

Lecture 18: Pipelining

- Today's topics:
 - 5-stage pipeline
 - Hazards
 - Data dependence handling with bypassing
 - Data dependence examples

Performance Improvements?

- Does it take longer to finish each individual job?
- Does it take shorter to finish a series of jobs?
- What assumptions were made while answering these questions?
 - No dependences between instructions
 - Easy to partition circuits into uniform pipeline stages
 - No latch overhead
- Is a 10-stage pipeline better than a 5-stage pipeline?

Quantitative Effects

- As a result of pipelining:
 - Time in ns per instruction goes up
 - Each instruction takes more cycles to execute
 - But... average CPI remains roughly the same
 - Clock speed goes up
 - Total execution time goes down, resulting in lower average time per instruction
 - Under ideal conditions, speedup
 - = ratio of *elapsed times between successive instruction completions*
 - = number of pipeline stages = increase in clock speed

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

Conflicts/Problems

- I-cache and D-cache are accessed in the same cycle – it helps to implement them separately
- Registers are read and written in the same cycle – easy to deal with if register read/write time equals cycle time/2
- Instructions can't skip the DM stage, else conflict for RW
- Consuming instruction may have to wait for producer
- Branch target changes only at the end of the second stage -- what do you do in the meantime?

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, add more register ports)

Data Hazards

- An instruction *produces* a value in a given pipeline stage
- A subsequent instruction *consumes* that value in a pipeline stage
- The consumer may have to be delayed so that the time of consumption is later than the time of production

รอผลลัพธ์ที่ตัวอื่นยังคำนวณไม่เสร็จ

Point of production ต้องอยู่ก่อน point of consumption แล่นั่นแหละ ถ้าไม่ตรงก็เลื่อนออกไปเรื่อยๆ

Example 1 – No Bypassing

- Show the instruction occupying each stage in each cycle (no bypassing)
if I1 is $R1+R2=R3$ and I2 is $R3+R4=R5$ and I3 is $R7+R8=R9$

CYC-1	CYC-2	CYC-3	CYC-4	CYC-5	CYC-6	CYC-7	CYC-8
IF	IF	IF	IF	IF	IF	IF	IF
D/R	D/R	D/R	D/R	D/R	D/R	D/R	D/R
ALU	ALU	ALU	ALU	ALU	ALU	ALU	ALU
DM	DM	DM	DM	DM	DM	DM	DM
RW	RW	RW	RW	RW	RW	RW	RW

