO	2	S2
mult2	YES	MULT	F10	F0	F2	✓	MULT1	YES	NO		S3
Add1	NO										
Add2	NO										

F0	F2	F4	F6	F8	F10	F12	F14
	MULT1				MULT2		

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3		
multd	3			
addd				

Scoreboard - Clk=6

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	YES	MULT	F2	F6	F8			NO	NO	1	S2		**addd**	1	2	4	5
mult2	YES	MULT	F10	F0	F2		MULT1	YES	NO		S3		**multd**	2	3		
Add1	YES	ADD2	F0	F12	F14			YES	YES		S4		**multd**	3			
Add2	NO												**addd**	6			
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
ADD2	MULT1				MULT2												

Scoreboard - Clk=7

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	St			Issue	Read Op	Exec Co.	Write R.
Mult1	YES	MULT	F2	F6	F8			NO	NO	0	S2		**addd**	1	2	4	5
mult2	YES	MULT	F10	F0	F2		MULT1	YES	NO		S3		**multd**	2	3	7	
Add1	YES	ADD2	F0	F12	F14			YES	YES	2	S4		**multd**	3			
Add2	NO												**addd**	6	7		
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
ADD2	MULT1				MULT2												

Scoreboard - Clk=8

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	NO												addd	1	2	4	5
mult2	YES	MULT	F10	F0	F2		✓	YES	YES		S3		multd	2	3	7	8
Add1	YES	ADD2	F0	F12	F14			NO	NO	1	S4		multd	3			
Add2	NO												addd	6	7		
F0	F2	F4	F6	F8	F10	F12	F14										
ADD2					MULT2												

Scoreboard - Clk=9

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			YES	YES	4	S3
Add1	YES	ADD2	F0	F12	F14			NO	NO	0	S4
Add2	NO										

F0	F2	F4	F6	F8	F10	F12	F14
ADD2					MULT2		

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	6	7	9	

Scoreboard - Clk=10

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			NO	NO	3	S3
Add1	NO										
Add2	NO										
F0	F2	F4	F6	F8	F10	F12	F14				
					MULT2						

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	6	7	9	10

Scoreboard - Clk=11

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	NO												**addd**	1	2	4	5
mult2	YES	MULT	F10	F0	F2			NO	NO	2	S3		**multd**	2	3	7	8
Add1	NO												**multd**	3	9		
Add2	NO												**addd**	6	7	9	10
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
					MULT2												

Scoreboard - Clk=12

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			NO	NO	1	S3
Add1	NO										
Add2	NO										
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**				
					MULT2						

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	6	7	9	10

Scoreboard - Clk=13

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	NO												**addd**	1	2	4	5
mult2	YES	MULT	F10	F0	F2			NO	NO	0	S3		**multd**	2	3	7	8
Add1	NO												**multd**	3	9	13	
Add2	NO												**addd**	6	7	9	10
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
					MULT2												

Scoreboard - Clk=14

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	NO										
Add1	NO										
Add2	NO										
F0	F2	F4	F6	F8	F10	F12	F14				

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9	13	14
addd	6	7	9	10

Open issues...

?

- More than 1 R.O

Scoreboard - Clk=8

Instruction status:

Instruction		j	k	*Issue*	*Read Oper*	*Exec Comp*	*Write Result*
LD	F6	34+	R2	1	2	3	4
LD	F2	45+	R3	5	6	7	8
MULTD	F0	F2	F4	6			
SUBD	F8	F6	F2	7			
DIVD	F10	F0	F6	8			
ADDD	F6	F8	F2				

Functional unit status:

Time	*Name*	*Busy*	*Op*	*dest Fi*	*S1 Fj*	*S2 Fk*	*FU Qj*	*FU Qk*	*Fj? Rj*	*Fk? Rk*
	Integer	No								
	Mult1	Yes	Mult	F0	F2	F4			Yes	Yes
	Mult2	No								
	Add	Yes	Sub	F8	F6	F2			Yes	Yes
	Divide	Yes	Div	F10	F0	F6	Mult1		No	Yes

Register result status:

Clock		*F0*	*F2*	*F4*	*F6*	*F8*	*F10*	*F12*	...	*F30*
8	*FU*	Mult1				Add	Divide			

Scoreboard - Clk=9

Instruction status:

