Control Unit for Multiple Cycle Implementation

- Control is more complex than in single cycle since:
  - Need to define control signals for each step
  - Need to know which step we are on
- Two methods for designing the control unit
  - Finite state machine and hardwired control (extension of the single cycle implementation)
  - Microprogramming

What are the control signals needed? (cf. Fig 5.32)

- Let's look at control signals needed at each of 5 steps
- Signals needed for
  - reading/writing memory
  - reading/writing registers
  - control the various muxes
  - control the ALU

Instruction fetch

- Need to read memory
  - Choose input address (mux with signal *IorD*)
  - Set *MemRead* signal
  - Set *IRwrite* signal (note that there is no write signal for MDR; Why?)
- Set sources for ALU
  - Source 1: mux set to “come from PC” (signal *ALUSrcA = 0*)
  - Source 2: mux set to “constant 4” (signal *ALUSrcB = 01)*
- Set ALU control to “+” (e.g., *ALUop = 00)*
- Set the mux to store in PC as coming from ALU (signal *PCsource = 01;* cf. Figure 5.33 later)

Instruction fetch (PC increment; cf. Figure 5.33)

- Set the mux to store in PC as coming from ALU (signal *PCsource = 01*)
- Set *PCwrite*
  - Note: this will become clearer when we look at step 3 of branch instructions

Instruction decode and read source registers

- Read registers in A and B
  - No need for control signals. This will happen at every cycle. No problem since neither IR (giving names of the registers) nor the registers themselves are modified. When we need A and B as sources for the ALU, e.g., in step 3, the muxes will be set accordingly
- Branch target computations. Select inputs for ALU
  - Source 1: mux set to "come from PC" (signal *ALUSrcA = 0*)
  - Source 2: mux set to "come from IR, sign-extended, shifted left 2" (signal *ALUSrcB = 11*)
- Set ALU control to "+" (e.g., *ALUop = 00)*

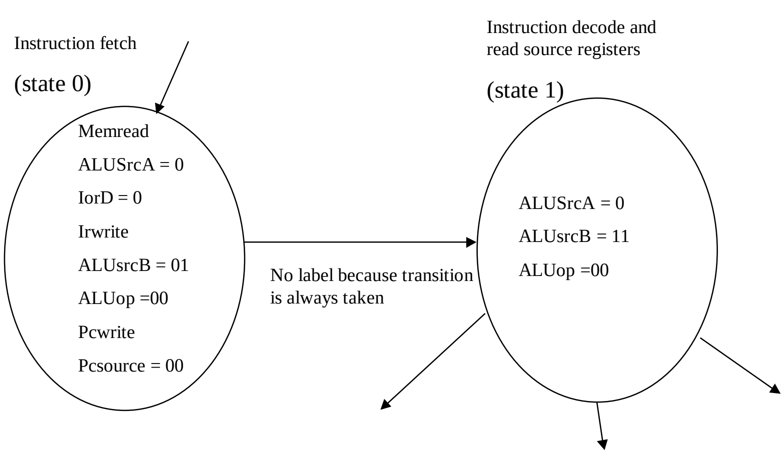
Concept of "state"

- During steps 1 and 2, all instructions do the same thing
- At step 3, opcode is directing
  - What control lines to assert (it will be different for a load, an add, a branch etc.)
  - What will be done at subsequent steps (e.g., access memory, writing a register, fetching the next instruction)
- At each cycle, the control unit is put in a specific state that depends only on the previous state and the opcode
  - (current state, opcode) $\rightarrow$ (next state) *Finite state machine* (cf. CSE370, CSE 322)

The first two states

- Since the data flow and the control signals are the same for all instructions in step 1 (instr. fetch) there is only one state associated with step 1, say *state 0*
- And since all operations in the next step are also always the same, we will have the transition
  - (state 0, all) → (state 1)

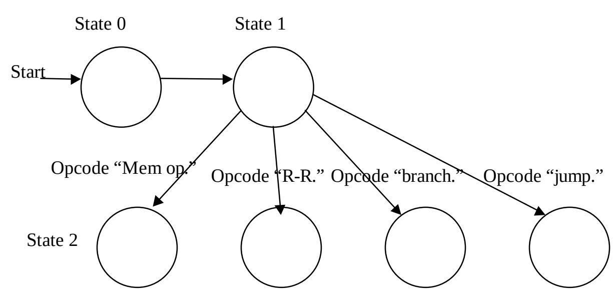
Customary notation



Transitions from State 1

- After the decode, the data flow depends on the type of instructions:
  - Register-Register : Needs to compute a result and store it
  - Load/Store: Needs to compute the address, access memory, and in the case of a load store the result
  - Branch: test the result of the condition and, if need be, change the PC
  - Jump: need to change the PC
  - Immediate: Not shown in the figures. Let's do it as an exercise

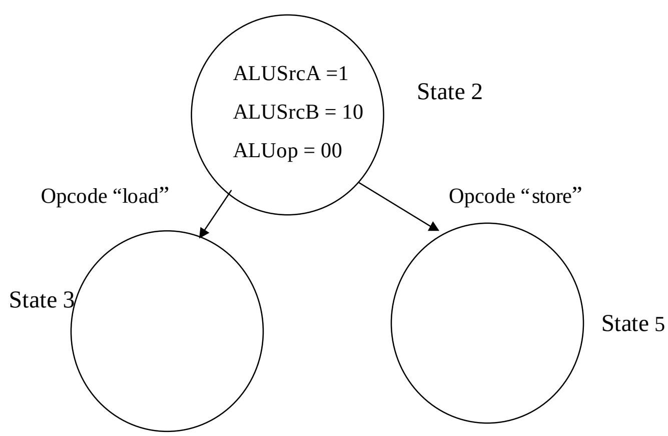
State transitions from State 1



State 2: Memory Address Computation

- Set sources for ALU
  - Source 1: mux set to "come from A" (signal *ALUSrcA = 1*)
  - Source 2: mux set to "imm. extended" (signal *ALUSrcB = 10)*
- Set ALU control to "+" (e.g., *ALUop = 00)*
- Transition from State 2
  - If we have a "load" transition to State 3
  - If we have a "store" transition to State 5

State 2: Memory address computation



One more example: State 5 --Store

- The control signals are:
  - Set mux for address as coming from ALUout (*IorD = 1)*
  - Set *MemWrite*
  - Note that what has to be written has been sitting in B all that time (and was rewritten, unmodified, at every cycle).
- Since the instruction is completed, the transition from State 5 is always to State 0 to fetch a new instruction.
  - (State 5, always) $\rightarrow$ (State 0)

Multiple Cycle Implementation: the whole story

- Data path with control lines: Figure 5.33
- Control unit Finite State Machine Figure 5.42
  - Immediate instructions are not there

Hardwired implementation of the control unit

- Single cycle implementation:
  - Input (Opcode + function bits) ⇒ Combinational circuit (PAL) ⇒ Output signals (data path)
- Multiple cycle implementation
  - Need to implement the finite state machine
  - Input (Opcode + function bits + Current State -- stable storage) ⇒ Combinational circuit (PAL) ⇒ Output signals (data path + setting next state)

Hardwired "diagram"