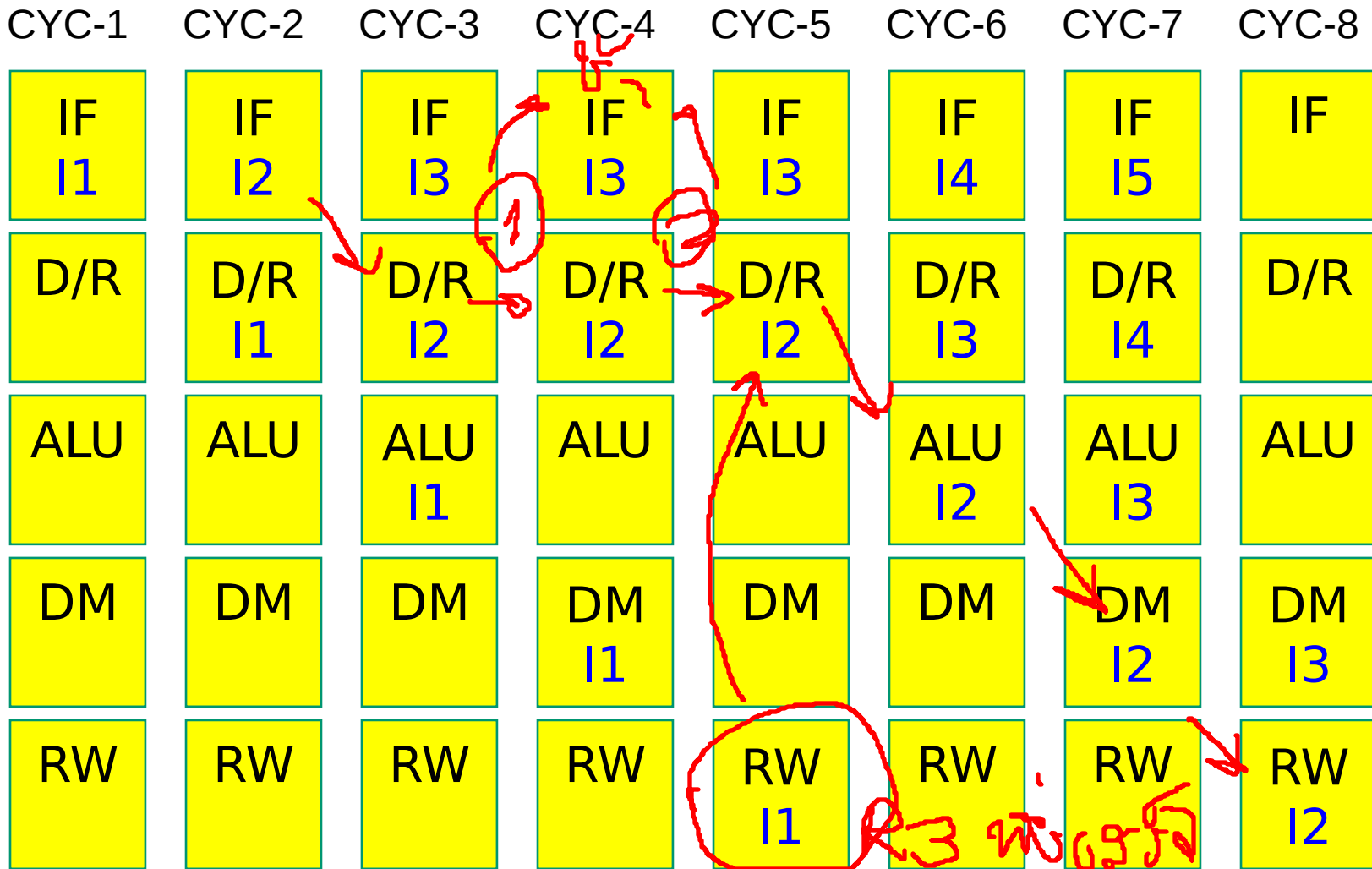
จะเห็นว่า แม้ว่า I3 ไม่ได้มีส่วนที่พึ่งพาตัวแปรอื่นมาก่อนเลย แต่ก็จะติดขัดไปคำสั่งที่ยังไม่เสร็จข้างหน้าได้ แบบนี้เรียกว่า in order

