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CS61C : Machine Structures

Lecture #20 – Controlling a Single-Cycle CPU

2007-7-30

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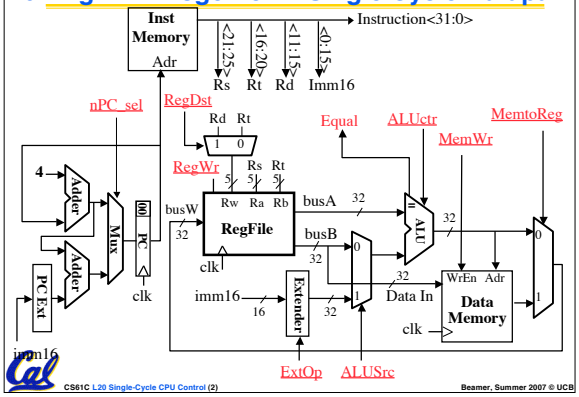
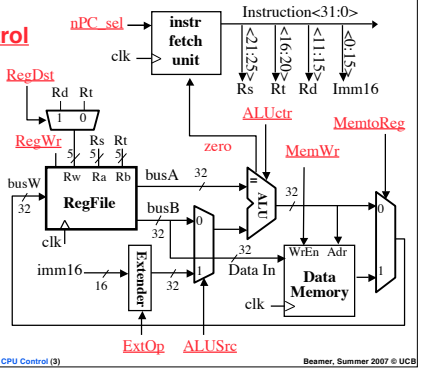
Instructor

Putting it All Together:A Single Cycle Datapath

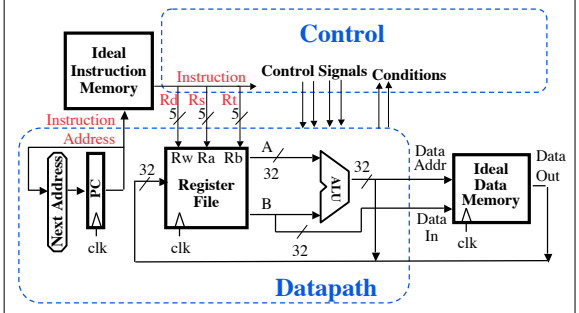


Review: A Single Cycle Datapath

- We have everything except control signals

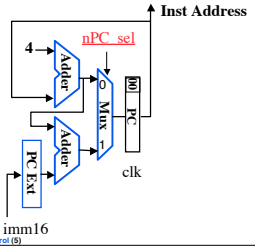


An Abstract View of the Implementation



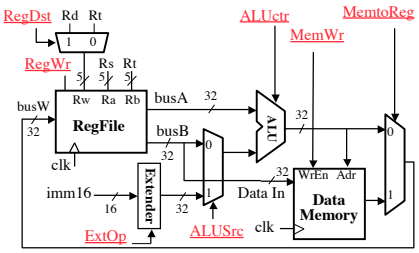
Recap: Meaning of the Control Signals

- nPC_sel: "+4" 0 ⇒ PC <– PC + 4
  "n"=next "br" 1 ⇒ PC <– PC + 4 + {SignExt(Im16) , 00 }
- Later in lecture: higher-level connection between mux and branch condition

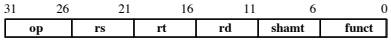


Recap: Meaning of the Control Signals

- ExtOp: "zero", "sign"
- ALUsrc: 0 ⇒ regB; 1 ⇒ immed
- ALUctr: "ADD", "SUB", "OR"
- MemWr: 1 ⇒ write memory
- MemtoReg: 0 ⇒ ALU; 1 ⇒ Mem
- RegDst: 0 ⇒ "rt"; 1 ⇒ "rd"
- RegWr: 1 ⇒ write register



