

Discussion 07

Single Cycle Datapath

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Announcements 📢

Agenda

- SDS Review
- Single Cycle Datapath

Definitions (Pt. 1)

- Clk
 - Central timing unit of the entire SDS; usually only one clock per system
- State element
 - Any clocked element: stores values
 - Only does computation things at the rising edge of the clock
 - E.g. registers
- Logic element
 - Any unclocked elements: does not store value
 - Computes ALL THE TIME!
 - E.g. combinatorial logic elements (AND gates, OR gates, etc.)

Definitions (Pt. 2)

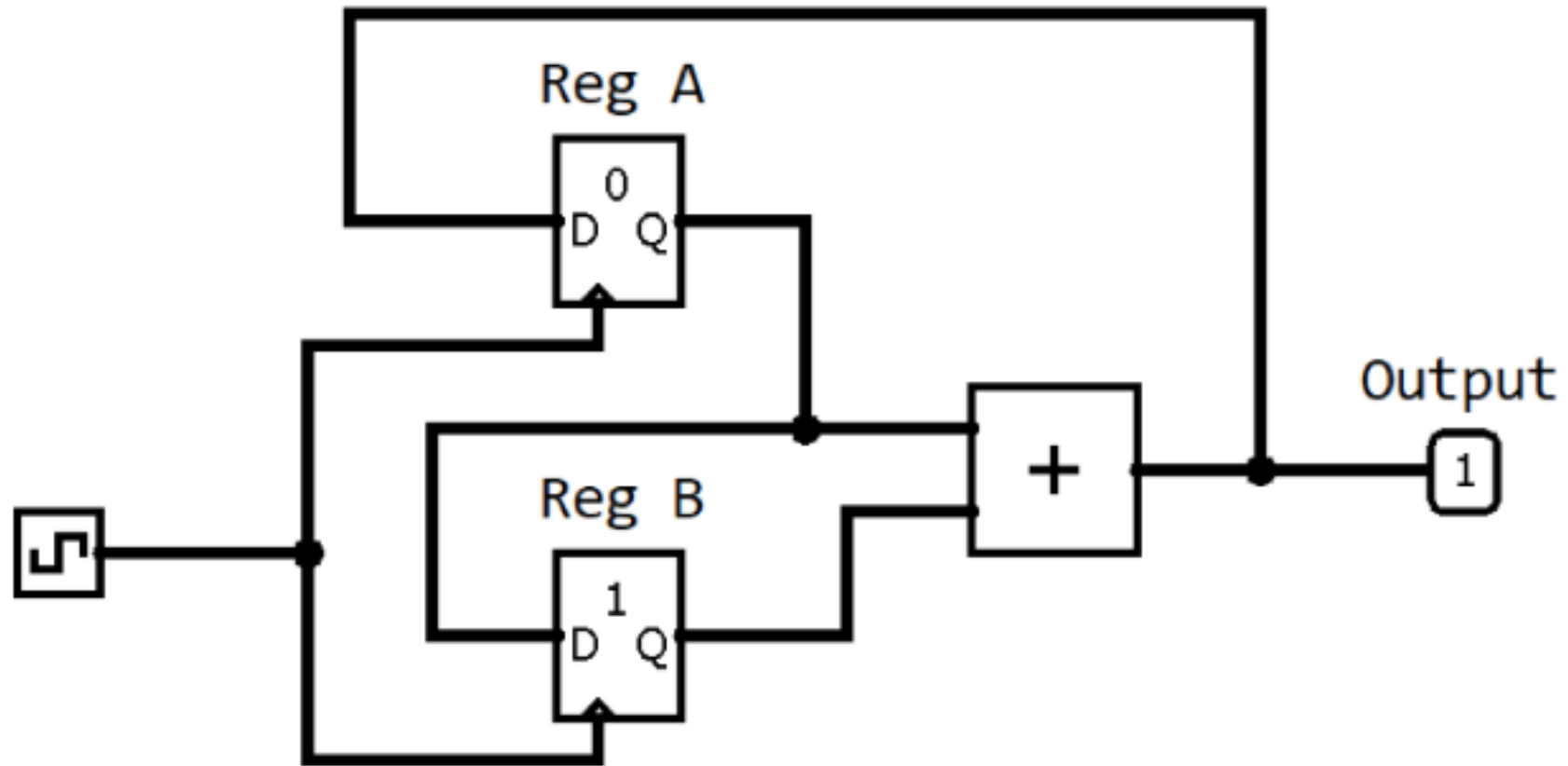
- Flip-flop
 - state element that stores 1 bit's value (0/1)
- Register
 - **n**-bit state element; created with **n** chained FFs
 - **D** = input; **Q** = output
 - Reads value from **D** at clock tick, puts value into **Q**

Definitions (Pt. 3)

- Rising clock edge (RCE)
 - clk goes from 0 => 1; Usually instantaneous
 - Triggers all the state elements dependent directly on the clock
- Falling clock edge
clk goes from 1 => 0
- Setup time
 - Time BEFORE RCE where input must be stable
- Hold time
 - Time AFTER RCE where input must be stable
- Clock-to-q time (c2q)
 - Time after RCE needed for value in Q to change

Definitions (Pt. 4)

- Combinational logic delay
 - Combinatorial delay between 2 state elements
 - Usually Sum of total delays within the path from the Q of one register to the D of another (or the same) register
- Critical path
 - Total delay between 2 state elements
 - Clk-to-q (reg1) + longest CL + setup time (reg2)
- Maximum clock frequency
 - $1 / \text{minimum clock period}$



Equations

$$\text{max hold time} \leq t_{\text{clock to q}} + \text{shortest CL}$$

- Any longer of a hold time means that value has potential to change

$$\text{cycle time} \geq t_{\text{clock to q}} + \text{longest CL} + t_{\text{setup}}$$

- Cycle time = clock period
- Any shorter cycle time means the values may not finish computing correctly in time

Single Cycle Datapath

What Even is a datapath?

