Department of Electrical and Computer Engineering
The University of Texas at Austin

EE 460N Fall 2013
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Final Exam
December 13, 2013

Name:_____

Problem 1 (25 points):_____

Problem 2 (10 points):_____

Problem 3 (10 points):_____

Problem 4 (10 points):_____

Problem 5 (20 points):_____

Problem 6 (20 points):_____

Problem 7 (30 points):_____

Total (125 points):_____

**You have 3 hours to take this exam.**
Note: Please be sure that your answers to all questions (and all supporting work that is required) are contained in the space provided.

Note: Please be sure your name is recorded on each sheet of the exam.

Please sign the following. I have not given nor received any unauthorized help on this exam.

Signature:_____

**GOOD LUCK!**

Name:_____

**Problem 1 (25 points):**

**Part a (5 points):** A [ ] controller copies data from disk to memory without using the processor.

**Part b (5 points):** What is the greatest positive sub-normal number in an IEEE-like binary floating point format where sign, exponent, and mantissa are 1, 3, and 4 bits respectively. The value of bias is 3.

Please answer in binary floating-point format.

[ ]

**Part c (5 points):** How many core-to-core connections are required in an N-core system where coherence interconnect is a ring? (assume only one uni-directional ring)

[ ]

**Part d (5 points):** Sun (now Oracle) built the Niagara chip where 8-processors shared the same Floating Point (FP) execution unit. To perform an FP operation, cores sent a request to this single FP unit over the interconnect and got a response back several cycles later. Knowing that this decision was made keeping bread-and-butter design in mind, what can you say about the software Sun expected to run on this chip. Answer in less than 10 words.

[ ]

**Part e (5 points):** Assume a byte-addressable 4GB physical memory with *N* channels, 8 ranks/channel, and 8 chips/rank. The bus width is 64B and each chip is 32MB. What is N?

[ ]

Name:_____

**Problem 2 (10 points):**

Design the stall logic for an in-order 2-wide machine that uses a scoreboard. Assume that the two instructions that enter the Decode stage concurrently are called Instruction0 and Instruction1, where Instruction0 comes before Instruction1 in program order.

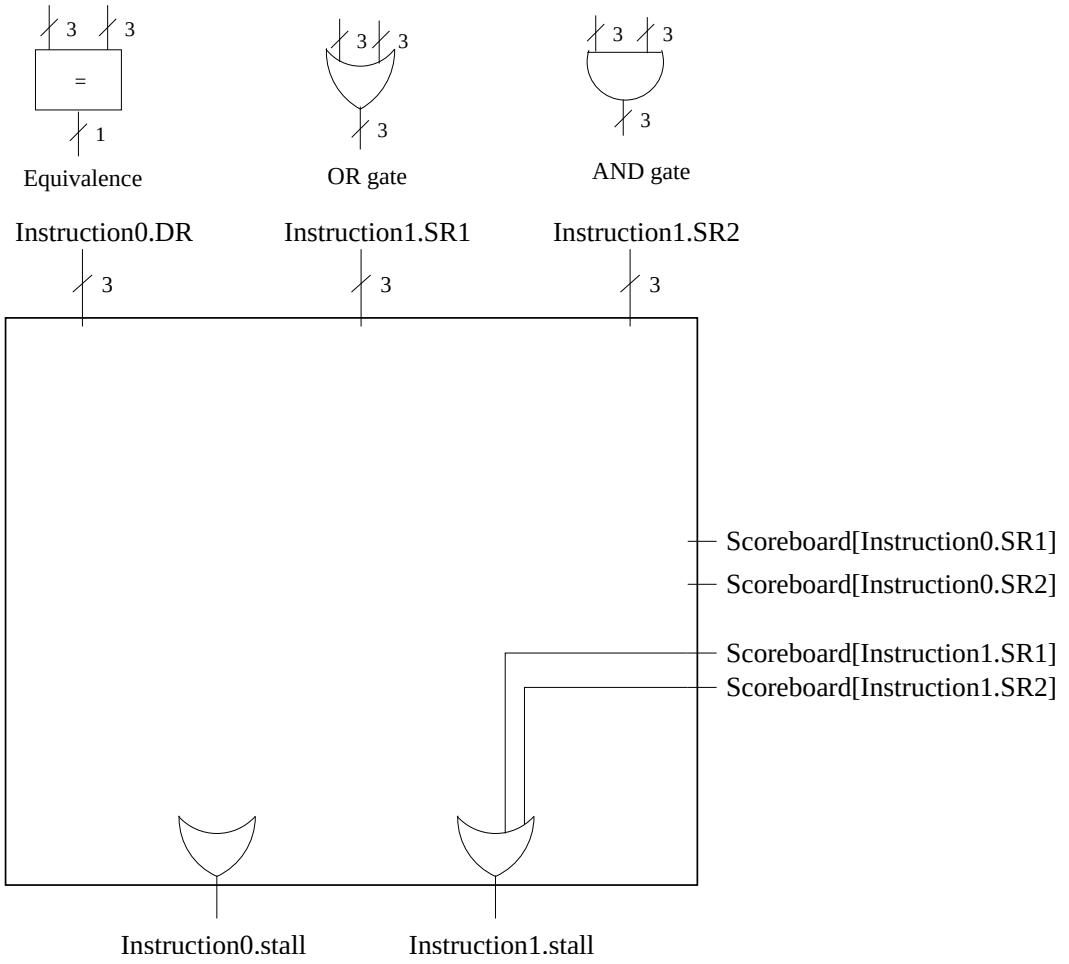
The stall logic has the following inputs and outputs:

**Inputs:**
1. The SR and DR (the source and destination registers) of the corresponding instruction. For example, Instruction0.DR is the destination register for Instruction0.
2. The Scoreboard bits. For example, Scoreboard[Instruction0.SR1] is the scoreboard bit for Instruction0's source register 1.

