CSU22022 Computer Architecture I

Twenty-second Lecture - Control Memory

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CPU_ControlMemory_XXXXXXXX [One of Six]

```vhdl
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use IEEE.NUMERIC_STD.ALL;

entity CPU_ControlMemory_XXXXXXXX is
    Port ( Address : in STD_LOGIC_VECTOR (16 downto 0);
           NA : out STD_LOGIC_VECTOR (16 downto 0);  -- 34-50
           MS : out STD_LOGIC_VECTOR (2 downto 0);   -- 31-33
           MC : out STD_LOGIC;                       -- 30
           IL : out STD_LOGIC;                       -- 29
           PI : out STD_LOGIC;                       -- 28
           PL : out STD_LOGIC;                       -- 27
           TD : out STD_LOGIC_VECTOR (3 downto 0);   -- 23-26
           TA : out STD_LOGIC_VECTOR (3 downto 0);   -- 19-22
           TB : out STD_LOGIC_VECTOR (3 downto 0);   -- 15-18
           MB : out STD_LOGIC;                       -- 14
           FS : out STD_LOGIC_VECTOR (4 downto 0);   -- 09-13
           MD : out STD_LOGIC;                       -- 08
           RW : out STD_LOGIC;                       -- 07
           MM : out STD_LOGIC;                       -- 06
           MW : out STD_LOGIC;                       -- 05
           RV : out STD_LOGIC;                       -- 04
           RC : out STD_LOGIC;                       -- 03
           RN : out STD_LOGIC;                       -- 02
           RZ : out STD_LOGIC;                       -- 01
           FL : out STD_LOGIC);                      -- 00
end CPU_ControlMemory_XXXXXXXX;
```

Listing 1: CPU_ControlMemory_XXXXXXXX Entity.

CPU_ControlMemory_XXXXXXXX [Two of Six]

```
architecture Behavioral of CPU_ControlMemory_XXXXXXXX is

-- we use the least significant 7 bit of the Address - array(0 to 127)
type ROM_array is array(0 to 127) of STD_LOGIC_VECTOR (50 downto 0);

signal ROM : ROM_array :=(

--|50                34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|  Next Address     |  MS  |MC| IL| PI| PL|  TD   |  TA   |  TB   | MB|   FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000000000000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 00
  "00000000000000001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 01
  "00000000000000010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 02
  "00000000000000011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 03
  "00000000000000100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 04
  "00000000000000101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 05
  "00000000000000110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 06
  "00000000000000111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 07
  "00000000000001000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 08
  "00000000000001001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 09
  "00000000000001010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0A
  "00000000000001011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0B
  "00000000000001100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0C
  "00000000000001101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0D
  "00000000000001110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0E
  "00000000000001111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0F

--|50                34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|  Next Address     |  MS  |MC| IL| PI| PL|  TD   |  TA   |  TB   | MB|   FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000000010000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 10
  "00000000000010001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 11
  "00000000000010010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 12
  "00000000000010011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 13
  "00000000000010100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 14
  "00000000000010101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 15
  "00000000000010110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 16
  "00000000000010111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 17
  "00000000000011000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 18
  "00000000000011001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 19
  "00000000000011010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1A
  "00000000000011011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1B
  "00000000000011100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1C
  "00000000000011101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1D
  "00000000000011110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1E
  "00000000000011111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',  -- 1F
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Listing 2: Control Memory Addresses 00_{16} to $1F_{16}$

CPU_ControlMemory_XXXXXXXX [Three of Six]

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--|50            34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13    09| 08| 07| 06| 05| 04| 03| 02| 01| 00|    Control Memory
--|  Next Address    |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|   FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|    Address
  "00000000000100000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 20
  "00000000000100001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 21
  "00000000000100010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 22
  "00000000000100011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 23
  "00000000000100100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 24
  "00000000000100101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 25
  "00000000000100110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 26
  "00000000000100111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 27
  "00000000000101000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 28
  "00000000000101001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 29
  "00000000000101010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2A
  "00000000000101011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2B
  "00000000000101100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2C
  "00000000000101101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2D
  "00000000000101110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2E
  "00000000000101111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 2F

--|50            34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13    09| 08| 07| 06| 05| 04| 03| 02| 01| 00|    Control Memory
--|  Next Address    |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|   FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|    Address
  "00000000000110000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 30
  "00000000000110001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 31
  "00000000000110010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 32
  "00000000000110011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 33
  "00000000000110100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 34
  "00000000000110101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 35
  "00000000000110110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 36
  "00000000000110111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 37
  "00000000000111000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 38
  "00000000000111001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 39
  "00000000000111010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3A
  "00000000000111011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3B
  "00000000000111100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3C
  "00000000000111101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3D
  "00000000000111110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3E
  "00000000000111111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 3F
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Listing 3: Control Memory Addresses 20_{16} to $3F_{16}$

CPU_ControlMemory_XXXXXXXX [Four of Six]

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--|50               34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|  Next Address     |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|  FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000001000000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 40
  "00000000001000001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 41
  "00000000001000010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 42
  "00000000001000011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 43
  "00000000001000100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 44
  "00000000001000101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 45
  "00000000001000110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 46
  "00000000001000111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 47
  "00000000001001000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 48
  "00000000001001001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 49
  "00000000001001010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4A
  "00000000001001011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4B
  "00000000001001100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4C
  "00000000001001101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4D
  "00000000001001110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4E
  "00000000001001111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 4F

--|50               34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|  Next Address     |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|  FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000001010000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 50
  "00000000001010001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 51
  "00000000001010010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 52
  "00000000001010011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 53
  "00000000001010100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 54
  "00000000001010101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 55
  "00000000001010110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 56
  "00000000001010111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 57
  "00000000001011000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 58
  "00000000001011001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 59
  "00000000001011010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5A
  "00000000001011011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5B
  "00000000001011100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5C
  "00000000001011101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5D
  "00000000001011110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5E
  "00000000001011111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 5F
```

