Computer Architecture

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BASIC COMPUTER ORGANIZATION AND DESIGN

Outlines

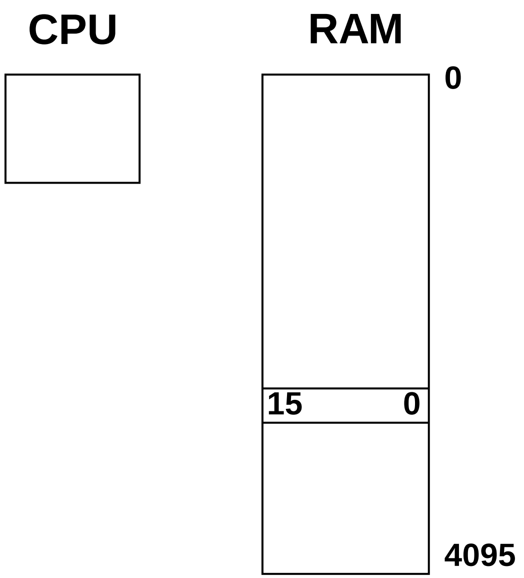
- Instruction Codes
- Computer Registers
- Computer Instructions
- Timing and Control
- Instruction Cycle
- Memory Reference Instructions
- Input-Output and Interrupt
- Complete Computer Description
- Design of Basic Computer
- Design of Accumulator Logic

INTRODUCTION

- **However, to understand how processors work, we will start with a simplified processor model**
- **This is similar to what real processors were like ~25 years ago**
- **M. Morris Mano introduces a simple processor model he calls the *Basic Computer***
- **We will use this to introduce processor organization and the relationship of the RTL model to the higher level computer processor**

THE BASIC COMPUTER

- The Basic Computer has two components, a processor and memory
- The memory has 4096 words in it
  - 4096 = 2^{12}, so it takes 12 bits to select a word in memory
- Each word is 16 bits long



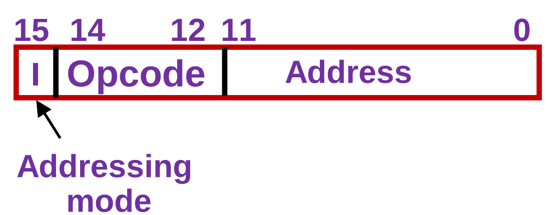
INSTRUCTIONS

- **Program**
  - **A sequence of (machine) instructions**
- **(Machine) Instruction**
  - **A group of bits that tell the computer to *perform a specific operation* (a sequence of micro-operation)**
- **The instructions of a program, along with any needed data are stored in memory**
- **The CPU reads the next instruction from memory**
- **Control circuitry in control unit then translates the instruction into the sequence of microoperations necessary to implement it**