**Outputs:** Instruction0.stall that stalls Instruction0 only and Instruction1.stall that stalls Instruction1 only.

You may assume that every instruction has valid DR, SR1, and SR2 fields.
You may also assume that there are no stalls related to memory dependencies.

We have drawn the stall logic partially below. Your job is to complete it using **only** wires and one or more of the gates provided below (Equivalence, OR, AND). You may assume that the OR gates shown in the diagram have unlimited fan-in.



Name:_____

**Problem 3 (10 points):**

Suppose we have added <u>two</u> 2-bit counter branch predictors to the LC-3b. The program below runs on the modified LC-3b.

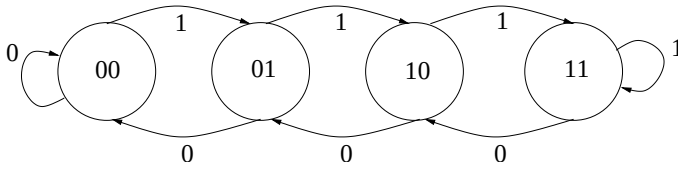
**Note:** Which counter to use for a branch is based on PC[1]. The branch predictor used by each branch is already specified below.

```
        .ORIG x3000
        AND R1, R1, #0
        ADD R0, R0, #0
A       BRn B           ; -- uses Branch Predictor 0
        ADD R1, R1, #1
B       ADD R0, R0, R0
        BRnp A          ; -- uses Branch Predictor 1
        HALT
```

**Part a (3 points):** Explain what the purpose of the program is. Answer in less than 20 words.

**Part b (7 points):** After the above program has run to completion, you notice that Branch Predictor 0 only predicted 1 out of 15 branches correctly and is in state 11. Assuming both branch predictors initially started in state 0, for what 16-bit input value for R0 would the branch predictor perform so poorly?

As a refresher, below is the state diagram representing a 2 bit counter. We predict Not-Taken in states 00 and 01 and Taken in states 10 and 11.




R0: _____

Name:_____

**Problem 4 (10 points):** Assume a system with byte-addressable memory, a 16-bit Virtual Address space, 14-bit Physical Address Space, page size of 4KB, and one level virtual to physical translation. What is the maximum size direct mapped cache that can be used in this system without introducing any cache consistency issues?

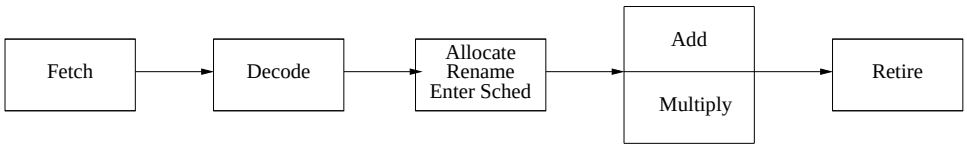
**Note 1:** Assume a Virtually Indexed Physically Tagged cache.
**Note 2:** The above provides the entire information required to solve this problem. Assume no restrictions on the Virtual Page Numbers.

[ ] KB

Name:_____

**Problem 5 (20 points):**

Recall the core460N microarchitecture discussed in class. In this problem we use core460N with *one modification*: the width of the machine has been reduced from 3-wide to 1-wide. Below is a diagram of the modified core460N.




**Notes:**
1. There is one 1-cycle non-pipelined adder
2. There is one 4-cycle non-pipelined multiplier
3. Instructions fill in the Reservation stations in program order **from top to bottom**
4. There are only two reservation station entries per reservation station
5. Fetch, decode, allocate, and retire take one cycle each
6. An instruction's reservation station entry is freed *after it completes execution*.
7. The ROB, RAT, and RS are updated at the *end* of the execution stage
8. The Source 1 and Source 2 fields in the RS correspond to SR1 and SR2 in the instruction respectively
9. The ROB and RS are initially invalid.

Contents of the two Reservation Stations and Re-order buffer (ROB) at the **end of the 6th cycle** are shown below. The identities of the functional units have been replaced with a "?". You will need to identify them to solve this problem.

| | Source 1 | | | Source 2 | |
|---|---|---|---|---|---|
| V | TAG | VALUE | V | TAG | VALUE |
| 0 | W | – | 1 | – | 2 |
| 0 | X | – | 1 | – | 6 |

?

| | Source 1 | | | Source 2 | |
|---|---|---|---|---|---|
| V | TAG | VALUE | V | TAG | VALUE |
| 1 | – | 4 | 1 | – | 5 |
| 0 | Y | – | 1 | – | 6 |

?

| Tag | Ready | DR | Value |
|---|---|---|---|
| W | 0 | _____ | _____ |
| X | 0 | _____ | _____ |
| Y | 0 | _____ | _____ |
| Z | 0 | _____ | _____ |

**PROBLEM IS CONTINUED ON THE NEXT PAGE!**

Name:_____

**Problem 5 continued**

Also shown below is the partial contents of the Register Alias Table (RAT) **after the 6th cycle**. After reset, four instructions (I1-I4) are executed.