- Given a program counter (the address of the instruction we need to execute)
- Update the registers to reflect the given instruction
- Every single update we need to make will be in the RISC-V Reference Card: VERY USEFUL
- Standard datapath accounts for all real RISC-V 32bit instructions
- No pseudoinstructions

Datapath Basics

- Wiring accounts for flow of data
- Control logic block does the hard work of "thinking"
- CL takes data/signal in from datapath \Rightarrow arrows point towards control logic
 - Instr[31:0]; BrEq; BrLT
- CL feeds signal back to datapath \Rightarrow arrows point away from control logic
 - Calculates signals to tell datapath what components of datapath to use
 - All other signals in standard datapath

Stages of a Single Cycle Datapath

Instruction Fetch (IF)

1. Update the value in PC

- (**PCSel** = 0) $PC = PC + 4$
- (**PCSel** = 1) $PC = \text{ALU output}$

2. Fetch instruction from IMEM at PC

- IMEM is “Instruction memory”, generally in the code section!

Instruction Decode (ID)

1. Parse instruction from 32 bits binary into useful signals
2. Access RegFile with `rs1`, `rs2`, and `rd`
 - a. We can obtain the register numbers from the reference card
RegFile output the data that is read
 - b. Access ImmGen using **ImmSel**
3. Generates immediate based on instruction type, and pad them to make full 32 bits

Execute (EX)

- ALU Operation using ALUSel
 - Inputs to the ALU:
 - (ASel = 0): Use R[rs1]
 - (ASel = 1): Use PC
 - (BSel = 0): Use R[rs2]
 - (BSel = 1): Use Immediate
 - Does regular ALU operations (for I and R type instructions)
 - Also does all the adding! (except for PC + 4)
- OR Branch Comparator
 - (BrUn = 0) Compare R[rs1] and R[rs2] signed
 - (BrUn = 1) Compare R[rs1] and R[rs2] unsigned
 - Outputs BrEq and BrLt

Memory Access (Mem)

1. Access DMEM (Data Memory)

a. Inputs:

- i. Addr: address we're accessing, calculated by ALU
- ii. DataW: data we want to put into memory; only used for **s** type instructions
- iii. (**MemRW** = 0) do not write into memory
- iv. (**MemRW** = 1) write into memory

Write Back (WB)

- Selects which value to write to `rd`
 - Inputs:
 - (**WBSEL** = 0) Data Memory that is read (with appropriate editing depending on whether we have `lb`, `lh`, `lw`)
 - (**WBSEL** = 1) ALU Output
 - (**WBSEL** = 2) PC + 4
- Output a value that goes into DataD of RegFile
 - **RegWEn** determines whether we actually update `rd`

Control Signals

Control Signal	Signal	Used for	Example
PCSel (Will never be *)	0	PC = PC + 4 Normal Instruction Flow; default next PC	No edit to PC in description
	1	PC = ALU Output J type instructions; B type instructions if branch is taken	jalr PC = rs1 + imm
ImmSel	I, I*, S, B, U, J	Identify how to generate the immediate (bits to use, how to extend, how to piece the bits together)	
	*	The immediate is not used	add rd = rs1 + rs2
RegWEn (Will never be *)	0	No writeback to RegFile allowed (we don't need to update rd)	beq if (rs1 == rs2) PC = PC + offset
	1	Update rd	add rd = rs1 + rs2
BrUn	0	Signed Branch Comparisons	bge
	1	Unsigned Branch Comparisons	bgeu
	*	Branching is not used	Any none B-type instruction

Control Signals Pt. 2

Control Signal	Signal	Used for	Example	
ASel	0	Operate on rs1	add	rd = rs1 + rs2
	1	Operate on PC	beq	PC = PC + offset
	*	A is not used in ALU; Only B is used in ALU Output; lui and auipc	lui	rd = imm
BSel	0	Operate on rs2	add	rd = rs1 + rs2
	1	Operate on imm	addi	rd = rs1 + imm
ALUSel	Various	Identify which ALU Operation		

Control Signals Pt. 3

Control Signal	Signal	Used for	Example
MemRW (Will never be *)	0	No writing to memory	Everything except for stores
	1	Write to memory	Sb, sh, sw
WBSel	0	rd = memory output; used for load instructions	lb, lh, lw
	1	rd = ALU output	add rd = rs1 + rs2
	2	rd = PC + 4 for jal and jalr exclusively	jal rd = PC + 4
	*	We don't write back to rd Exclusively when RegWEn == 0	

Thank you!