RTL: The Add Instruction

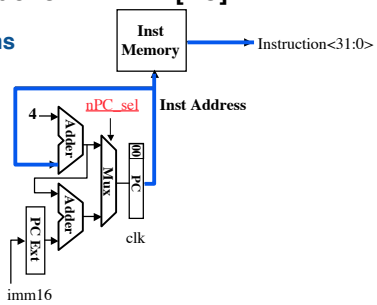


`add rd, rs, rt`

- MEM[PC] Fetch the instruction from memory
- R[rd] = R[rs] + R[rt] The actual operation
- PC = PC + 4 Calculate the next instruction's address

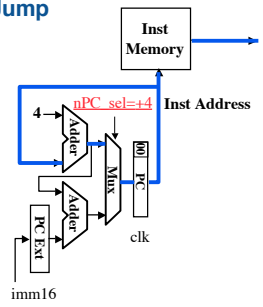
Instruction Fetch Unit at the Beginning of Add

- Fetch the instruction from Instruction memory: Instruction = MEM[PC]
  - same for all instructions

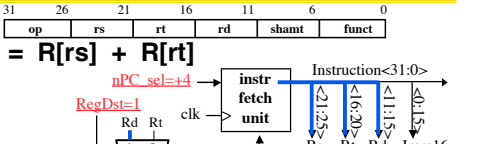


Instruction Fetch Unit at the End of Add

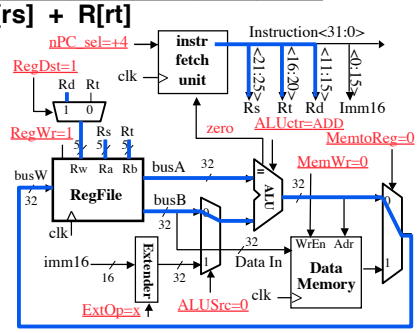
- PC = PC + 4
  - This is the same for all instructions except: Branch and Jump



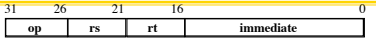
The Single Cycle Datapath during Add



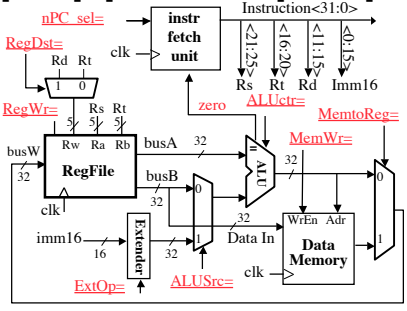
R[rd] = R[rs] + R[rt]



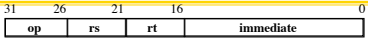
Single Cycle Datapath during Or Immediate?



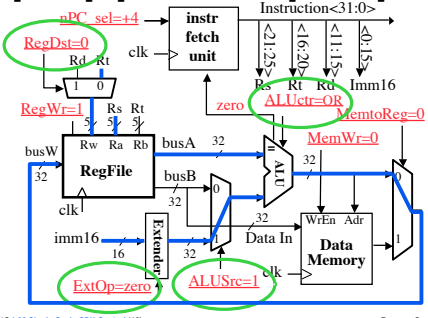
- R[rt] = R[rs] OR ZeroExt[Imm16]



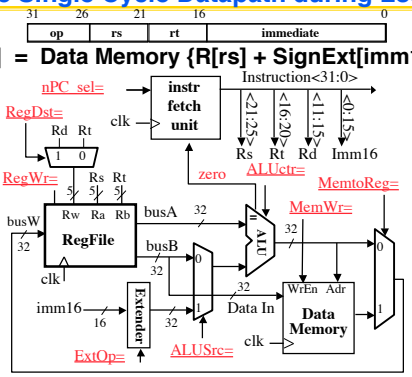
Single Cycle Datapath during Or Immediate?



