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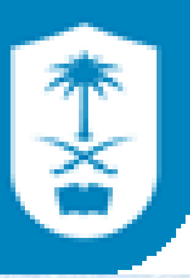

CSC 220: Computer Organization

Unit 8
Registers and RTL

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Overview

- Registers Construction
  - Basic Registers
  - Shift Registers
- Bus Construction
- Register Transfer Language
  - Micro operations

Chapter-6

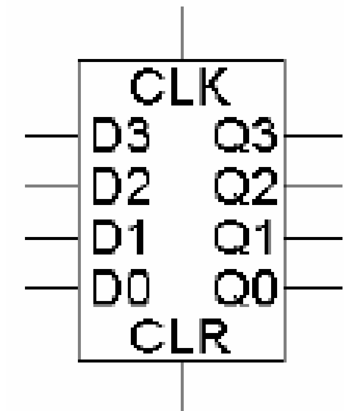
M. Morris Mano, Charles R. Kime and Tom Martin, **Logic and Computer Design Fundamentals**, Global (5th) Edition, Pearson Education Limited, 2016. ISBN: 9781292096124

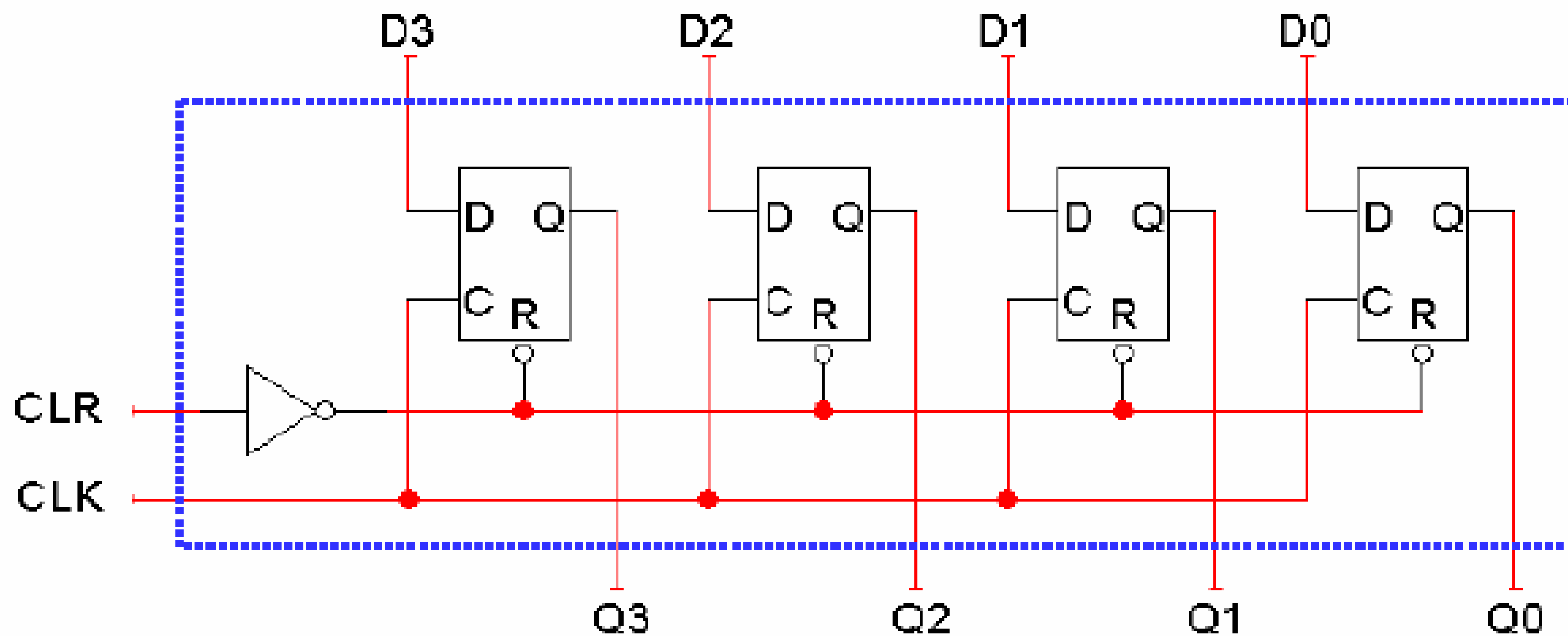
Registers

- Flip-flops are limited because they can store only one bit.
  - We had to use two flip-flops for most of our examples so far.
  - Most computers work with integers and single-precision floating-point numbers that are 32-bits long.
- A register is an extension of a flip-flop that can store multiple bits.
- Registers are commonly used as temporary storage in a processor.
  - They are faster and more convenient than main memory.
  - More registers can help speed up complex calculations.
- Later we'll learn more about how registers are used in processors, and some of the differences between registers and random-access memories or RAM.

A basic register

- Basic registers are easy to build. We can store multiple bits just by putting a bunch of flip-flops together!
- A 4-bit register from LogicWorks, Reg-4, is on the right, and its internal implementation is below.
  - This register uses D flip-flops, so it's easy to store data without worrying about flip-flop input equations.
  - All the flip-flops share a common CLK and CLR signal.



