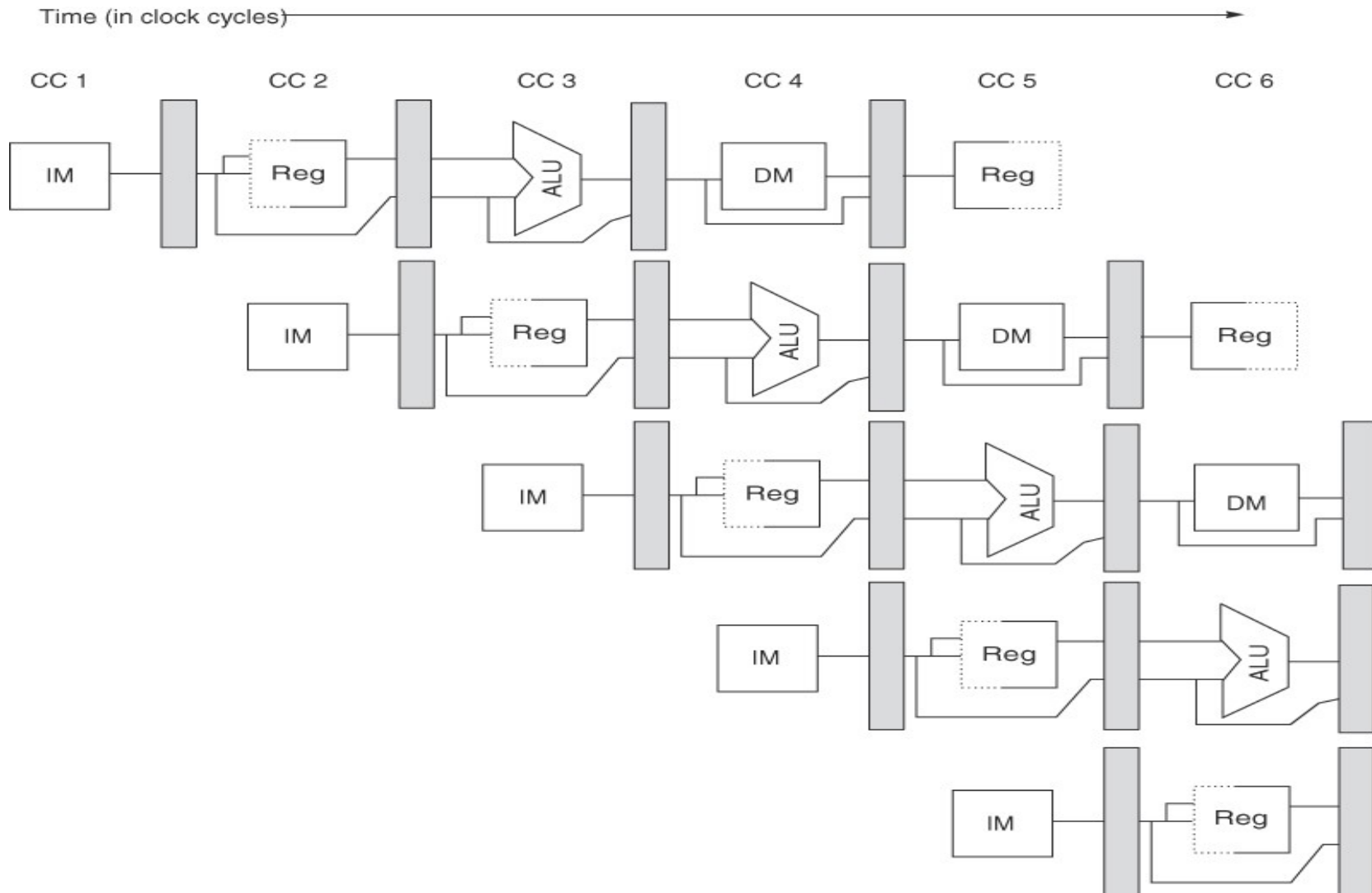


250P: Computer Systems Architecture

Lecture 5: Pipelining and pipelining hazards

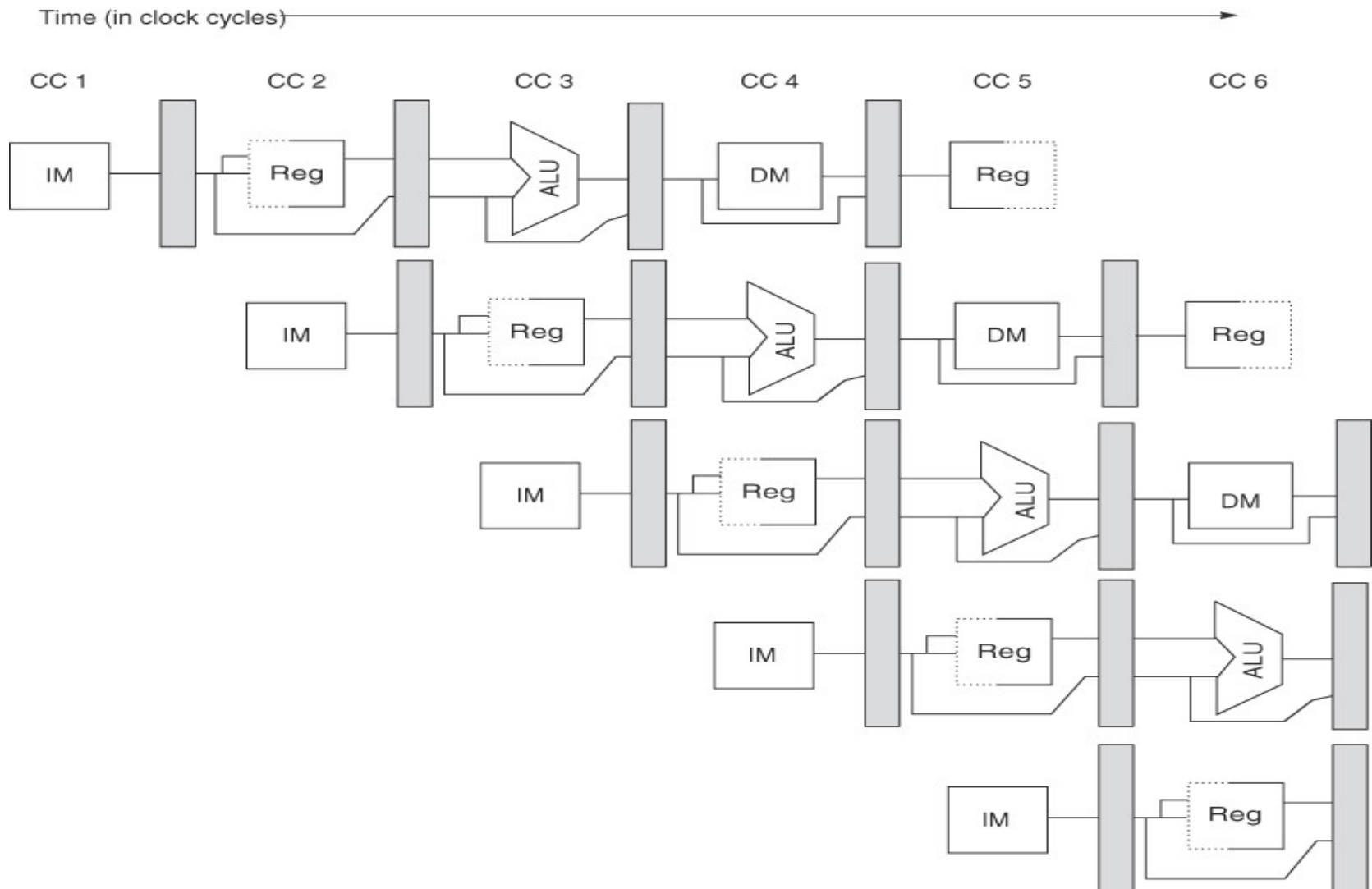
Anton Burtsev
October, 2021

A 5-Stage Pipeline



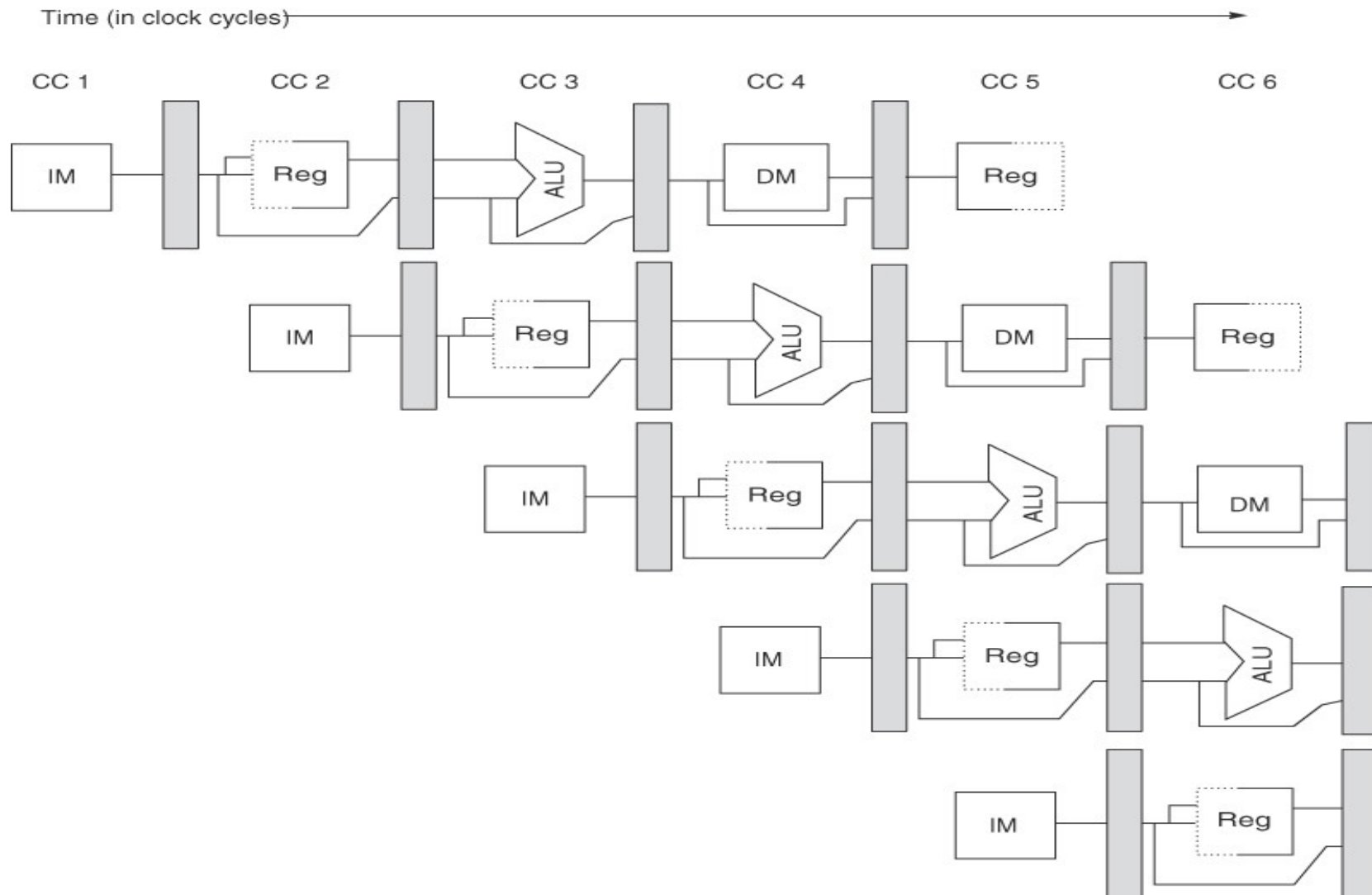
A 5-Stage Pipeline