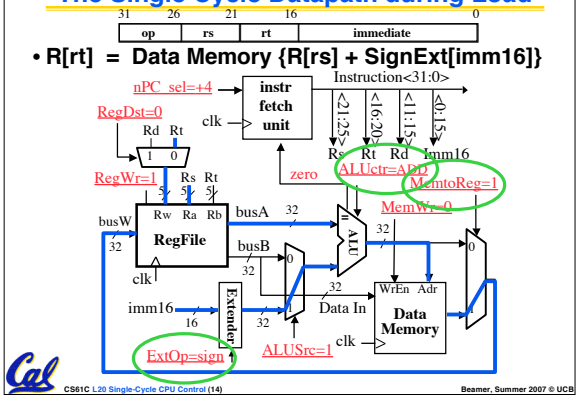
- R[rt] = R[rs] OR ZeroExt[Imm16]



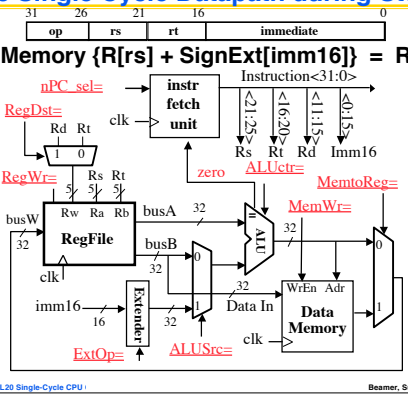
The Single Cycle Datapath during Load?



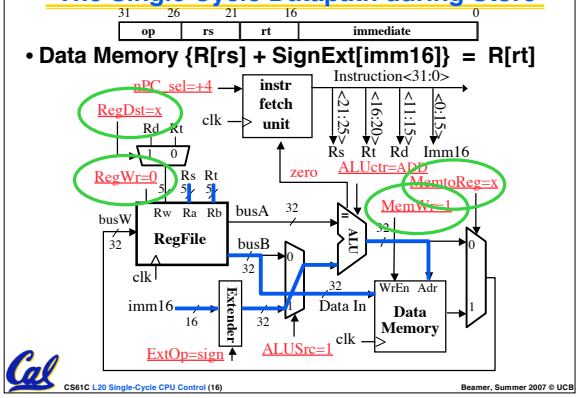
The Single Cycle Datapath during Load



The Single Cycle Datapath during Store?



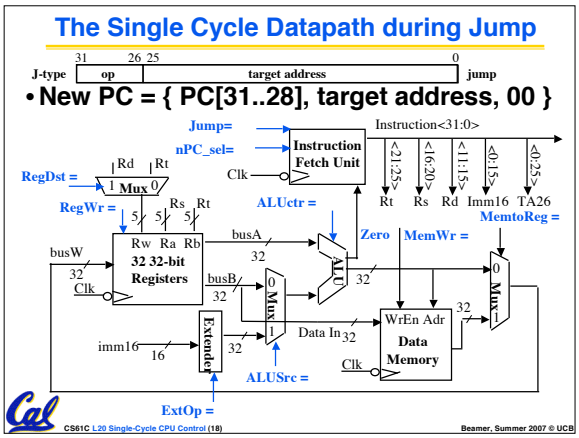
The Single Cycle Datapath during Store



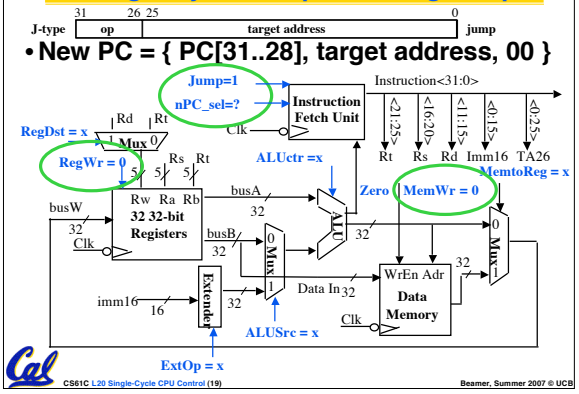
Administrivia

- **Assignments**
  - HW7 due 8/2
  - Proj3 due 8/5
- **Assignment Grading**
  - Grades should be coming in now (HW1, HW2 done, expect HW3, HW4, Proj1 soon)
  - Reader info posted on webpage
- **Midterm Regrades due Wed 8/1**