Instruction		j	k	Issue	Read Oper	Exec Comp	Write Result
LD	F6	34+	R2	1	2	3	4
LD	F2	45+	R3	5	6	7	8
MULTD	F0	F2	F4	6	9		
SUBD	F8	F6	F2	7	9		
DIVD	F10	F0	F6	8			
ADDD	F6	F8	F2				

Functional unit status:

Note → Remaining

Time	Name	Busy	Op	dest Fi	S1 Fj	S2 Fk	FU Qj	FU Qk	Fj? Rj	Fk? Rk
	Integer	No								
10	Mult1	Yes	Mult	F0	F2	F4			Yes	Yes
	Mult2	No								
2	Add	Yes	Sub	F8	F6	F2			Yes	Yes
	Divide	Yes	Div	F10	F0	F6	Mult1		No	Yes

Register result status:

Clock		F0	F2	F4	F6	F8	F10	F12	...	F30
9	FU	Mult1				Add	Divide			

RAW Conflict

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Scoreboard - Clk=7

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	YES	MULT	F2	F6	F8			NO	NO	0	S2
mult2	YES	MULT	F10	F0	F2		MULT1	YES	NO		S3
Add1	YES	ADD2	F0	F12	F14			YES	YES	2	S4
Add2	NO										

	Issue	**Read Op**	**Exec Co.**	**Write R.**
addd	1	2	4	5
multd	2	3	7	
multd	3			
addd	6	7		

F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**
ADD1	MULT1				MULT2		

Scoreboard - Clk=8

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist			Issue	Read Op	Exec Co.	Write R.
Mult1	NO												**addd**	1	2	4	5
mult2	YES	MULT	F10	F0	F2			YES	YES		S3		**multd**	2	3	7	8
Add1	YES	ADD2	F0	F12	F14			NO	NO	1	S4		**multd**	3			
Add2	NO												**addd**	6	7		
F0	**F2**	**F4**	**F6**	**F8**	**F10**	**F12**	**F14**										
ADD1					MULT2												

Scoreboard - Clk=9

S1: **ADDD F0, F2, F4**

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: **ADDD F0, F12, F14**

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			YES	YES	4	S3
Add1	YES	ADD2	F0	F12	F14			NO	NO	0	S4
Add2	NO										

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	6	7	9	

F0	F2	F4	F6	F8	F10	F12	F14
ADD1					MULT2		

WAR Conflict

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Scoreboard - Clk=9

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

S4 can complete its exe but it MUST WAIT to WriteR

till S3 reads the op

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			YES	YES	4	S3
Add1	YES	ADD2	F0	F12	F14			NO	NO	0	S4
Add2	NO										
F0	F2	F4	F6	F8	F10	F12	F14				
ADD1					MULT2						

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	6	7	9	

Scoreboard - Clk=10

S1: ADDD F0, F2, F4

S2: MULTD F2, F6, F8

S3: MULTD F10, F0, F2

S4: ADDD F0, F12, F14

Name	Busy	Op	Fi	Fj	Fk	Qj	Qk	Rj	Rk	Et	Ist
Mult1	NO										
mult2	YES	MULT	F10	F0	F2			NO	NO	3	S3
Add1	NO										
Add2	NO										
F0	F2	F4	F6	F8	F10	F12	F14				
					MULT2						

	Issue	Read Op	Exec Co.	Write R.
addd	1	2	4	5
multd	2	3	7	8
multd	3	9		
addd	8	7	9	10