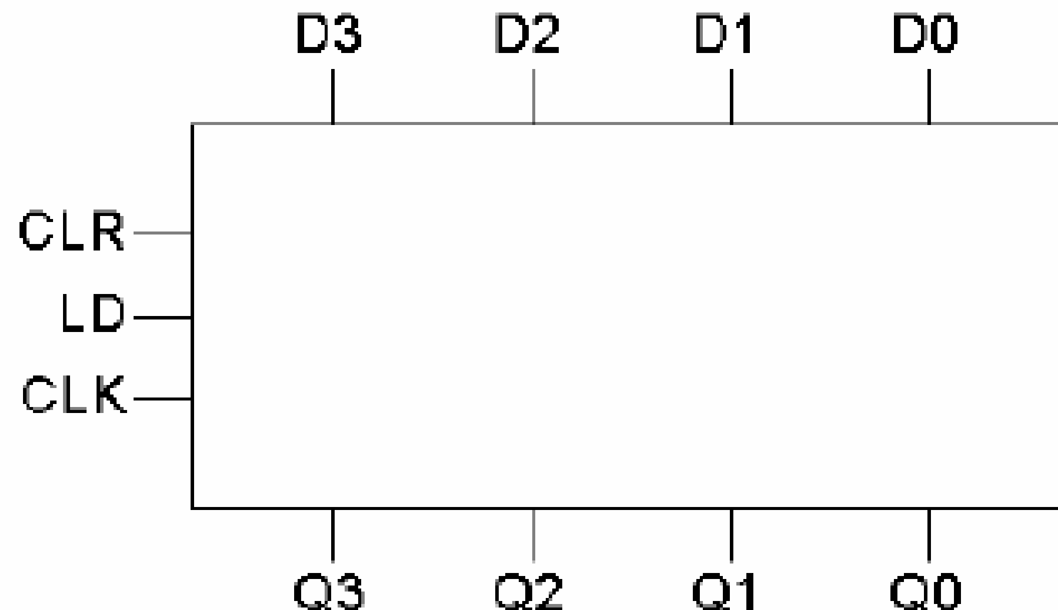


A Register with parallel load

Adding another operation

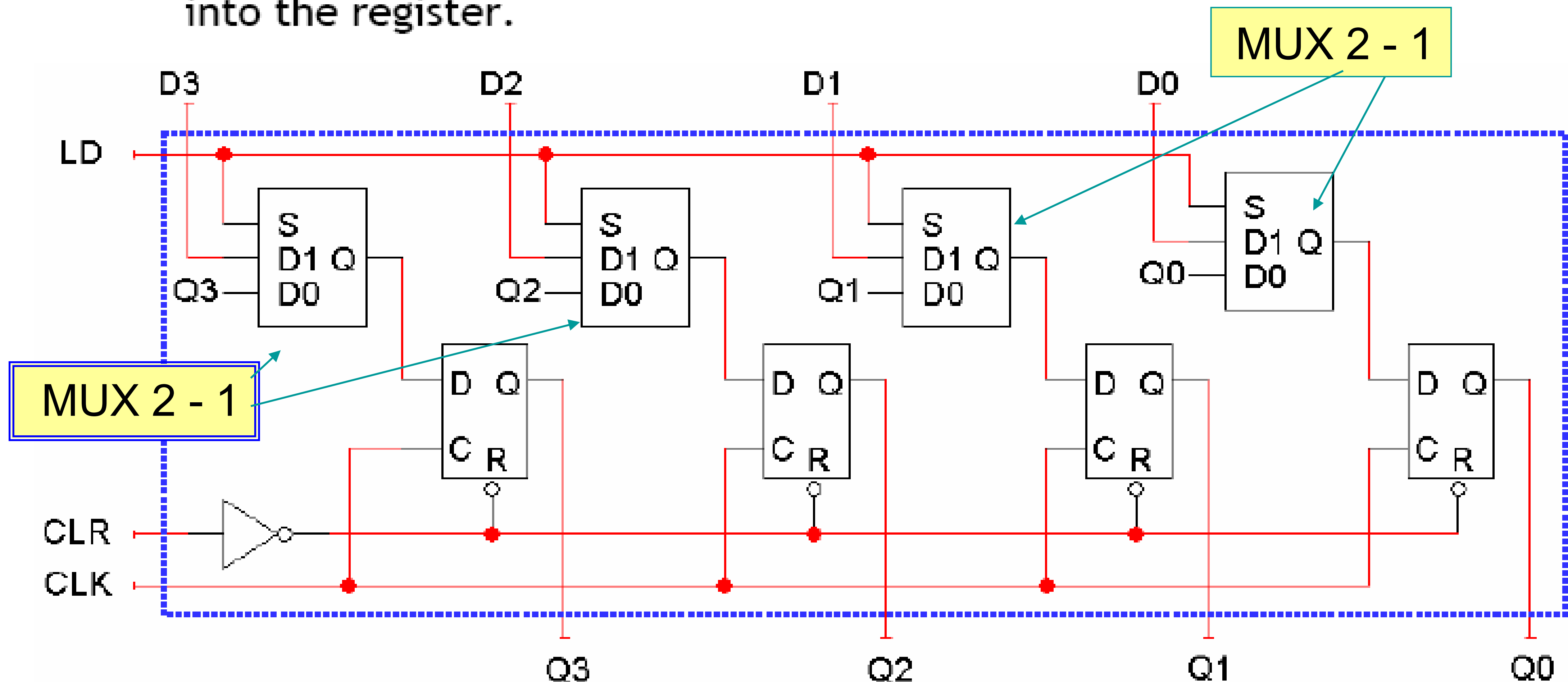
- The input D3-D0 is copied to the output Q3-Q0 on *every* clock cycle.
- How can we store the current value for more than one cycle?
- Let's try to add a load input signal LD to the register.
  - If LD = 0, the register keeps its current contents.
  - If LD = 1, the register stores a new value, taken from inputs D3-D0.