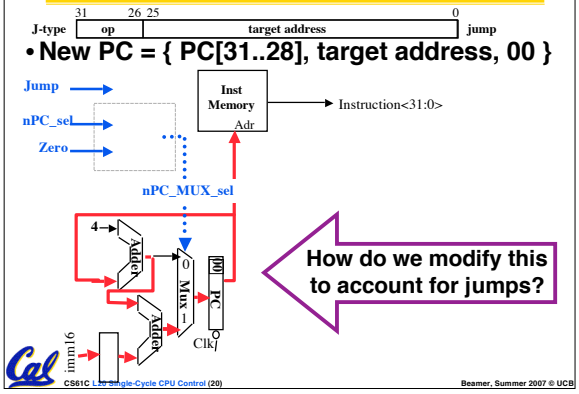
The Single Cycle Datapath during Jump



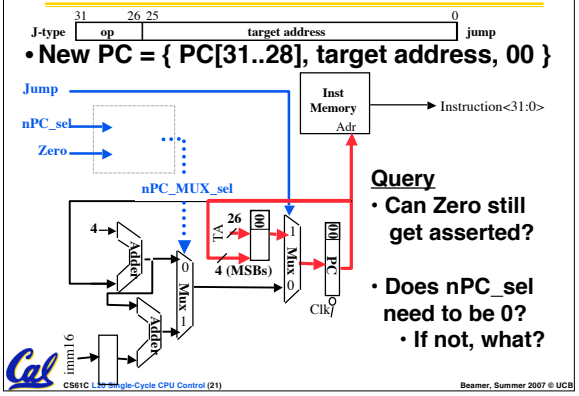
The Single Cycle Datapath during Jump



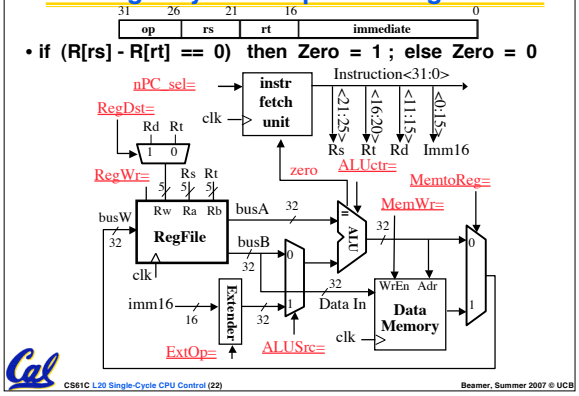
Instruction Fetch Unit at the End of Jump



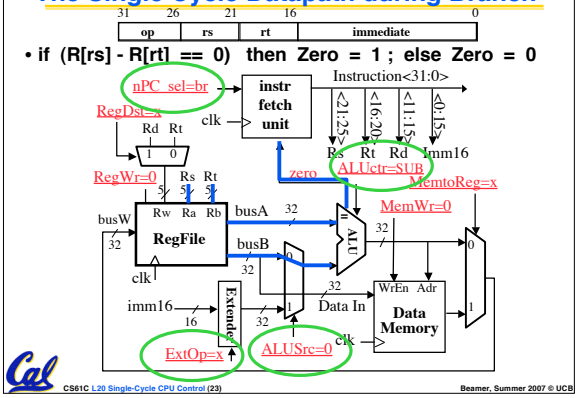
Instruction Fetch Unit at the End of Jump



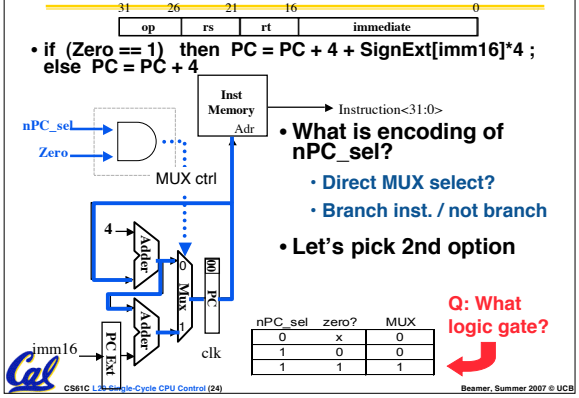
The Single Cycle Datapath during Branch?