INSTRUCTION FORMAT

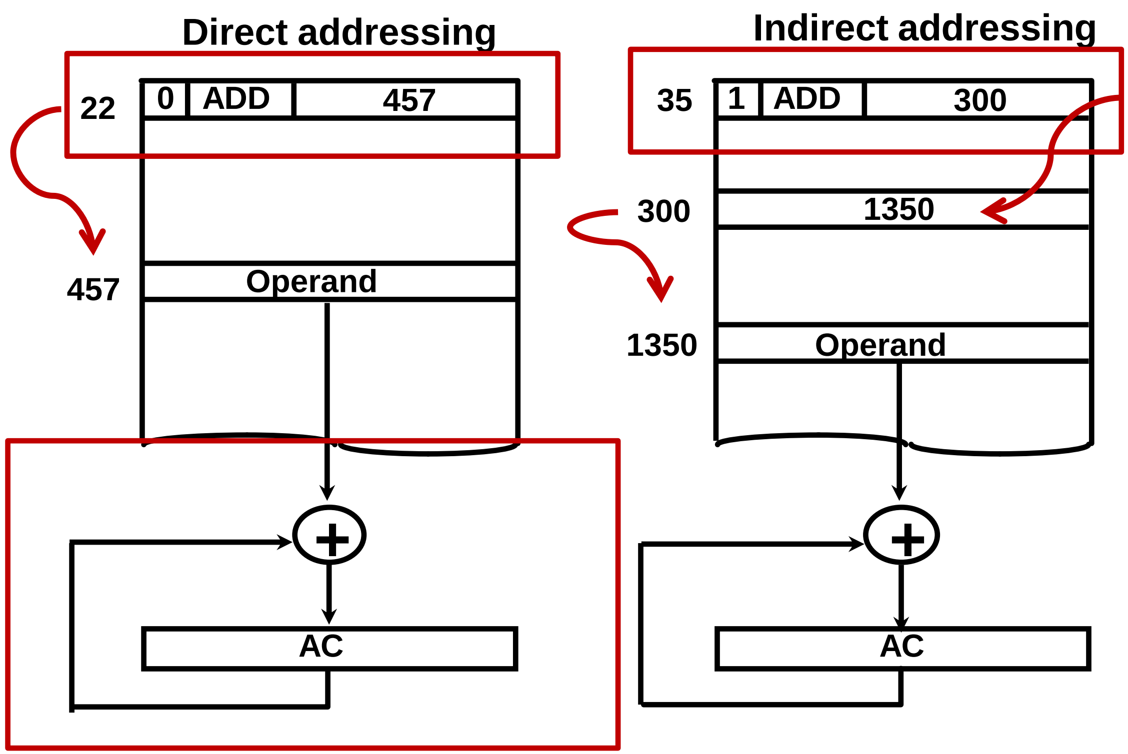
- **A computer instruction is often divided into two parts**
  - **An *opcode* (Operation Code) that specifies the operation for that instruction**
  - **An *address* that specifies the registers and/or locations in memory to use for that operation**
- **In the Basic Computer, since the memory contains 4096 (= 2^{12}) words, we needs 12 bit to specify which memory address this instruction will use**
- **In the Basic Computer, bit 15 of the instruction specifies the *addressing mode* (0: direct addressing, 1: indirect addressing)**
- **Since the memory words, and hence the instructions, are 16 bits long, that leaves 3 bits for the instruction's opcode**

Instruction Format



ADDRESSING MODES

- The address field of an instruction can represent either
  - **Direct address**: the address in memory of the data to use (the address of the operand), or
  - **Indirect address**: the address in memory of the address in memory of the data to use



- **Effective Address (EA)**
  - The address that can be directly used without modification to access an operand for a computation-type instruction, or as the target address for a branch-type instruction

PROCESSOR REGISTERS

- **A processor has many registers to hold instructions, addresses, data, etc**
- **The processor has a register, the *Program Counter* (PC) that holds the memory address of the next instruction to get**
  - **Since the memory in the Basic Computer only has 4096 locations, the PC only needs 12 bits**

12-bit

PC

- **The CPU reads the next instruction from memory**
- **It is placed in an *Instruction Register* (IR)**

PROCESSOR REGISTERS

- In a direct or indirect addressing, the processor needs to keep track of what locations in memory it is addressing
  - The Address Register (AR) is used for this
  - The AR is a 12-bit register in the Basic Computer
- When an operand is found, using either direct or indirect addressing, it is placed in the *Data Register* (DR)
  - The processor then uses this value as data for its operation
- The Basic Computer has a single *general purpose register* – the *Accumulator* (AC)