Use the PC to access the I-cache and increment PC by 4



A 5-Stage Pipeline

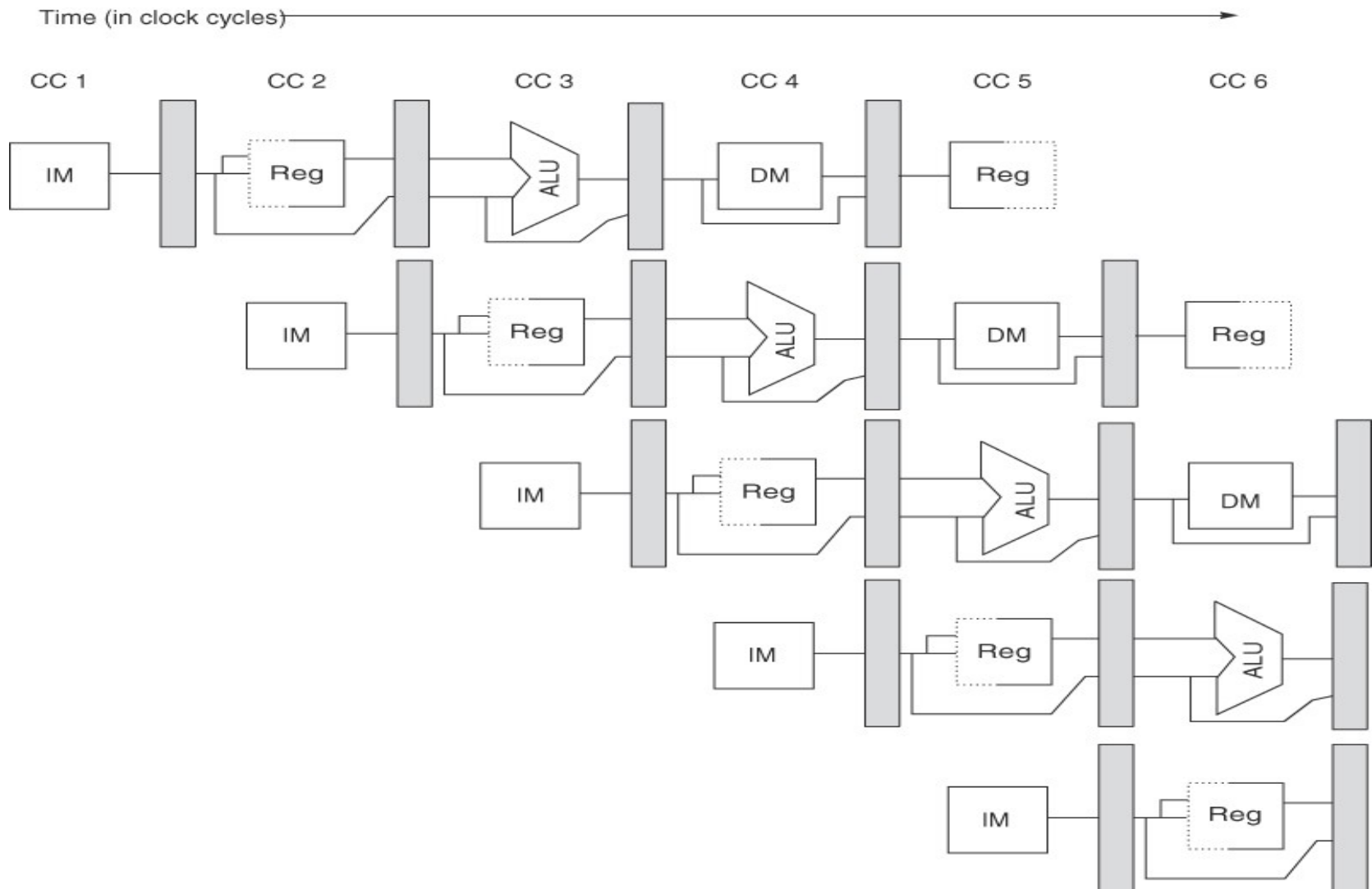
Read registers, compare registers, compute branch target; for now, assume branches take 2 cyc (there is enough work that branches can easily take more)