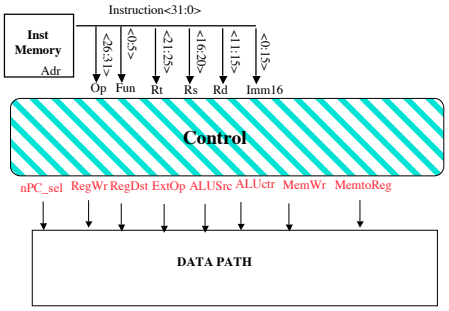
The Single Cycle Datapath during Branch



Instruction Fetch Unit at the End of Branch



Step 4: Given Datapath: RTL → Control



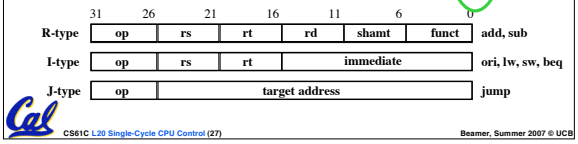
A Summary of the Control Signals (1/2)

inst	Register Transfer
add	R[rd] ← R[rs] + R[rt]; PC ← PC + 4
	ALUsrc = RegB, ALUctr = "ADD", RegDst = rd, RegWr, nPC_sel = "+4"
sub	R[rd] ← R[rs] – R[rt]; PC ← PC + 4
	ALUsrc = RegB, ALUctr = "SUB", RegDst = rd, RegWr, nPC_sel = "+4"
ori	R[rt] ← R[rs] + zero_ext(Imm16); PC ← PC + 4
	ALUsrc = Im, Extop = "Z", ALUctr = "OR", RegDst = rt, RegWr, nPC_sel = "+4"
lw	R[rt] ← MEM[R[rs] + sign_ext(Imm16)]; PC ← PC + 4
	ALUsrc = Im, Extop = "sn", ALUctr = "ADD", MemtoReg, RegDst = rt, RegWr, nPC_sel = "+4"
sw	MEM[R[rs] + sign_ext(Imm16)] ← R[rs]; PC ← PC + 4
	ALUsrc = Im, Extop = "sn", ALUctr = "ADD", MemWr, nPC_sel = "+4"
beq	if (R[rs] == R[rt]) then PC ← PC + sign_ext(Imm16)] || 00 else PC ← PC + 4
	nPC_sel = "br", ALUctr = "SUB"

A Summary of the Control Signals (2/2)

See Appendix A

	func	10 0000	10 0010	We Don't Care :-)				
	op	00 0000	00 0000	00 1101	10 0011	10 1011	00 0100	00 0010
		add	sub	ori	lw	sw	beq	jump
RegDst		1	1	0	0	x	x	x
ALUSrc		0	0	1	1	1	0	x
MemtoReg		0	0	0	1	x	x	x
RegWrite		1	1	1	1	0	0	0
MemWrite		0	0	0	0	1	0	0
nPCsel		0	0	0	0	0	1	?
Jump		0	0	0	0	0	0	1
ExtOp		x	x	0	1	1	x	x
ALUctr<2:0>		Add	Subtract	Or	Add	Add	Subtract	x



Boolean Expressions for Controller

RegDst = add + sub
ALUSrc = ori + lw + sw
MemtoReg = lw
RegWrite = add + sub + ori + lw
MemWrite = sw
nPCsel = beq
Jump = jump
ExtOp = lw + sw
ALUctr[0] = sub + beq (assume ALUctr is 0 ADD, 01: SUB, 10: OR)
ALUctr[1] = or