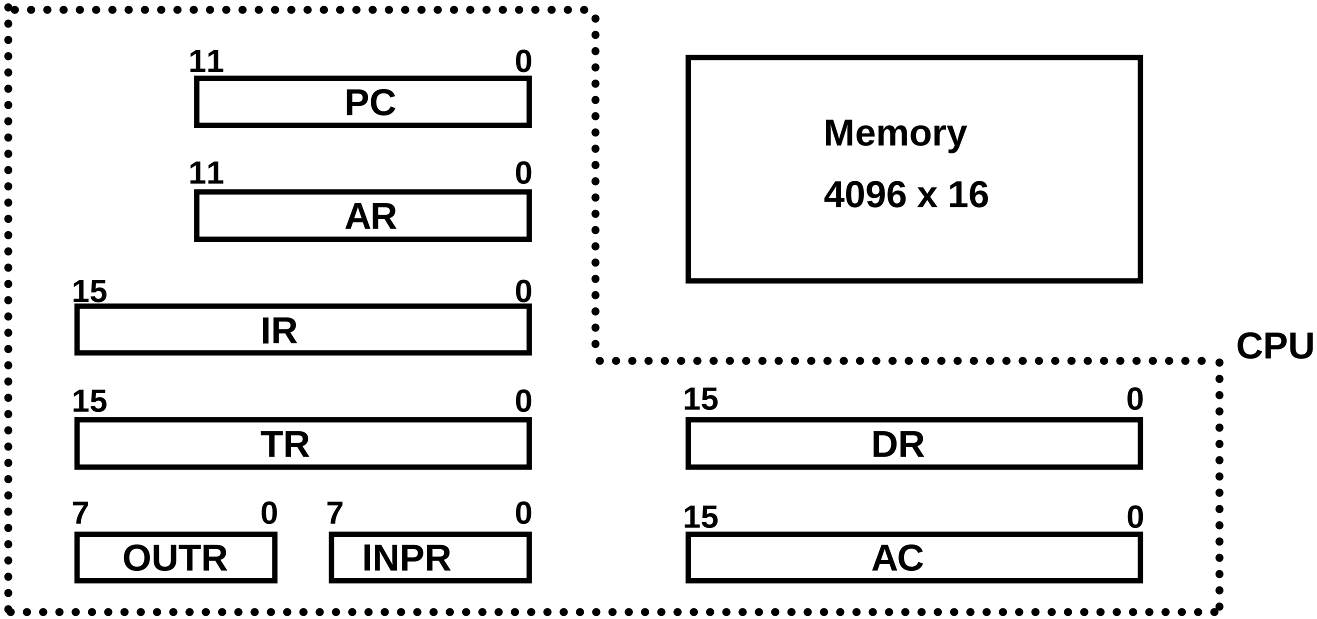
PROCESSOR REGISTERS

- **The significance of a general purpose register is that it can be referred to in instructions**
  - **e.g. load AC with the contents of a specific memory location; store the contents of AC into a specified memory location**
- **Often a processor will need a scratch register to store intermediate results or other temporary data**
  - **In the Basic Computer this is the *Temporary Register* (TR)**

PROCESSOR REGISTERS

- **The Basic Computer uses a very simple model of input/output (I/O) operations**
  - **Input devices are considered to send 8 bits of character data to the processor**
  - **The processor can send 8 bits of character data to output devices**
- **The *Input Register* (INPR) holds an 8 bit character gotten from an input device**
- **The *Output Register* (OUTR) holds an 8 bit character to be send to an output device**

BASIC COMPUTER REGISTERS



List of BC Registers

DR	16	Data Register	Holds memory operand
AR	12	Address Register	Holds address for memory
AC	16	Accumulator	Processor register
IR	16	Instruction Register	Holds instruction code
PC	12	Program Counter	Holds address of instruction
TR	16	Temporary Register	Holds temporary data
INPR	8	Input Register	Holds input character
OUTR	8	Output Register	Holds output character