RISC/CISC Loads/Stores

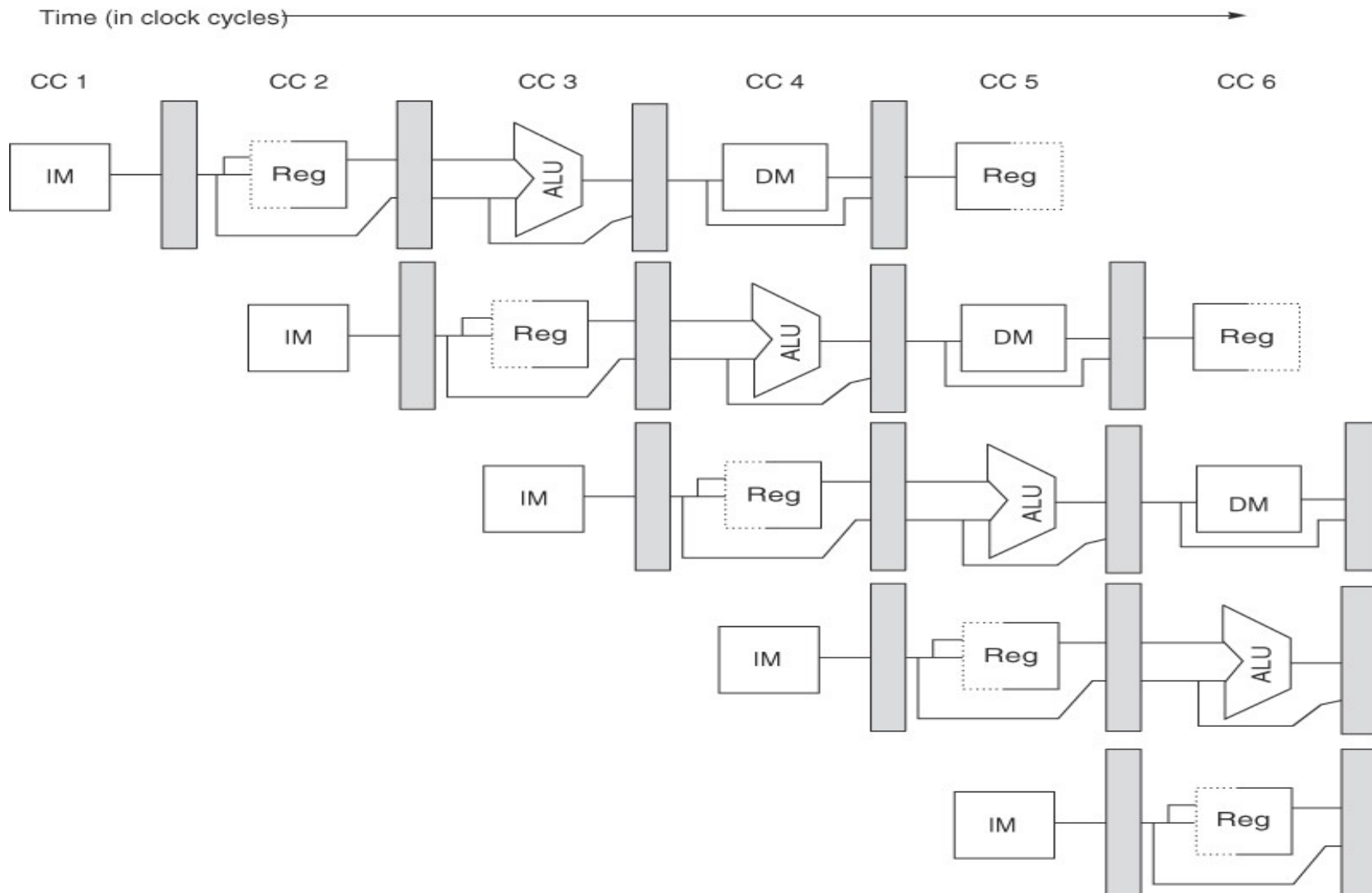
A 5-Stage Pipeline

ALU computation, effective address computation for load/store



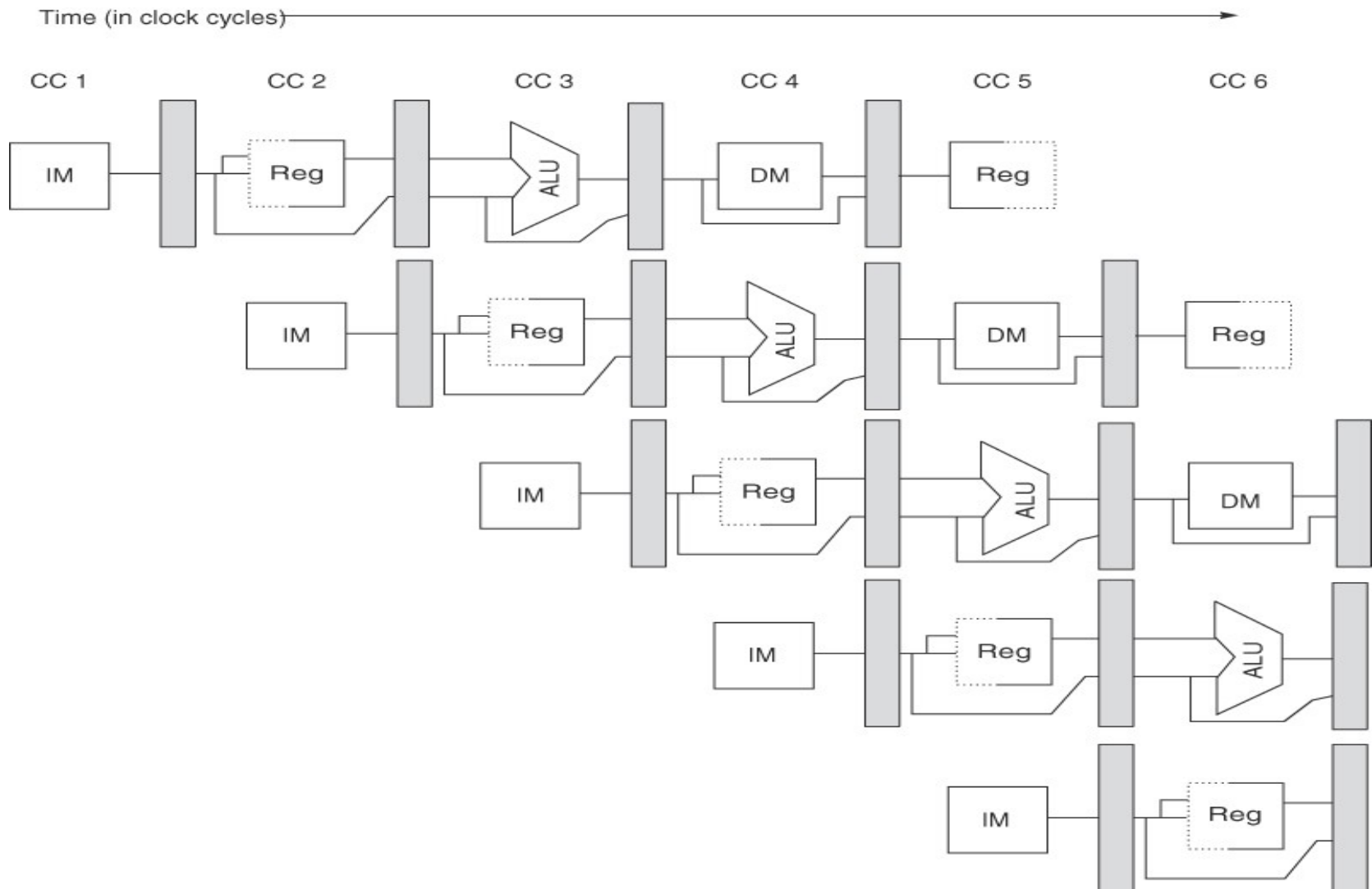
A 5-Stage Pipeline

Memory access to/from data cache, stores finish in 4 cycles



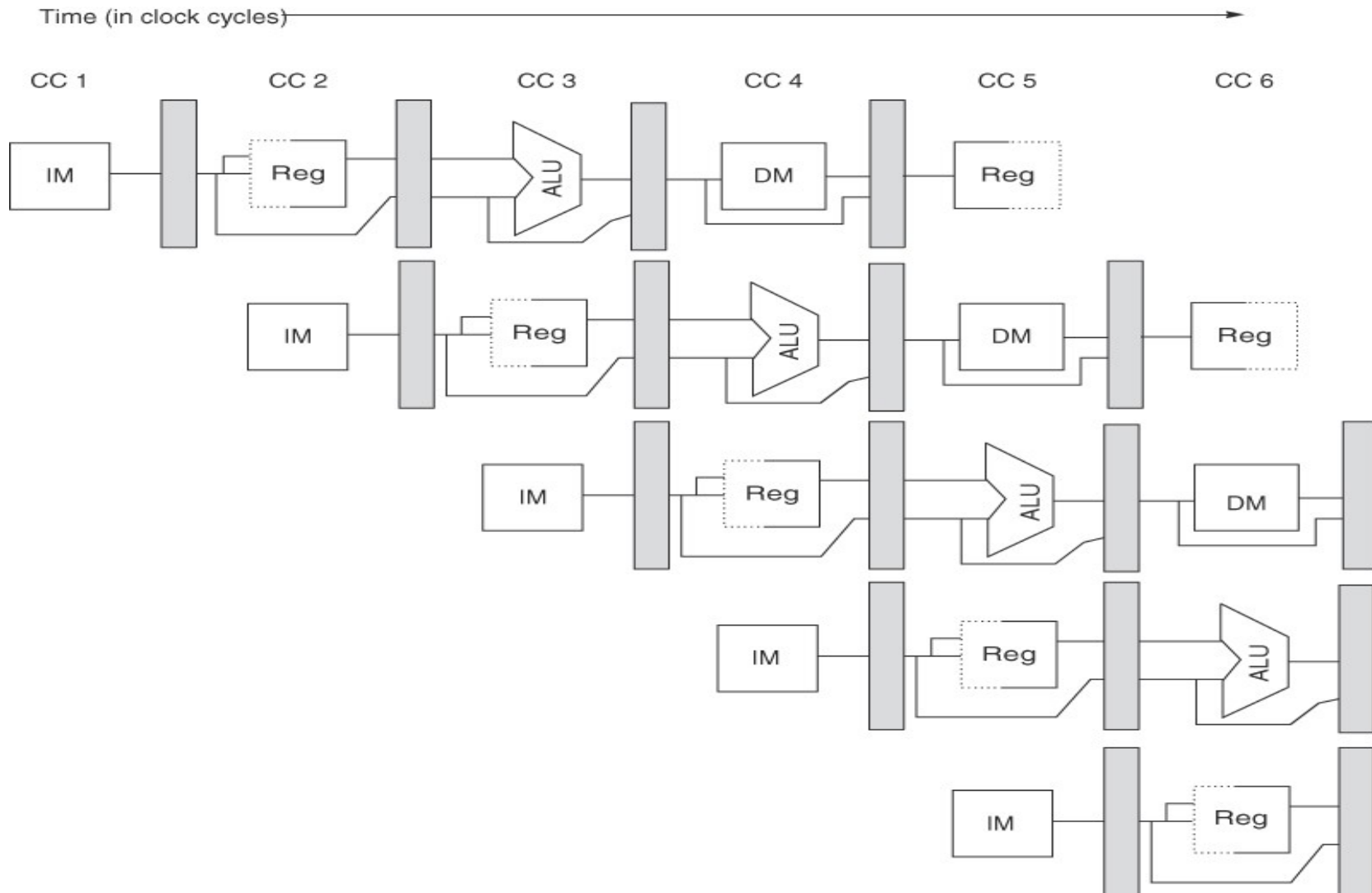
A 5-Stage Pipeline

Write result of ALU computation or load into register file



Pipelining Hazards

A 5-Stage Pipeline

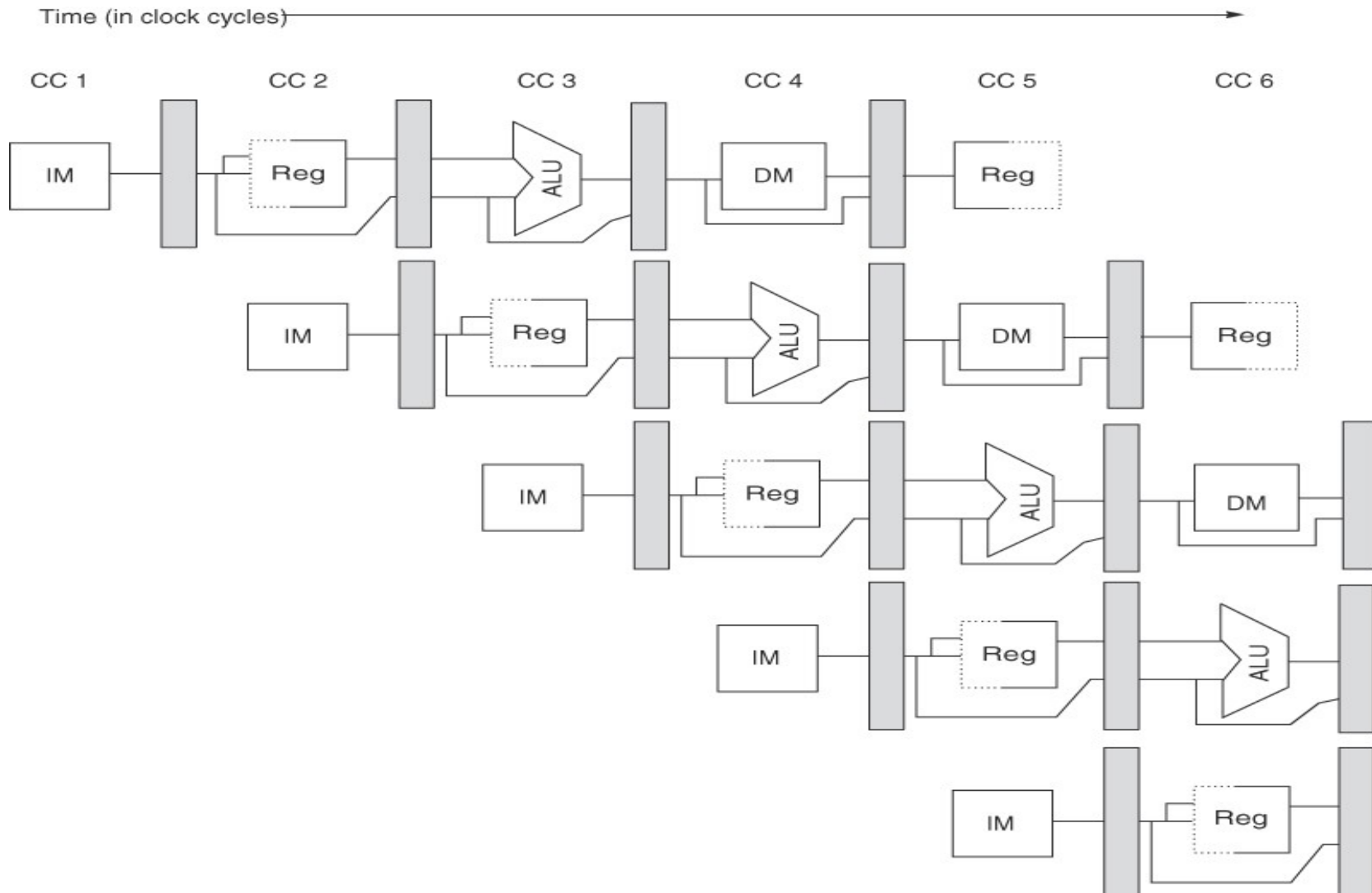


Hazards

- Structural hazards: different instructions in different stages (or the same stage) conflicting for the same resource
- Data hazards: an instruction cannot continue because it needs a value that has not yet been generated by an earlier instruction
- Control hazard: fetch cannot continue because it does not know the outcome of an earlier branch – special case of a data hazard – separate category because they are treated in different ways