ยัง stall เอะยัง cpi เอะ

$$CPI \rightarrow 1 + \frac{2}{3} = 1.66$$

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Example 2 – Bypassing

by pass กับ forwarding อันเดียวกัน

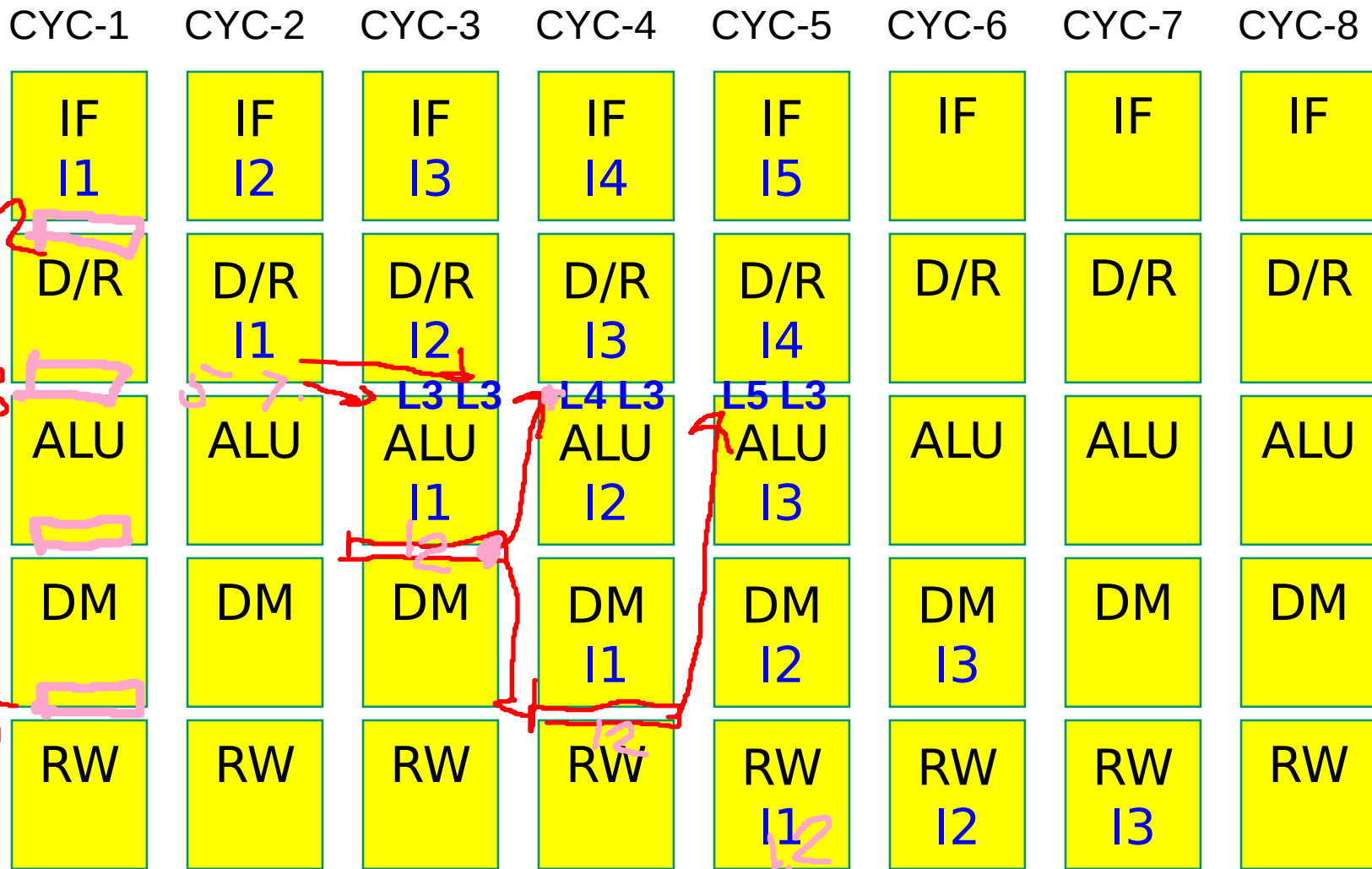
- Show the instruction occupying each stage in each cycle (with bypassing)
if I1 is $R1+R2=R3$ and I2 is $R3+R4=R5$ and I3 is $R3+R8=R9$.
Identify the input latch for each input operand.

ปกติ เราจะอ่านค่าที่มัน dependence จากตัว register คือตัวอื่นต้องเขียนไปก่อนถึงจะอ่านได้ แต่ bypassing คืออ่านค่าคัดจาก latch ก่อนที่จะถูกเขียนลง register เสียอีก

CYC-1	CYC-2	CYC-3	CYC-4	CYC-5	CYC-6	CYC-7	CYC-8
IF	IF	IF	IF	IF	IF	IF	IF
D/R	D/R	D/R	D/R	D/R	D/R	D/R	D/R
ALU	ALU	ALU	ALU	ALU	ALU	ALU	ALU
DM	DM	DM	DM	DM	DM	DM	DM
RW	RW	RW	RW	RW	RW	RW	RW

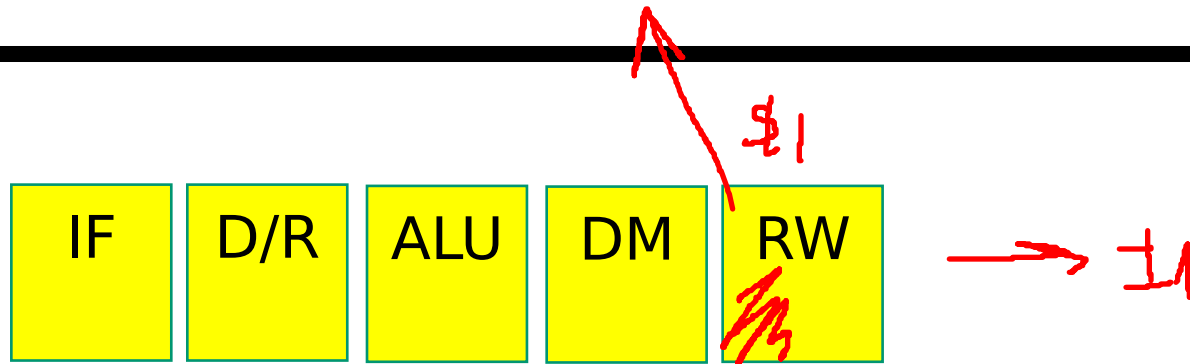
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Problem 1