**Your job:**

- Identify I1-I4.
- Identify the missing valid bits in the RAT by filling in the figures below.

| | Opcode(+ OR *) | DR | SR1 | SR2 |
|---|---|---|---|---|
| I1 | | | | |
| I2 | | | R0 | |
| I3 | | R2 | R0 | R2 |
| I4 | | | | |

Figure 1: Instruction Table

| | VALID | TAG | VALUE |
|---|---|---|---|
| R0 | | X | 1 |
| R1 | | W | 4 |
| R2 | | Y | 6 |
| R3 | | Z | 6 |
| R4 | | X | 5 |
| R5 | | Y | 2 |

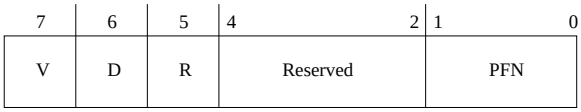
Figure 2: Register Alias Table after the 6th cycle

Name:_____

**Problem 6 (20 points):**

Assume an x86-like virtual memory system where virtual addresses are 6 bits. The system page table is indexed using VA[5:4] and the user page table is indexed using VA[3:2]. When virtual address X is translated, there are no TLB hits or page faults, and the corresponding physical address is 0xA.

Each PTE is 8 bits and has the following fields:




Here are the complete contents of physical memory:

| | |
|---|---|
| 0x0 | 00000000 |
| 0x1 | 10000011 |
| 0x2 | 10000001 |
| 0x3 | 00000000 |
| 0x4 | 00000000 |
| 0x5 | 00000000 |
| 0x6 | 00000000 |
| 0x7 | 10000000 |
| 0x8 | 00000011 |
| 0x9 | 10000010 |
| 0xA | 11111111 |
| 0xB | 10101010 |
| 0xC | 00000000 |
| 0xD | 10000010 |
| 0xE | 00000010 |
| 0xF | 00000000 |

**Part a (2 points):** Calculate the number of frames in physical memory.

**PROBLEM IS CONTINUED ON THE NEXT PAGE!**

Name:_____

**Problem 6 continued**

**Part b (8 points):** Which one of these addresses could/couldn't contain the PTE of the page containing Virtual Address X? Why?

| **Addr** | **Value** | **Circle one** | **Why?** |
|---|---|---|---|
| 0x7 | 10000000 | Y/N | |
| 0x9 | 10000010 | Y/N | |
| 0xB | 10101010 | Y/N | |
| 0xD | 10000010 | Y/N | |
| 0xE | 00000010 | Y/N | |

**Part c (3 points):** What is the SBR?

**Part d (7 points):** What is the Virtual Address X?

Name:_____

**Problem 7 (30 points):**

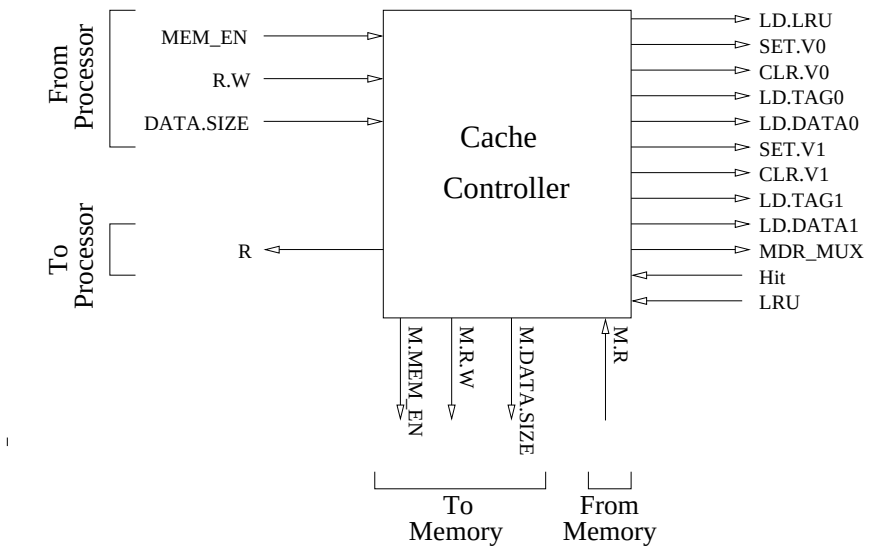
Little Computers Inc. has decided to add a fully-associative 2-entry writethrough cache with a line size of 2B to the non-pipelined LC3b. Your job is to help us integrate this cache with the LC-3b. *For simplicity, you will implement ONLY the LDW instruction.*

The figure below shows the cache controller and its Inputs/Outputs. The controller interfaces with the processor, cache, and memory as follows:

**Processor:** To read data, the processor loads the address in MAR and sets the MEM_EN signal, R.W, and DATA.SIZE signals. When the access is complete, the controller loads the data in MDR and asserts the R signal.