Rj, Rk update: 10

Si - Sj (i<j): WAR

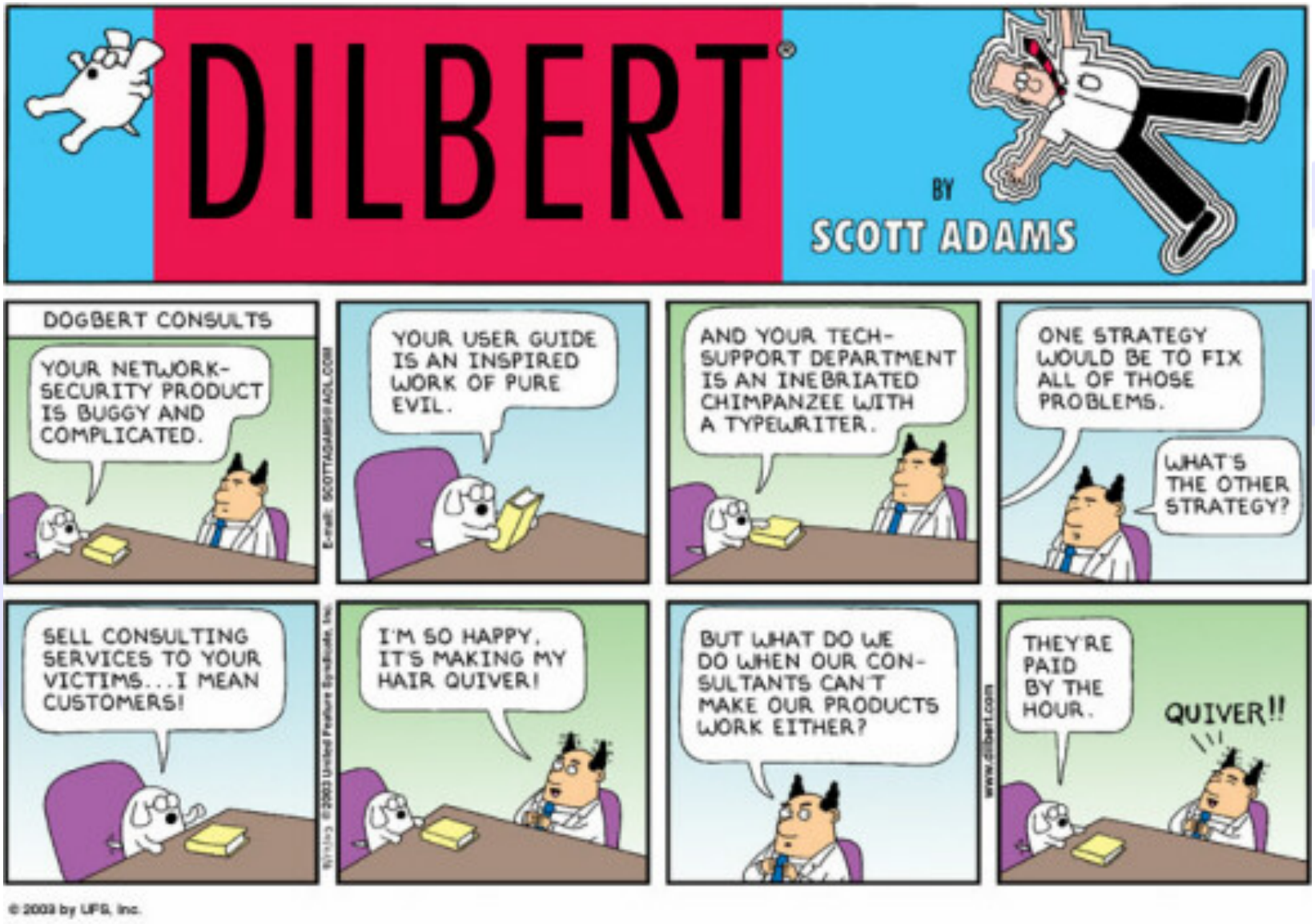
MUST: Clk_EXE_ Sj < Clk_WRITE_Sj

If: Clk_READ_ Si < Clk_EXE_ Sj no prob at all

If: Clk_READ_ Si ≥ Clk_EXE_ Sj MUST BE: Clk_WRITE_ Sj > Clk_READ_ Si

(Clk_WRITE_ Sj = Clk_READ_ Si + 1)

Questions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ONE STRATEGY WOULD BE TO FIX ALL OF THOSE PROBLEMS.
WHAT'S THE OTHER STRATEGY?
SELL CONSULTING SERVICES TO YOUR VICTIMS...I MEAN CUSTOMERS!
I'M SO HAPPY. IT'S MAKING MY HAIR QUIVER!
BUT WHAT DO WE DO WHEN OUR CONSULTANTS CAN'T MAKE OUR PRODUCTS WORK EITHER?
THEY'RE PAID BY THE HOUR.
QUIVER!!
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