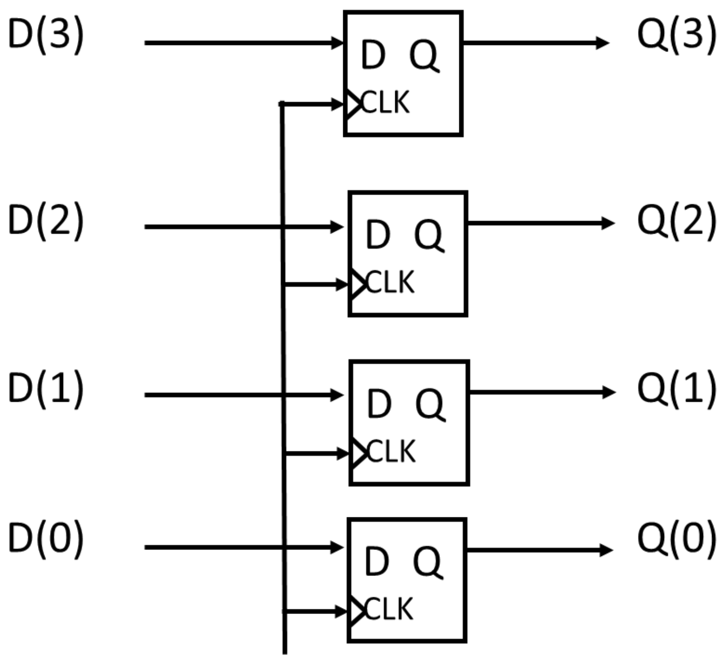
COMMON BUS SYSTEM

The registers in the Basic Computer are connected using a bus

This gives a savings in circuitry over complete connections between registers

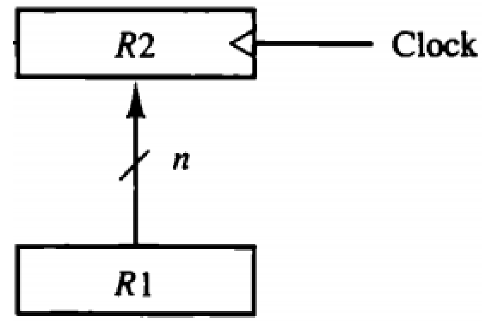
Register Definition

- Register
  - In typical nomenclature, a register is a name for a collection of flip-flops used to hold data (i.e. std_logic_vector)
  - Registers are the fastest place to hold data in a computer, so we want to use them as much as possible.