Producer



No bypasses



add \$1, \$2, \$3



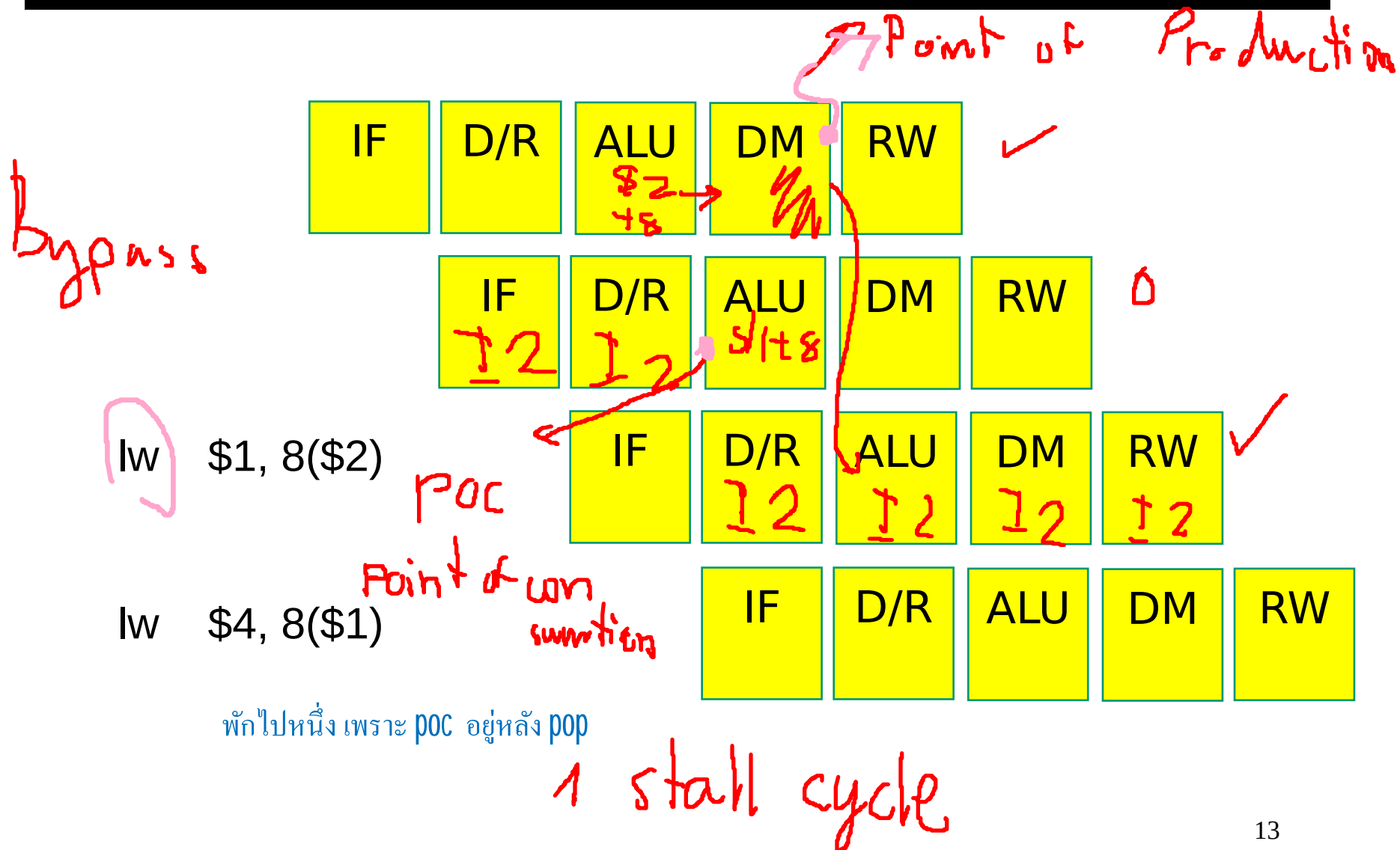
lw \$4, 8(\$1)



With bypasses
success

Consumer

Problem 2



Problem 3