Structural hazards

A 5-Stage Pipeline

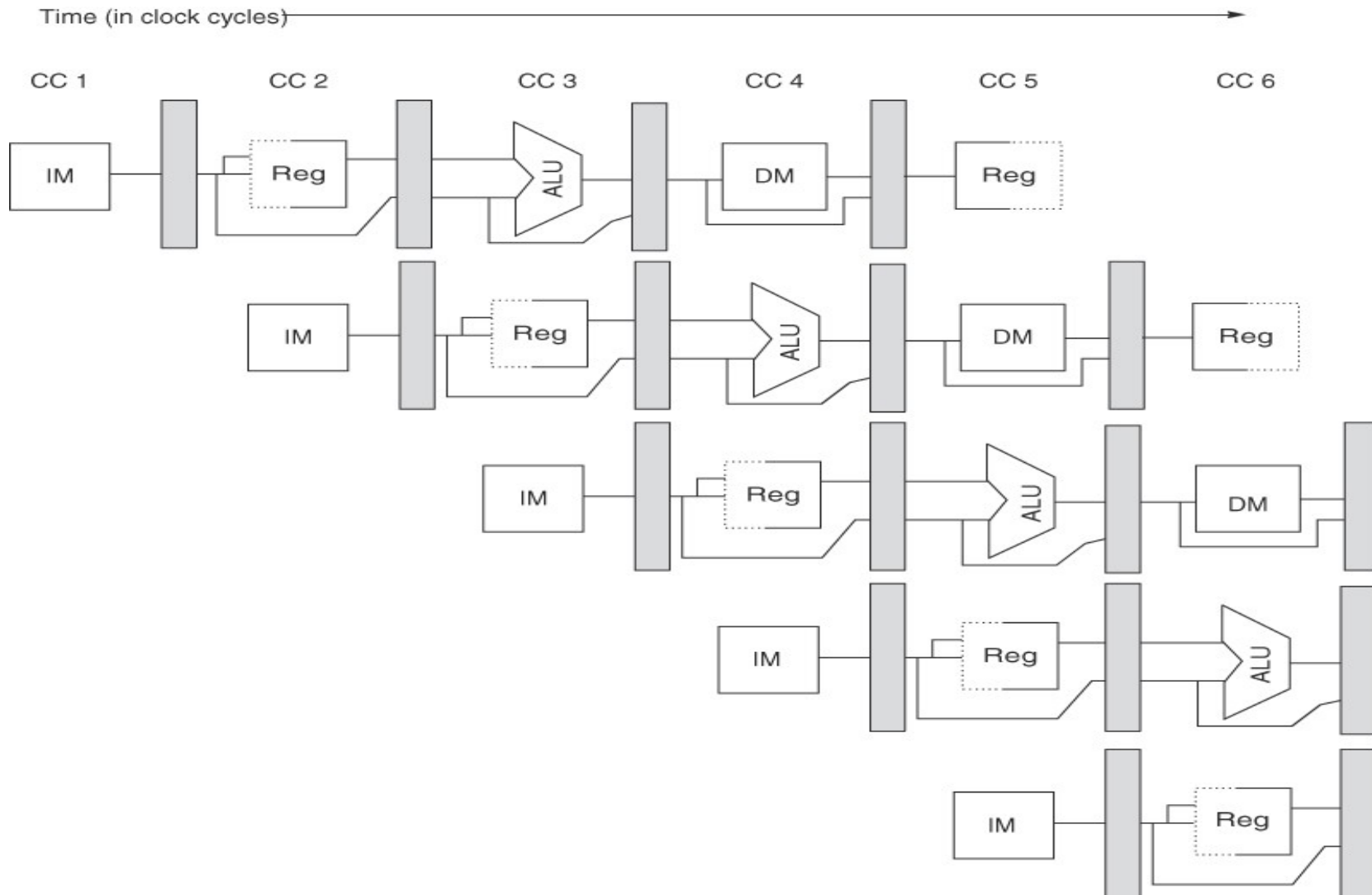


Structural Hazards

- Example: a unified instruction and data cache → stage 4 (MEM) and stage 1 (IF) can never coincide
- The later instruction and all its successors are delayed until a cycle is found when the resource is free → these are pipeline bubbles
- Structural hazards are easy to eliminate – increase the number of resources (for example, implement a separate instruction and data cache)