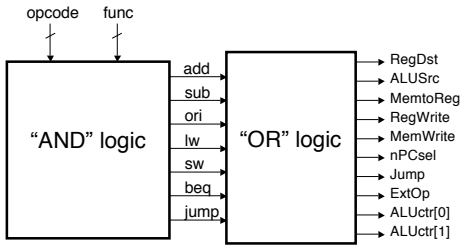
where,

$rtype = \sim op_5 \bullet \sim op_4 \bullet \sim op_3 \bullet \sim op_2 \bullet \sim op_1 \bullet \sim op_0$,
$ori = \sim op_5 \bullet \sim op_4 \bullet op_3 \bullet op_2 \bullet \sim op_1 \bullet op_0$
$lw = op_5 \bullet \sim op_4 \bullet \sim op_3 \bullet \sim op_2 \bullet op_1 \bullet op_0$
$sw = op_5 \bullet \sim op_4 \bullet op_3 \bullet \sim op_2 \bullet op_1 \bullet op_0$
$beq = \sim op_5 \bullet \sim op_4 \bullet \sim op_3 \bullet op_2 \bullet \sim op_1 \bullet \sim op_0$
$jump = \sim op_5 \bullet \sim op_4 \bullet \sim op_3 \bullet \sim op_2 \bullet op_1 \bullet \sim op_0$

How do we implement this in gates?

$add = rtype \bullet func_5 \bullet \sim func_4 \bullet \sim func_3 \bullet \sim func_2 \bullet \sim func_1 \bullet \sim func_0$
$sub = rtype \bullet func_5 \bullet \sim func_4 \bullet \sim func_3 \bullet \sim func_2 \bullet func_1 \bullet \sim func_0$

Controller Implementation



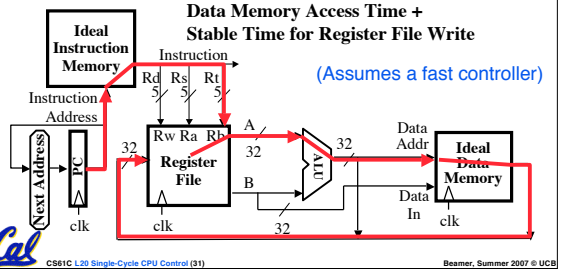
Other Programmable Logic Arrays

- There are other types of PLAs which can be reprogrammed on the fly
- The most common is called a Field Programmable Gate Array (FPGA)
  - made up of configurable logic blocks (CLBs) and flip-flops which can be programmed by software
  - Berkeley has on-going research into reconfigurable computing with FPGAs
    - Check out RAMP and BEE3 projects

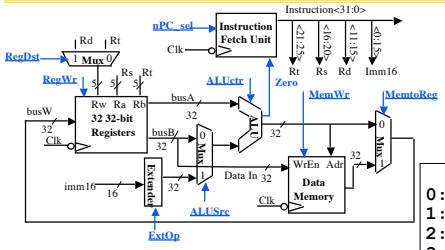
An Abstract View of the Critical Path

Critical Path (Load Instruction) =
Delay clock through PC (FFs) +
Instruction Memory's Access Time +
Register File's Access Time, +
ALU to Perform a 32-bit Add +
Data Memory Access Time +
Stable Time for Register File Write

(Assumes a fast controller)



Peer Instruction



A. MemToReg='x' & ALUctr='sub'. SUB or BEQ?

B. ALUctr='add'. Which 1 signal is different for all 3 of: ADD, LW, & SW? RegDst or ExtOp?

C. "Don't Care" signals are useful because we can simplify our PLA personality matrix. F / T?

	ABC
0:	SRF
1:	SRT
2:	SEF
3:	SET
4:	BRF
5:	BRT
6:	BEF
7:	BET

Summary: Single-cycle Processor

- 5 steps to design a processor
  - 1. Analyze instruction set → datapath requirements
  - 2. Select set of datapath components & establish clock methodology
  - 3. Assemble datapath meeting the requirements
  - 4. Analyze implementation of each instruction to determine setting of control points that effects the register transfer.
  - 5. Assemble the control logic
    - Formulate Logic Equations
    - Design Circuits