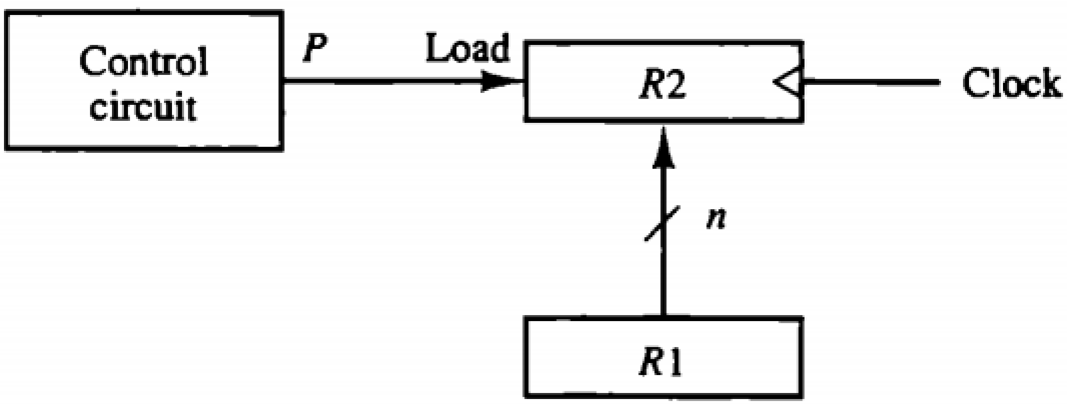
Register Transfer Level

$$R2 \leftarrow R1$$



$$\textit{If } (P = 1) \textit{ then } (R2 \leftarrow R1)$$

$$P\text{:} \quad R2 \leftarrow R1$$

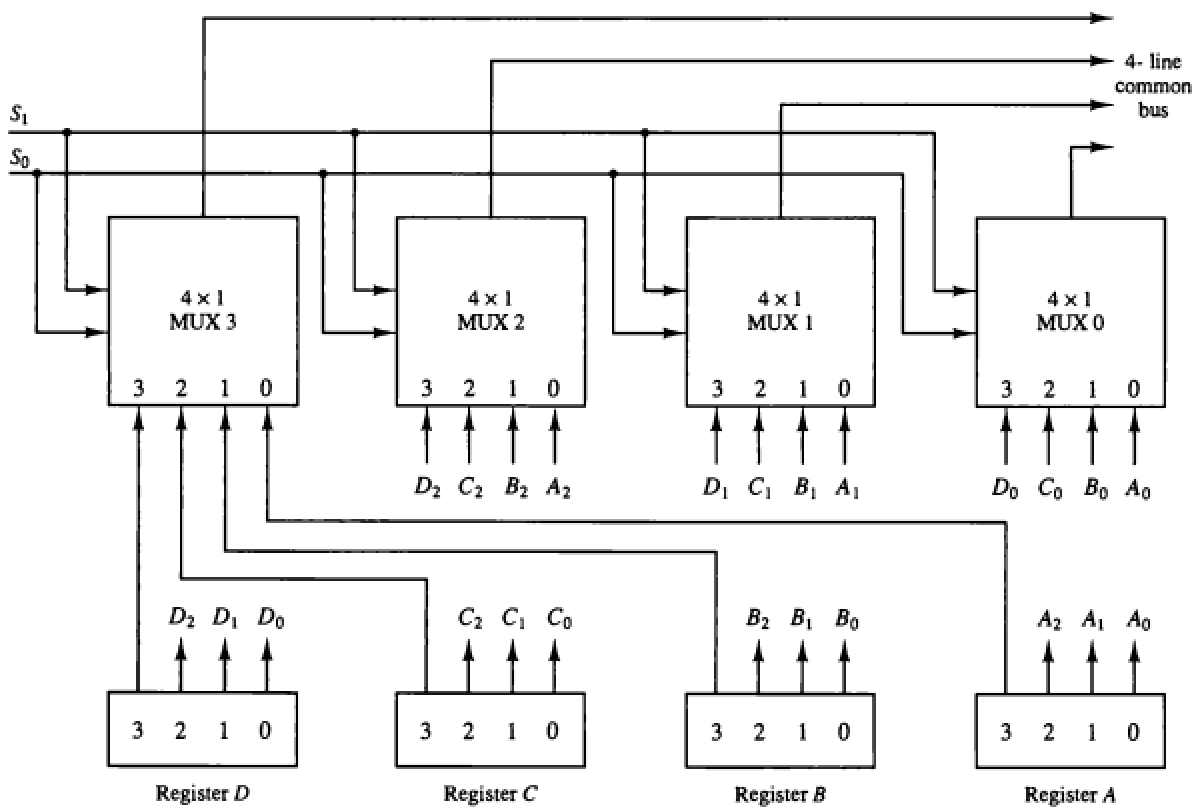


$$T\text{:} \quad R2 \leftarrow R1, \quad R1 \leftarrow R2$$

Register Transfer Level

Symbol	Description	Examples
Letters (and numerals)	Denotes a register	MAR, $R2$
Parentheses ( )	Denotes a part of a register	$R2(0\text{–}7)$, $R2(L)$
Arrow $\leftarrow$	Denotes transfer of information	$R2 \leftarrow R1$
Comma ,	Separates two microoperations	$R2 \leftarrow R1$, $R1 \leftarrow R2$