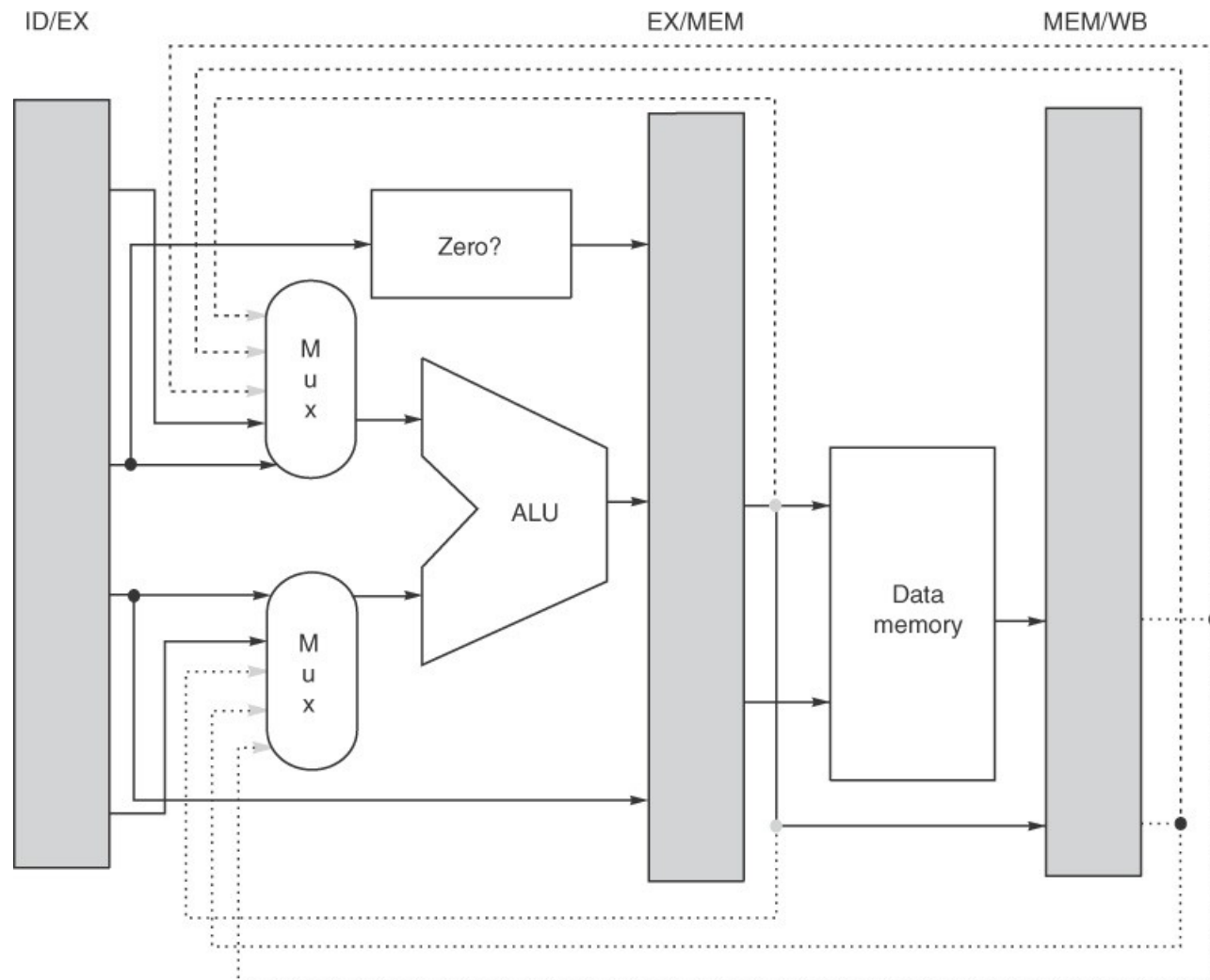
Data hazards

A 5-Stage Pipeline

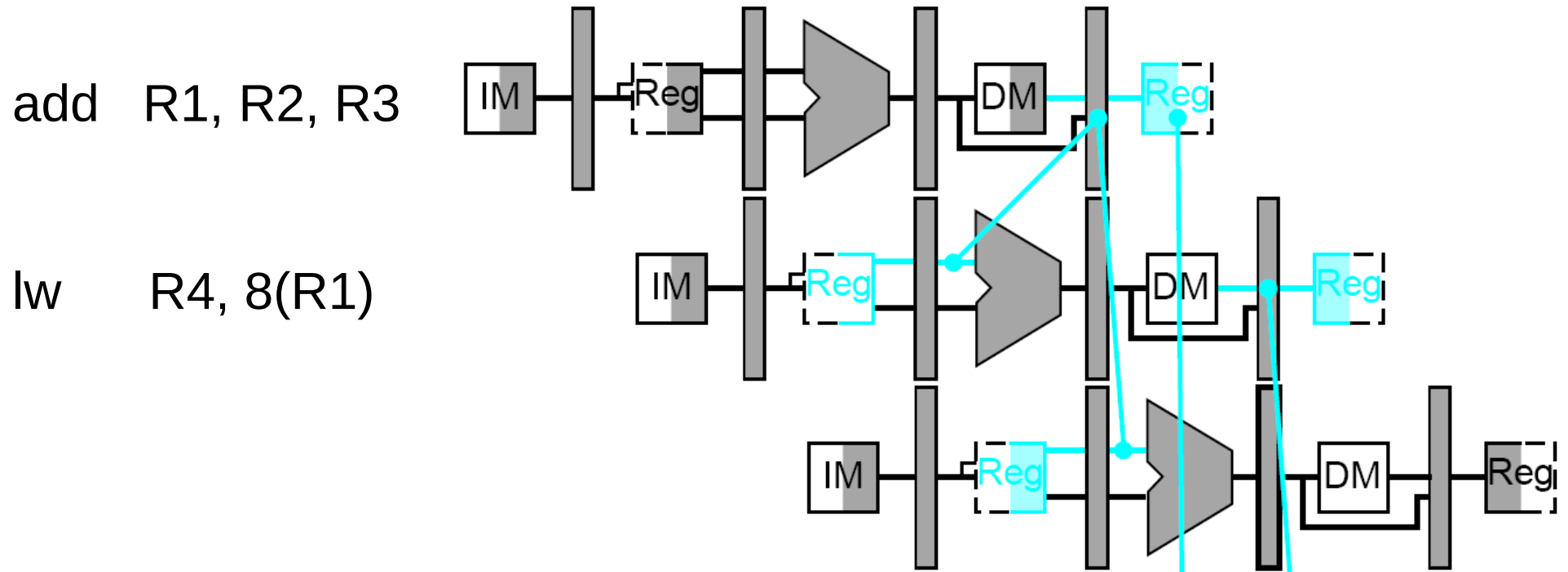


Pipeline Implementation

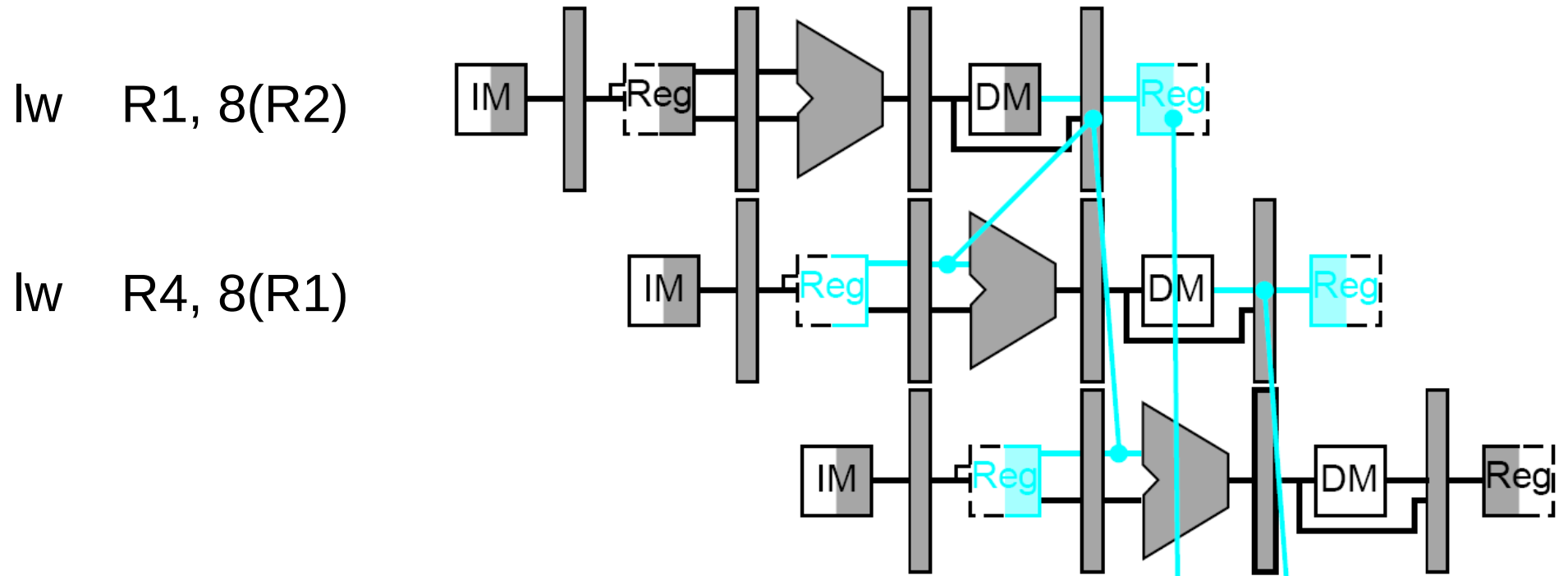
- Signals for the muxes have to be generated – some of this can happen during ID
- Need look-up tables to identify situations that merit bypassing/stalling – the number of inputs to the muxes goes up