**Cache:** To perform an access, the controller first accesses the Tag Store of the cache to check for a cache hit/miss. If there is a cache hit, it loads MDR with the data in the corresponding data store entry. If there is a cache miss, it accesses the memory.

**Memory:** To access memory, the controller asserts M.MEM_EN signal, M.R.W, and M.DATA.SIZE signals. When the data from memory is ready, it loads the data in MDR and the cache, updating both the tag and data store of the cache.

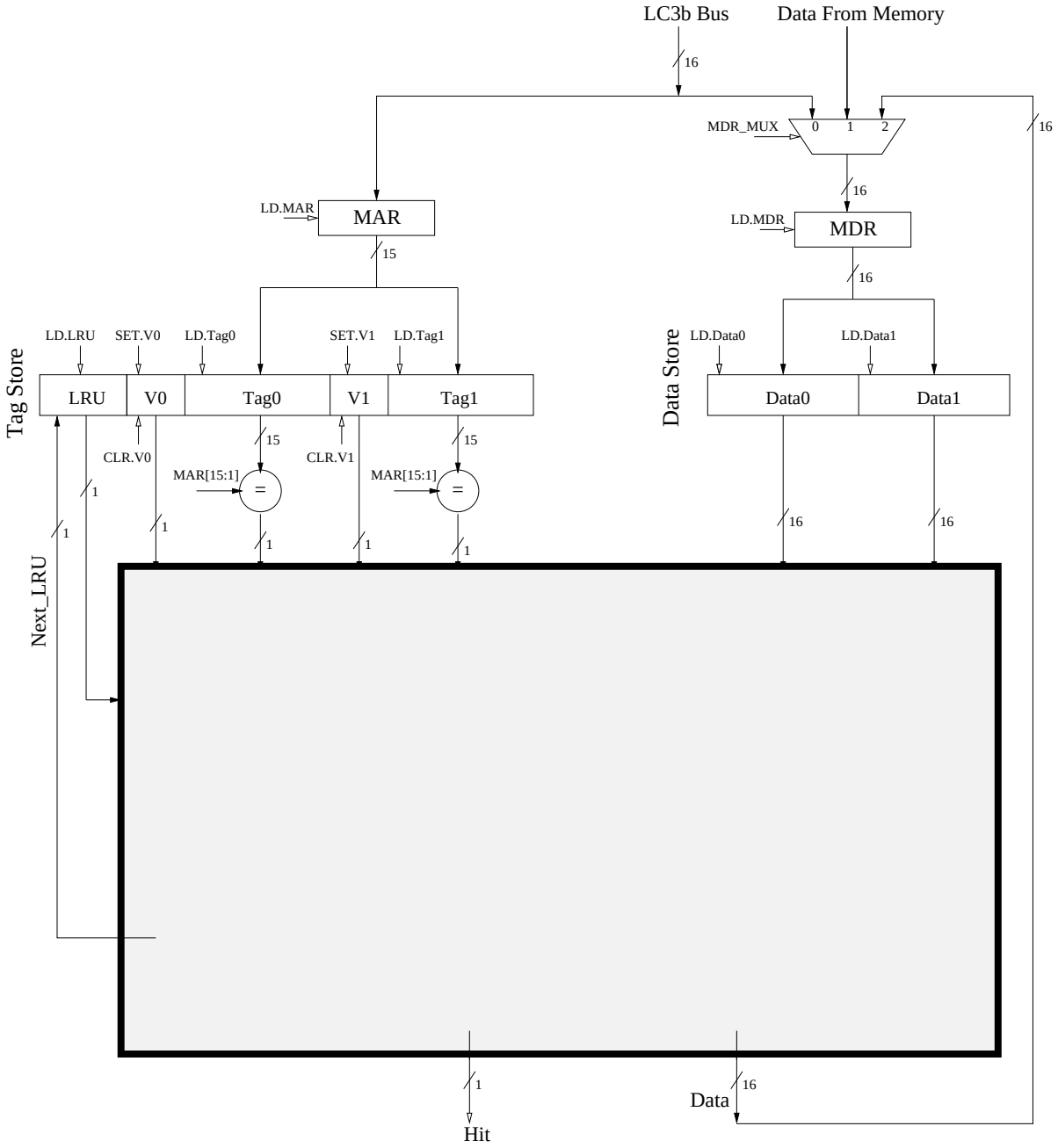


Name:_____

**Problem 7 continued**

**Part a (15 points):** Below are additions to the LC-3b data path to support loads from the cache. Draw the combinational logic that should reside in the shaded empty box. Control signals are generated by the cache controller shown above.

**Hint:** Part a and Part b of this problem are interdependent. You may find it helpful to read and analyze Part b before you start working on Part a.