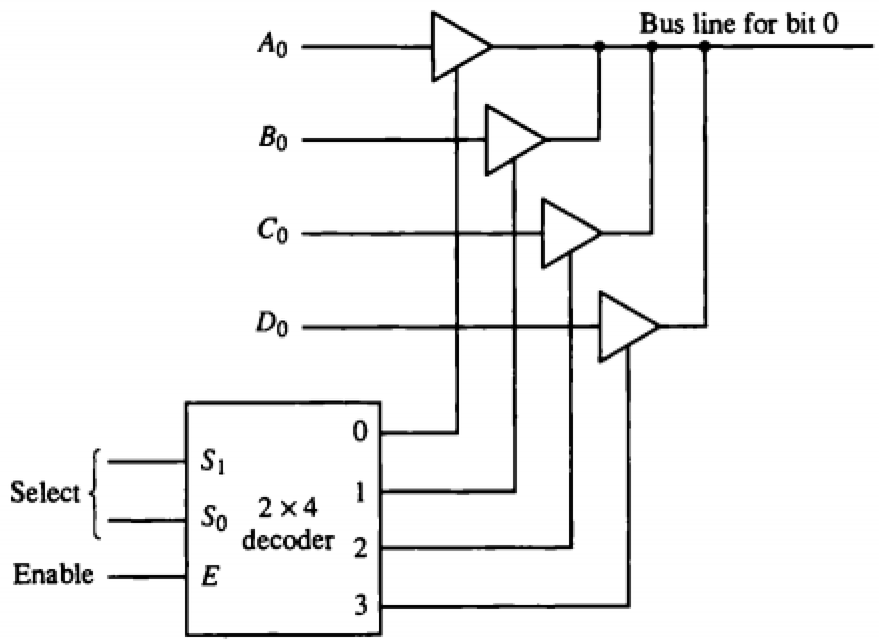
RTL- BUS



$BUS \leftarrow C, \quad R1 \leftarrow BUS$

$R1 \leftarrow C$

RTL- BUS



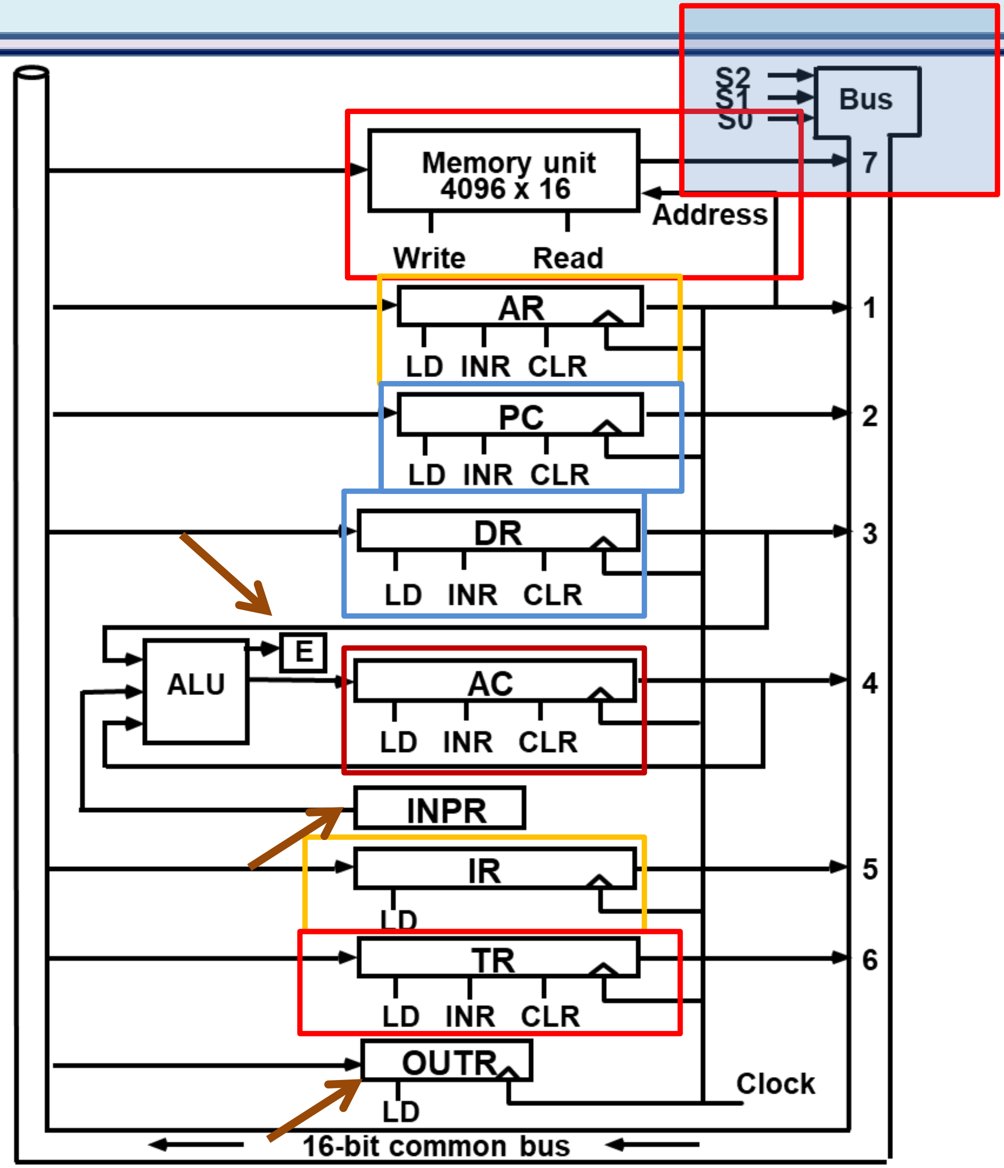
Bus line for bit 0
A_0
B_0
C_0
D_0
Select
Enable
S_1
S_0
E
2 × 4
decoder
0
1
2
3