Listing 4: Control Memory Addresses 40_{16} to $5F_{16}$

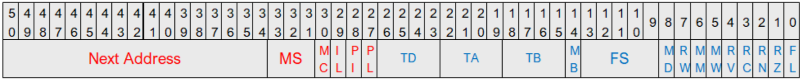
CPU_ControlMemory_XXXXXXXX [Five of Six]

```
--|50                34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|   Next Address     |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|  FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000001100000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 60
  "00000000001100001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 61
  "00000000001100010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 62
  "00000000001100011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 63
  "00000000001100100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 64
  "00000000001100101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 65
  "00000000001100110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 66
  "00000000001100111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 67
  "00000000001101000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 68
  "00000000001101001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 69
  "00000000001101010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6A
  "00000000001101011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6B
  "00000000001101100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6C
  "00000000001101101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6D
  "00000000001101110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6E
  "00000000001101111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 6F

--|50                34|33  31|30| 29| 28| 27|26  23|22  19|18  15| 14|13   09| 08| 07| 06| 05| 04| 03| 02| 01| 00|   Control Memory
--|   Next Address     |  MS  |MC| IL| PI| PL|  TD  |  TA  |  TB  | MB|  FS   | MD| RW| MM| MW| RV| RC| RN| RZ| FL|   Address
  "00000000001110000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 70
  "00000000001110001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 71
  "00000000001110010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 72
  "00000000001110011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 73
  "00000000001110100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 74
  "00000000001110101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 75
  "00000000001110110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 76
  "00000000001110111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 77
  "00000000001111000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 78
  "00000000001111001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 79
  "00000000001111010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 7A
  "00000000001111011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 7B
  "00000000001111100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 7C
  "00000000001111101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 7D
  "00000000001111110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0',    -- 7E
  "00000000001111111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'     -- 7F
);
```

Listing 5: Control Memory Addresses 60_{16} to $7F_{16}$

CPU_ControlMemory_XXXXXXXX [Six of Six]