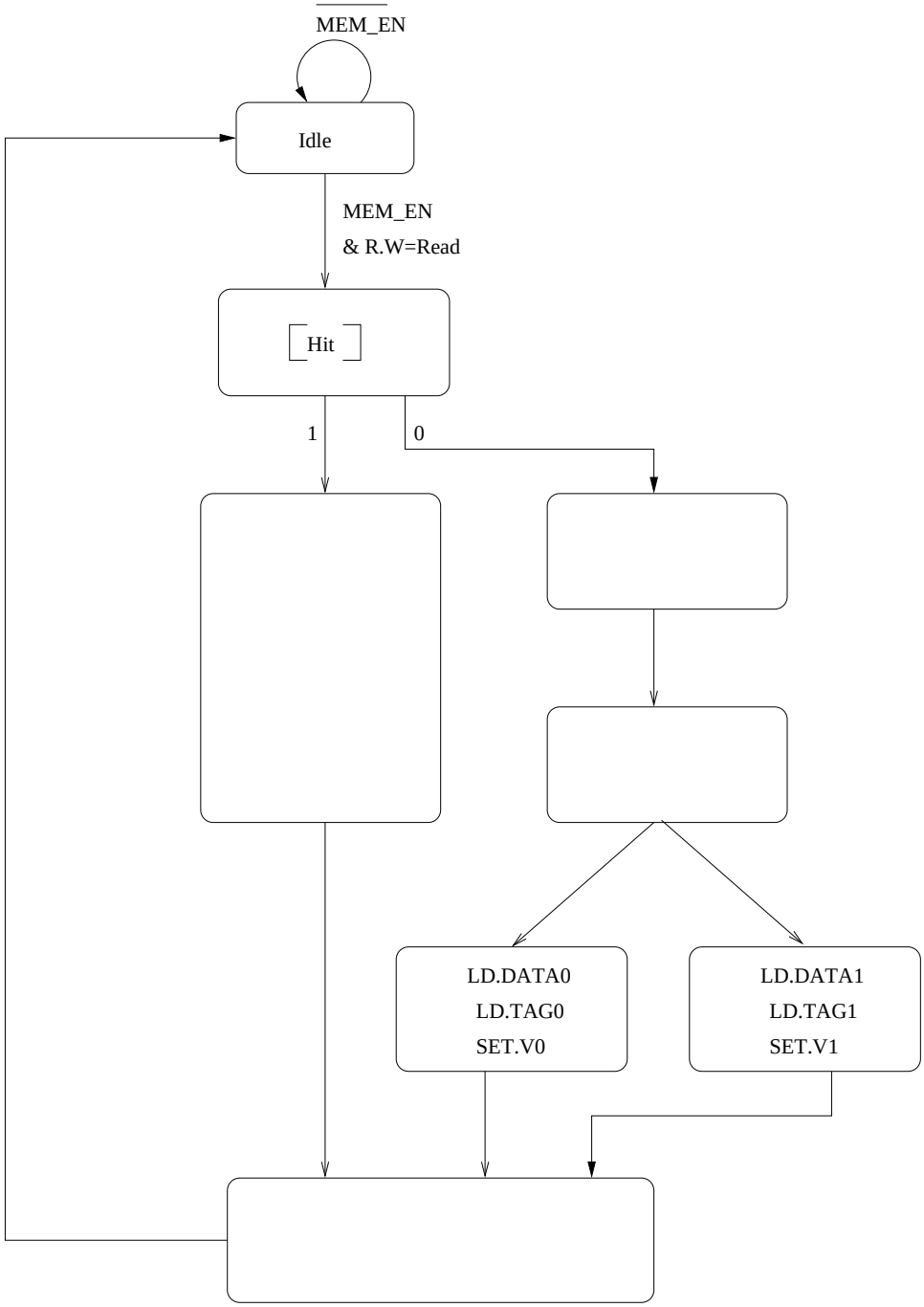


Name:_____

**Problem 7 continued**

**Part b (15 points):** Below is a partially complete state diagram of the cache controller. Complete this diagram by filling in the **missing states and any missing transitions.**

**Note:** Please follow the convention that signal names listed inside the state bubble are assumed high and all remainig signals are assumed low.