RTL- Memory Transfer

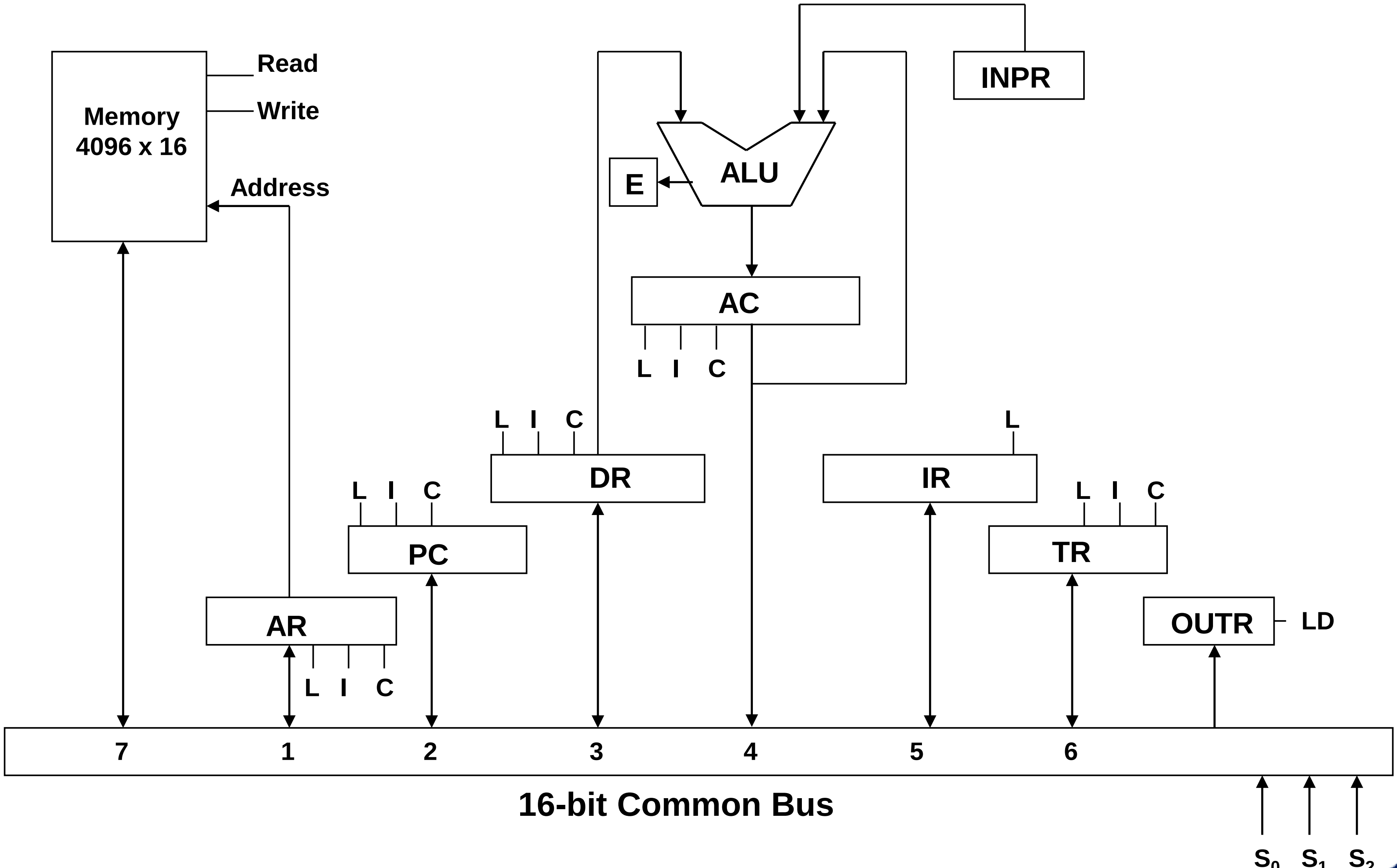
Read: DR $\leftarrow$ M[AR]

Write: M[AR] $\leftarrow$ R1

COMMON BUS SYSTEM



COMMON BUS SYSTEM



COMMON BUS SYSTEM

- Three control lines, S_2, S_1, and S_0 control which register the bus selects as its input

S_2 S_1 S_0	Register
0 0 0	x
0 0 1	AR
0 1 0	PC
0 1 1	DR
1 0 0	AC
1 0 1	IR
1 1 0	TR
1 1 1	Memory

- Either one of the registers will have its load signal activated, or the memory will have its read signal activated
  - Will determine where the data from the bus gets loaded
- The 12-bit registers, AR and PC, have 0's loaded onto the bus in the high order 4 bit positions
- When the 8-bit register OUTR is loaded from the bus, the data comes from the low order 8 bits on the bus

to be continued