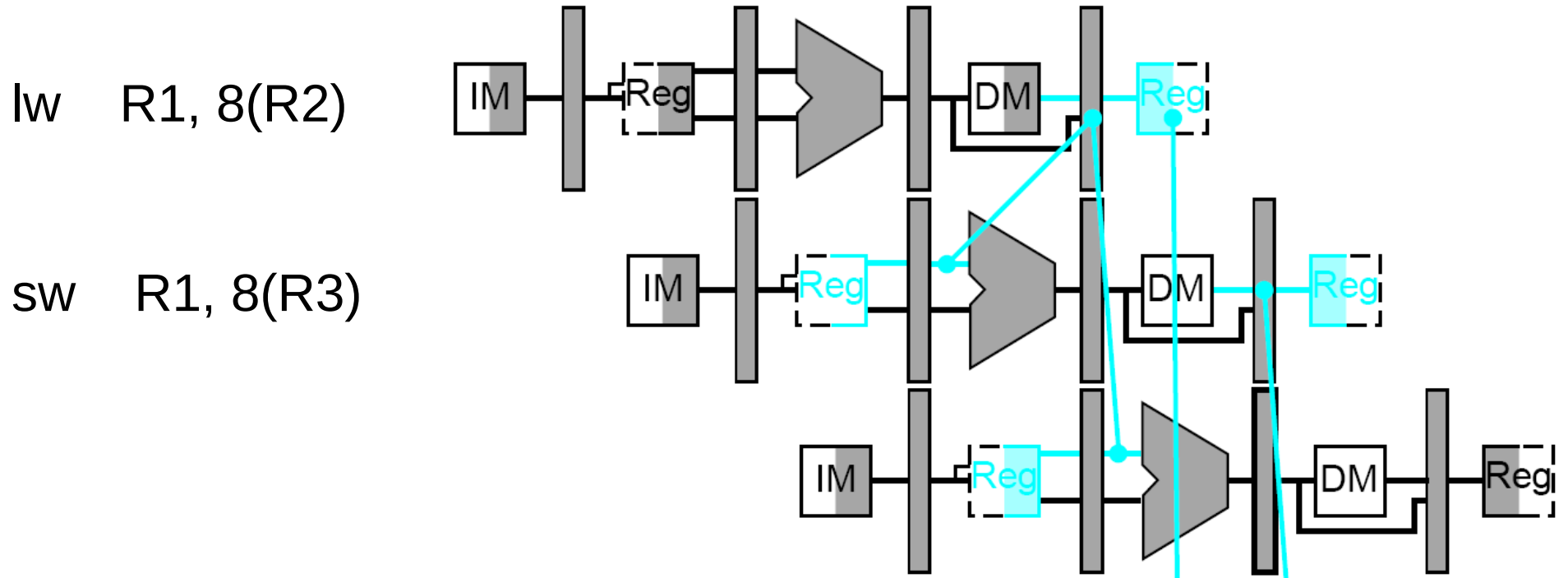
Example



Example



Example



Summary

- For the 5-stage pipeline, bypassing can eliminate delays between the following example pairs of instructions:

add/sub R1, R2, R3

add/sub/lw/sw R4, R1, R5

lw R1, 8(R2)

sw R1, 4(R3)

- The following pairs of instructions will have intermediate stalls:

lw R1, 8(R2)

add/sub/lw R3, R1, R4 or sw R3, 8(R1)

fmul F1, F2, F3

fadd F5, F1, F4

Control hazards

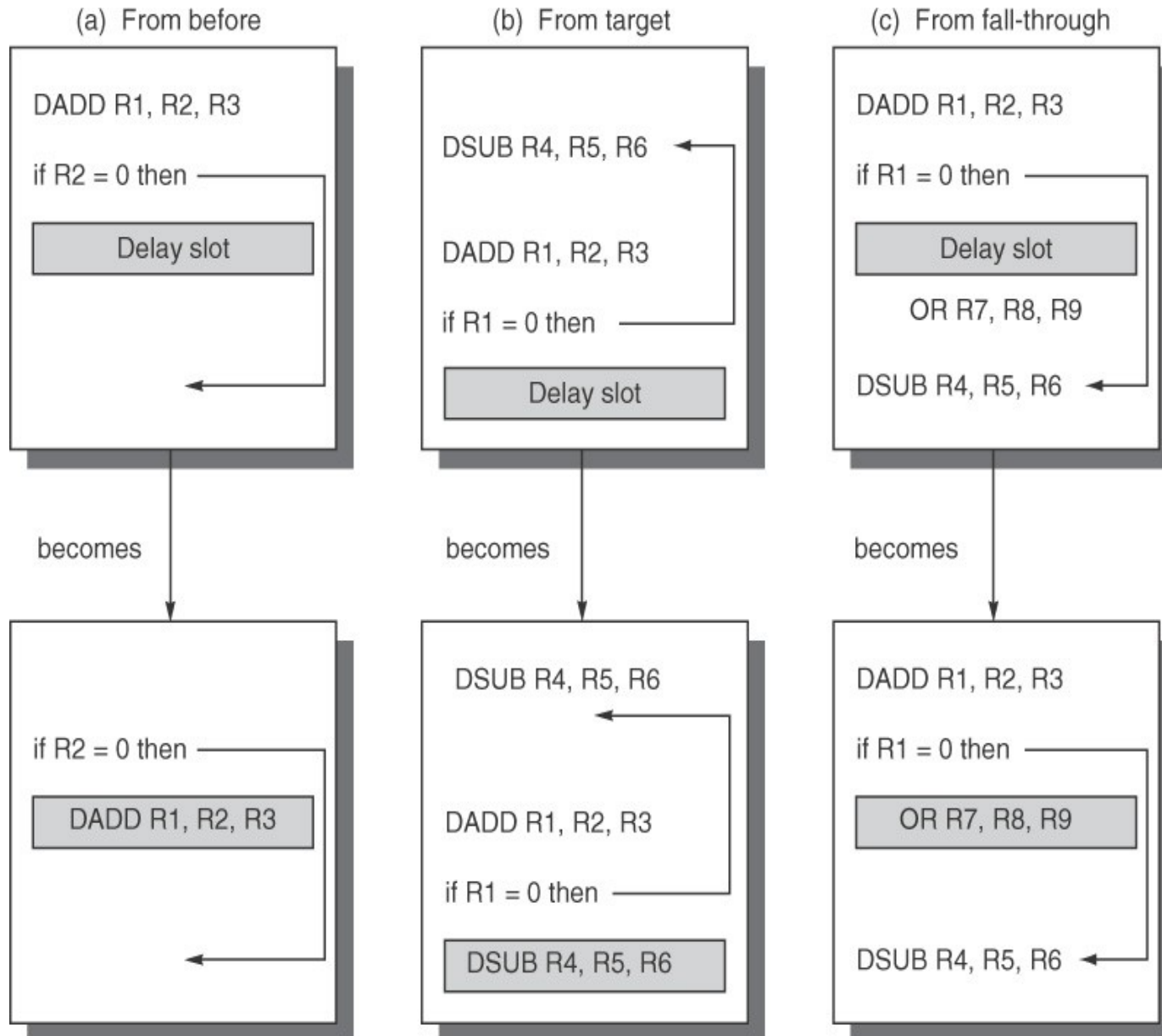
Hazards

- Structural hazards
- Data hazards
- Control hazards

Control Hazards

- Simple techniques to handle control hazard stalls:
 - for every branch, introduce a stall cycle (note: every 6th instruction is a branch on average!)
 - assume the branch is not taken and start fetching the next instruction – if the branch is taken, need hardware to cancel the effect of the wrong-path instructions
 - predict the next PC and fetch that instr – if the prediction is wrong, cancel the effect of the wrong-path instructions
 - fetch the next instruction (branch delay slot) and execute it anyway – if the instruction turns out to be on the correct path, useful work was done – if the instruction turns out to be on the wrong path, hopefully program state is not lost

Branch delay slot



Thank you!