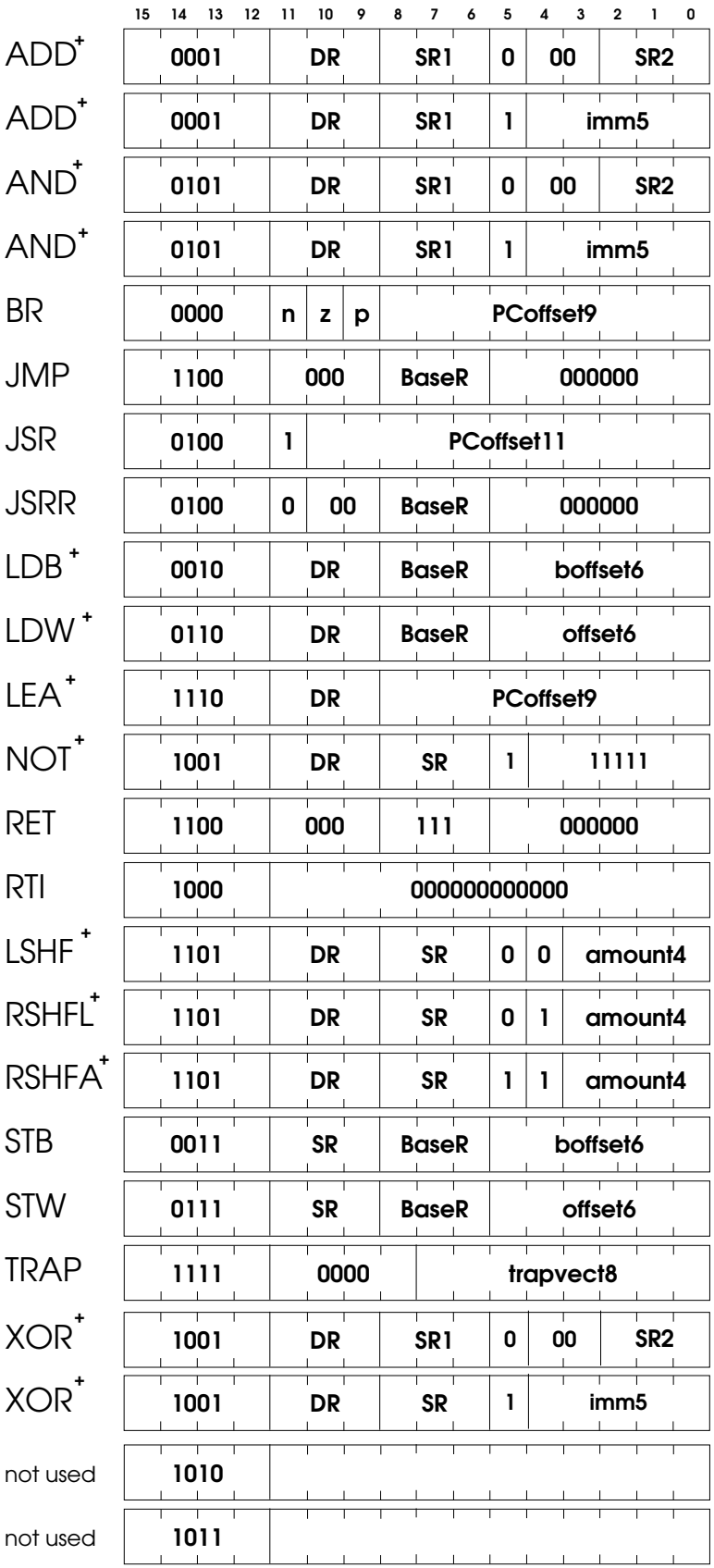



Figure 3: LC-3b Instruction Encodings

Table 1: Data path control signals

| Signal Name | Signal Values | |
|---|---|---|
| LD.MAR/1: | NO(0), LOAD(1) | |
| LD.MDR/1: | NO(0), LOAD(1) | |
| LD.IR/1: | NO(0), LOAD(1) | |
| LD.BEN/1: | NO(0), LOAD(1) | |
| LD.REG/1: | NO(0), LOAD(1) | |
| LD.CC/1: | NO(0), LOAD(1) | |
| LD.PC/1: | NO(0), LOAD(1) | |
| GatePC/1: | NO(0), YES(1) | |
| GateMDR/1: | NO(0), YES(1) | |
| GateALU/1: | NO(0), YES(1) | |
| GateMARMUX/1: | NO(0), YES(1) | |
| GateSHF/1: | NO(0), YES(1) | |
| PCMUX/2: | PC+2(0) | ;select pc+2 |
| | BUS(1) | ;select value from bus |
| | ADDER(2) | ;select output of address adder |
| DRMUX/1: | 11.9(0) | ;destination IR[11:9] |
| | R7(1) | ;destination R7 |
| SR1MUX/1: | 11.9(0) | ;source IR[11:9] |
| | 8.6(1) | ;source IR[8:6] |
| ADDR1MUX/1: | PC(0), BaseR(1) | |
| ADDR2MUX/2: | ZERO(0) | ;select the value zero |
| | offset6(1) | ;select SEXT[IR[5:0]] |
| | PCoffset9(2) | ;select SEXT[IR[8:0]] |
| | PCoffset11(3) | ;select SEXT[IR[10:0]] |
| MARMUX/1: | 7.0(0) | ;select LSHF(ZEXT[IR[7:0]],1) |
| | ADDER(1) | ;select output of address adder |
| ALUK/2: | ADD(0), AND(1), XOR(2), PASSA(3) | |
| MIO.EN/1: | NO(0), YES(1) | |
| R.W/1: | RD(0), WR(1) | |
| DATA.SIZE/1: | BYTE(0), WORD(1) | |
| LSHF1/1: | NO(0), YES(1) | |

Table 2: Microsequencer control signals

| Signal Name | Signal Values | |
|---|---|---|
| J/6: | | |
| COND/2: | $COND_0$ | ;Unconditional |
| | $COND_1$ | ;Memory Ready |
| | $COND_2$ | ;Branch |
| | $COND_3$ | ;Addressing Mode |
| IRD/1: | NO, YES | |

