Pipelining Notes

Key understandings
1. Forwarding has several ways to forward (forwarding to non branches can go straight to EX, skipping ID; forwarding to branches must go to ID)
    a. Non lw -> non branch dependency: EX to EX, MEM to EX
    b. Lw -> non branch dependency: MEM to EX
    c. Non lw -> branch dependency: EX to ID, MEM to ID
    d. Lw -> branch dependency: MEM to ID
2. Branch prediction depends on whether early branching is used
    a. Early branching used: +1 delay at most
    b. No early branching used: +3 delay at most
3. Branching decision information available after ID or MEM stage
4. Branch prediction information available at ID or MEM stage so if branch taken then ditch everything until (including) the ID/MEM
5. Non lw instructions have information ready at end of EX stage, but requires WB stage to occur before written to register
6. Lw instructions have information ready at end of MEM stage, but requires WB stage to occur before written to register

Data Dependency

Load word?	Before Branch?	Forwarding	
		No	Yes
N	N	2	0
Y	N	2	1
N	Y	2	1
Y	Y	2	2

Control Dependency

Branch Prediction (Not Taken)	Prediction Right?	Early Branching	
		No	Yes
N	—	3	1
Y	N	3	1
Y	Y	0	0

Full Pipeline Examples

Non-LW without Forwarding (+2)

add	F	D	E	M	W			
sub		F			D	E	M	W

Non-LW with Forwarding (+0)

add	F	D	E	M	W			
sub		F	D	E	M	W		
sub			F	D	E	M	W	

LW without Forwarding (+2)

lw	F	D	E	M	W			
sub		F			D	E	M	W

LW with Forwarding (+1)

lw	F	D	E	M	W			
sub		F		D	E	M	W	
sub				F	D	E	M	W

Non-LW without Forwarding before Branch (+2)

add	F	D	E	M	W			
beq		F			D	E	M	W

Non-LW with Forwarding before Branch (+1)

add	F	D	E	M	W			
beq		F		D	E	M	W	

LW without Forwarding before Branch (+2)

lw	F	D	E	M	W			
beq		F			D	E	M	W

LW with Forwarding before Branch (+2)

lw	F	D	E	M	W			
beq		F			D	E	M	W

Branch without Early Branching (+3)

beq	F	D	E	M	W			
add		🟥	🟥	🟥	F	D	E	M	W

Branch with Early Branching (+1)

beq	F	D	E	M	W		
add		🟥	F	D	E	M	W

Branch without Early Branching With Branch Prediction (Taken) (+3)

beq	F	D	E	M	W			
add		F	~~D~~	~~E~~	~~M~~	~~W~~		
sub			~~F~~	~~D~~	~~E~~	~~M~~	~~W~~	
add				~~F~~	~~D~~	~~E~~	~~M~~	~~W~~
add		🟥	🟥	🟥	F	D	E	M

Branch with Early Branching With Branch Prediction (Taken) (+1)

beq	F	D	E	M	W		
add		F	~~D~~	~~E~~	~~M~~	~~W~~	
sub		🟥	F	D	E	M	W

Branch with(out) Early Branching With Branch Prediction (Not Taken) (+0)

beq	F	D	E	M	W	
add		F	D	E	M	W