50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Next Address																	MS			MC	IL	PI	PL	TD				TA				TB				MB	FS					MD	RW	MM	MW	RV	RC	RN	RZ	FL

```
signal content_at_address : STD_LOGIC_VECTOR (50 downto 0);

begin

content_at_address <= ROM(to_integer(unsigned(Address(6 downto 0)))) after 2ns;

                NA <= content_at_address(50 downto 34);    -- 34-50
                MS <= content_at_address(33 downto 31);    -- 31-33
                MC <= content_at_address(30);              -- 30
                IL <= content_at_address(29);              -- 29
                PI <= content_at_address(28);              -- 28
                PL <= content_at_address(27);              -- 27
                TD <= content_at_address(26 downto 23);    -- 23-26
                TA <= content_at_address(22 downto 19);    -- 19-22
                TB <= content_at_address(18 downto 15);    -- 15-18
                MB <= content_at_address(14);              -- 14
                FS <= content_at_address(13 downto 9);     -- 09-13
                MD <= content_at_address(8);               -- 08
                RW <= content_at_address(7);               -- 07
                MM <= content_at_address(6);               -- 06
                MW <= content_at_address(5);               -- 05
                RV <= content_at_address(4);               -- 04
                RC <= content_at_address(3);               -- 03
                RN <= content_at_address(2);               -- 02
                RZ <= content_at_address(1);               -- 01
                FL <= content_at_address(0);               -- 00

end Behavioral;
```

Listing 6: Entity's output signals and vectors.

Processor's ASM Snippet

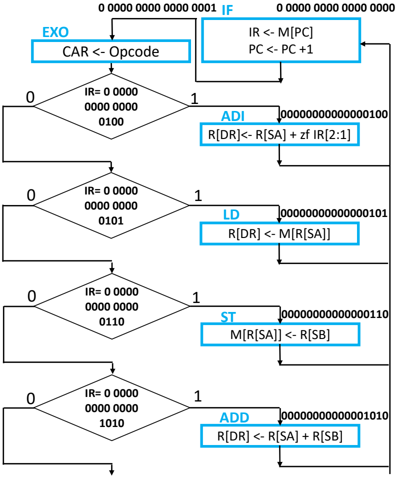
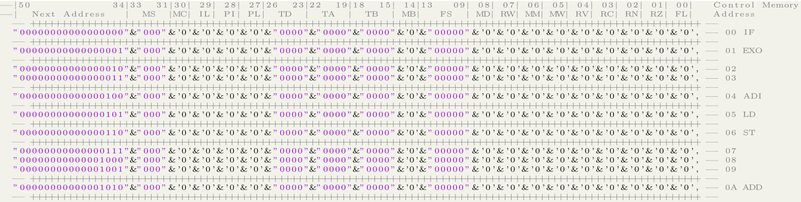


Figure 1: This ASM snippet shows the IF, EXO, ADI, LD, ST, and ADD mico-operations.

Processor's Control Memory Snippet



```
--|50                 34|33   31|30|  29|  28|  27|26   23|22   19|18   15|  14|13     09|  08|  07|  06|  05|  04|  03|  02|  01|  00|     Control Memory
--|    Next Address     |   MS    |MC|  IL|  PI|  PL|   TD    |   TA    |   TB    |  MB|   FS     |  MD|  RW|  MM|  MW|  RV|  RC|  RN|  RZ|  FL|     Address
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 00 IF
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 01 EXO
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 02
  "00000000000000011"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 03
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000100"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 04 ADI
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000101"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 05 LD
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000110"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 06 ST
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000000111"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 07
  "00000000000001000"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 08
  "00000000000001001"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 09
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
  "00000000000001010"&"000"&'0'&'0'&'0'&'0'&"0000"&"0000"&"0000"&'0'&"00000"&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0'&'0', -- 0A ADD
  -- +++++++++++++++++++++++++++++++++++++++++++++++++++ --
```

Listing 7: This ASM snippet shows the IF EXO ADI LD ST and ADD mico operations.

Figure 2: This control memory snippet shows the IF, EXO, ADI, LD, ST, and ADD mico-operations.