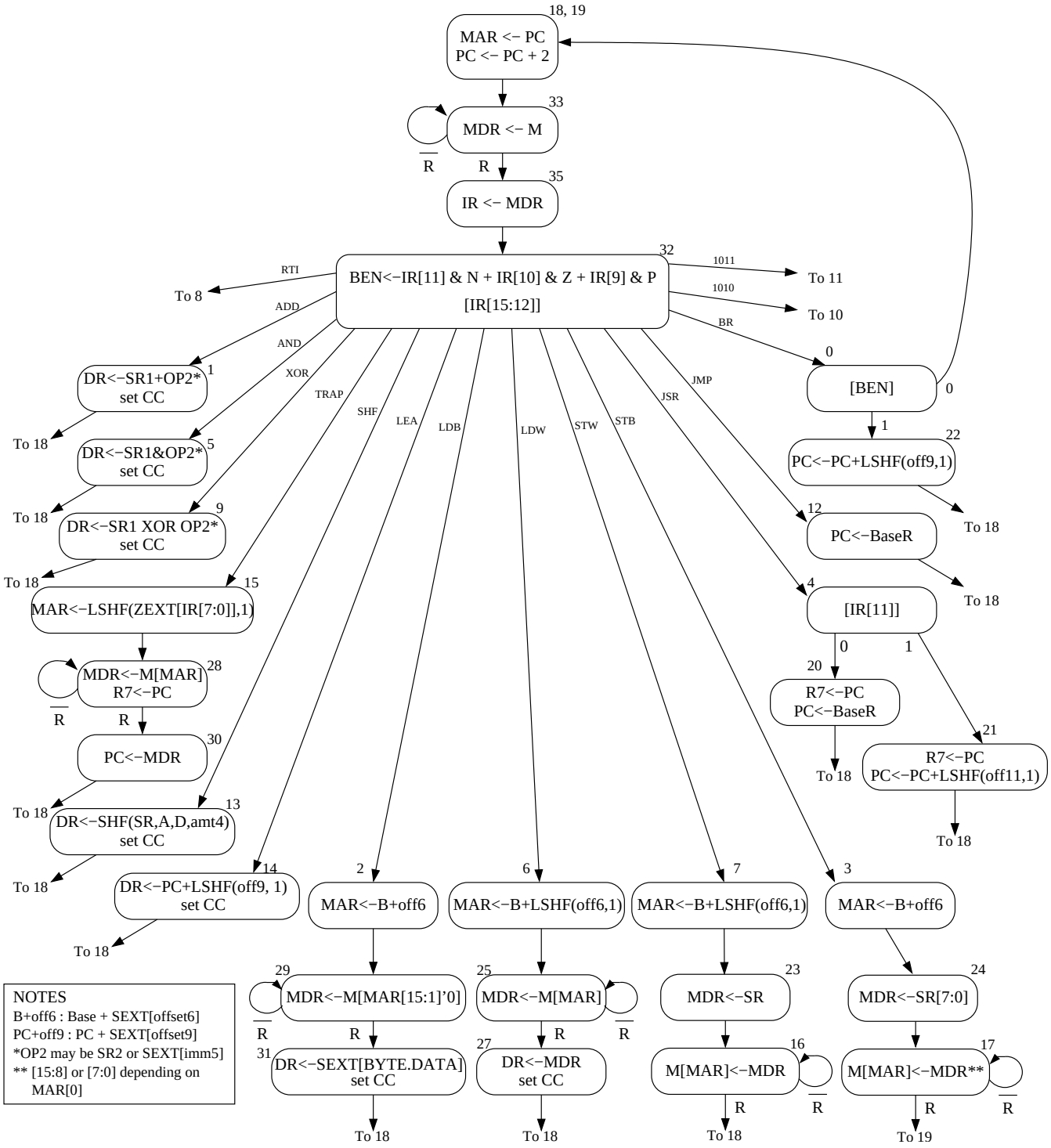



Figure 4: A state machine for the LC-3b

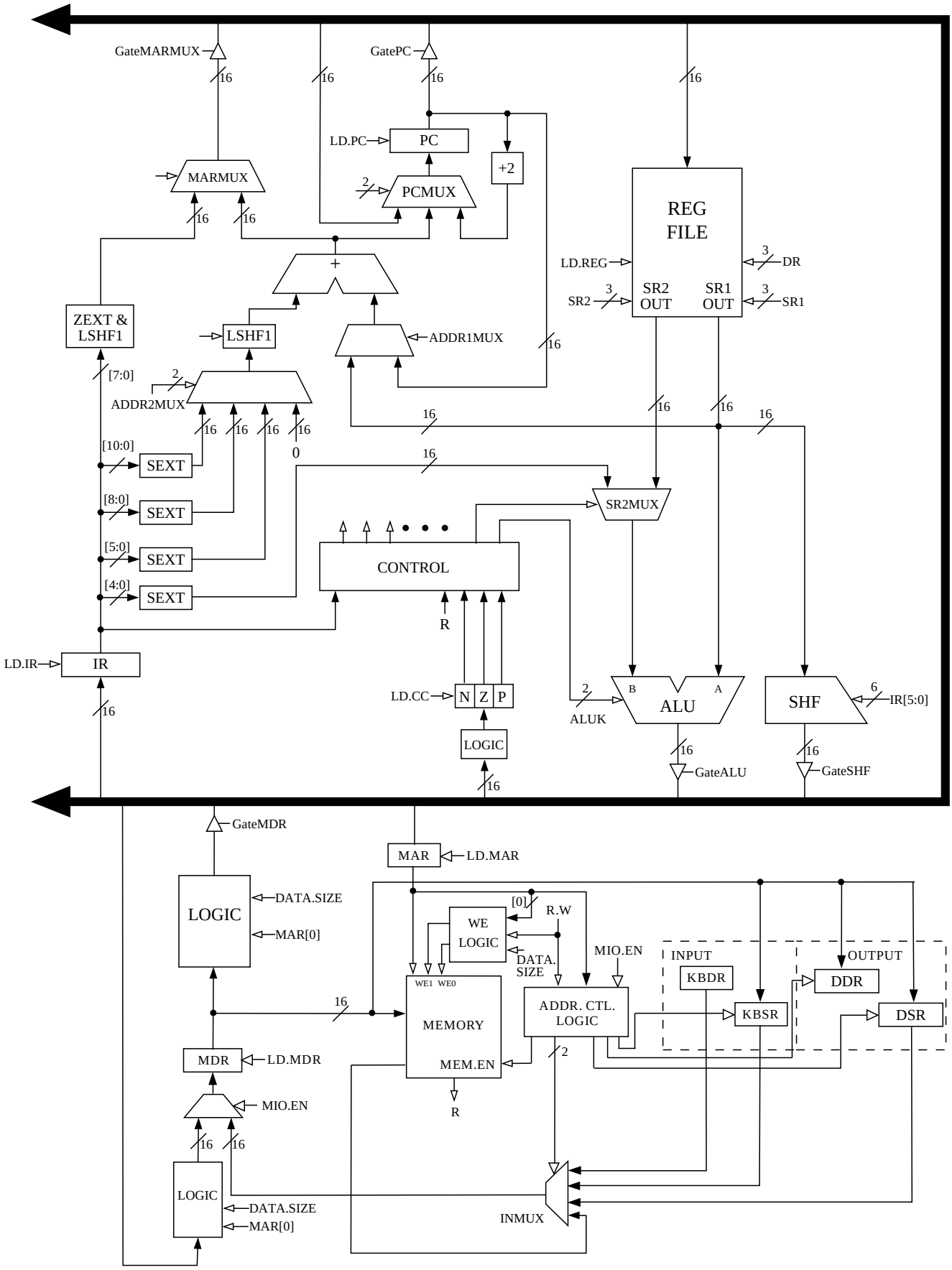



Figure 5: The LC-3b data path

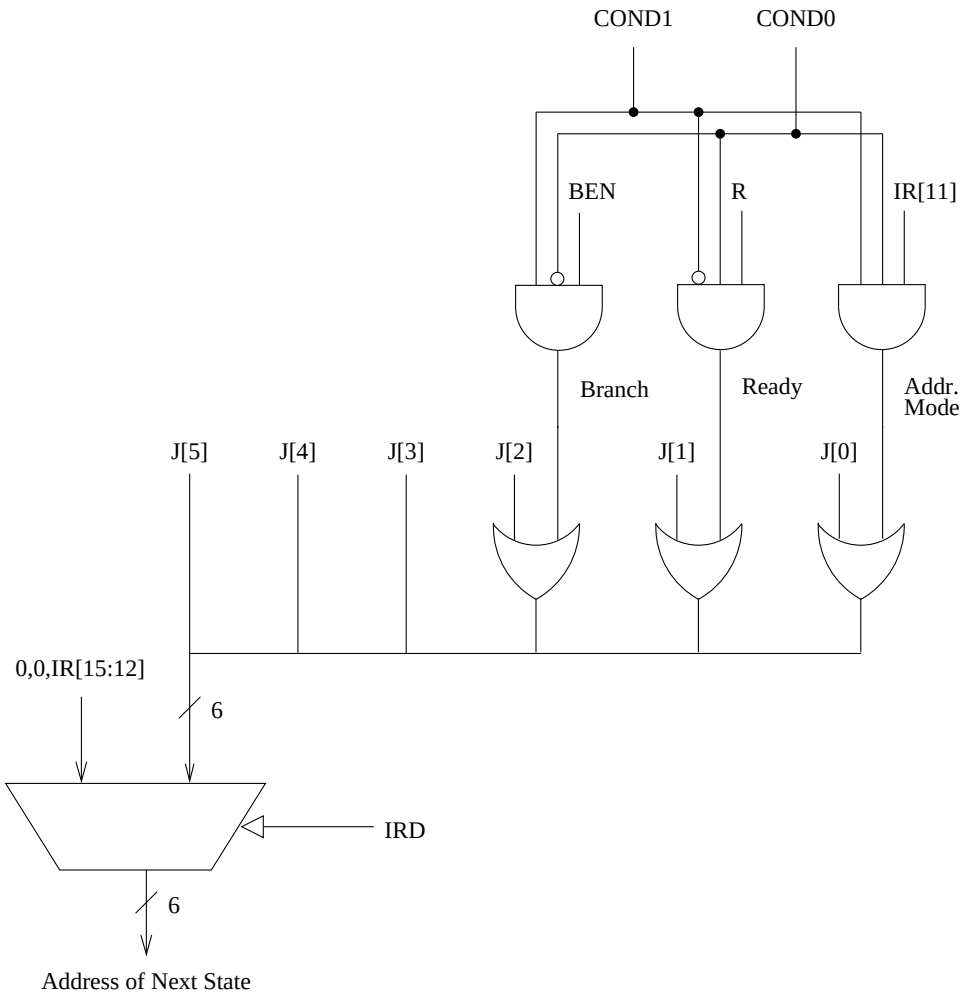



Figure 6: The microsequencer of the LC-3b base machine