LD	Q(t+1)
0	Q(t)
1	D_3-D_0



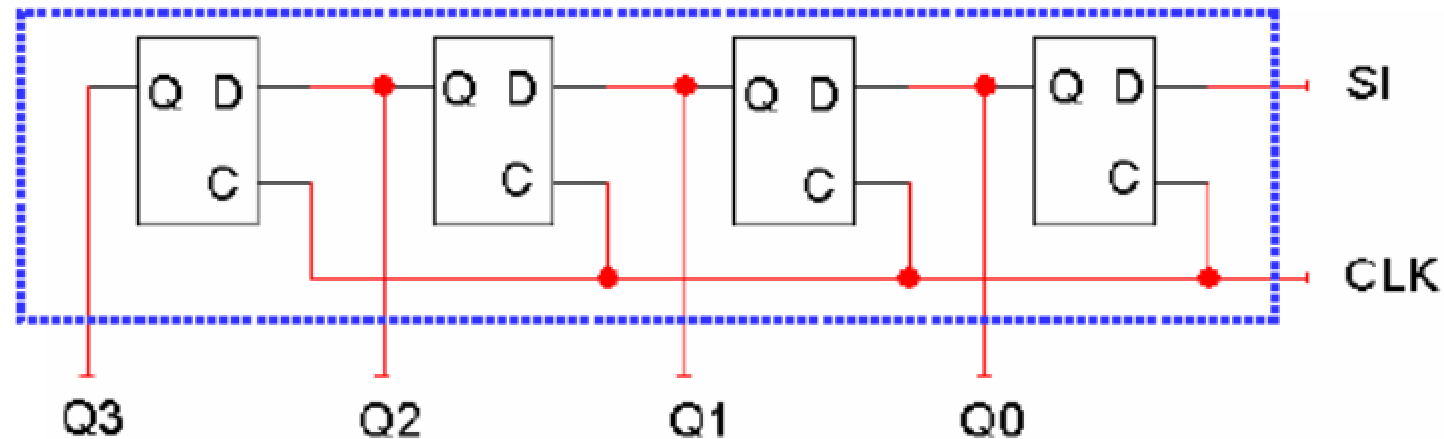
A better parallel load

- Another idea is to modify the flip-flop D inputs and not the clock signal.
  - When LD = 0 the flip-flop inputs are Q3-Q0, so each flip-flop keeps its current value.
  - When LD = 1 the flip-flop inputs are D3-D0, so this new value is loaded into the register.



Shift registers (Left Shift)

- A shift register "shifts" its output once every clock cycle. SI is an input that supplies a new bit to shift "into" the register.



Q0(t+1) = SI
Q1(t+1) = Q0(t)
Q2(t+1) = Q1(t)
Q3(t+1) = Q2(t)

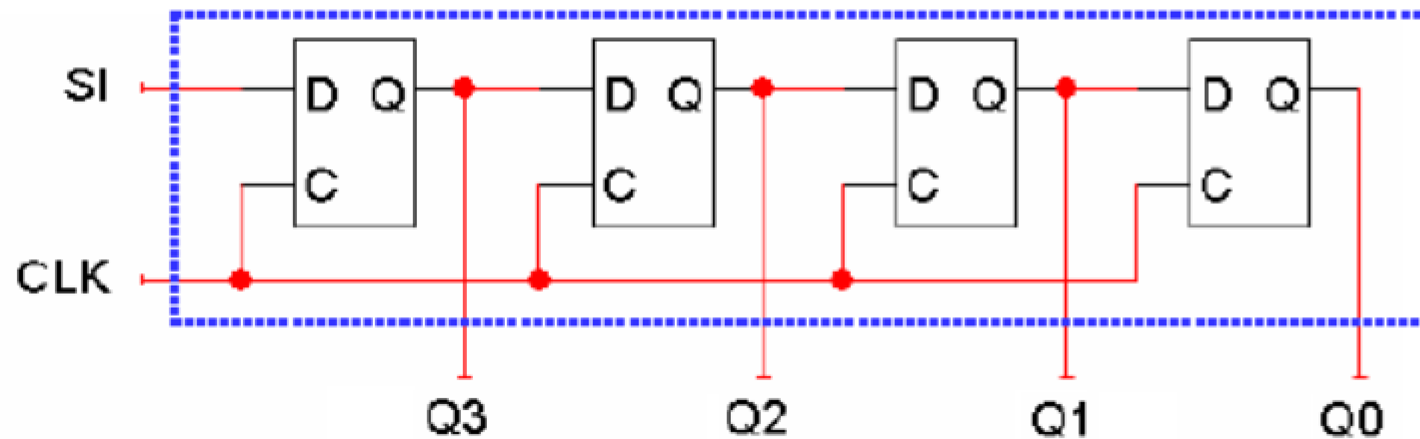
- Here is one example transition.

Present State Q3-Q0	Input SI	Next State Q3-Q0
0110	1	1101

- The current Q3 (0 in this example) will be lost on the next cycle.

Shift registers (Right Shift)

- A shift register "shifts" its output once every clock cycle. SI is an input that supplies a new bit to shift "into" the register.



- Here is one example transition.

Present State Q3-Q0	Input SI	Next State Q3-Q0
0110	1	1011

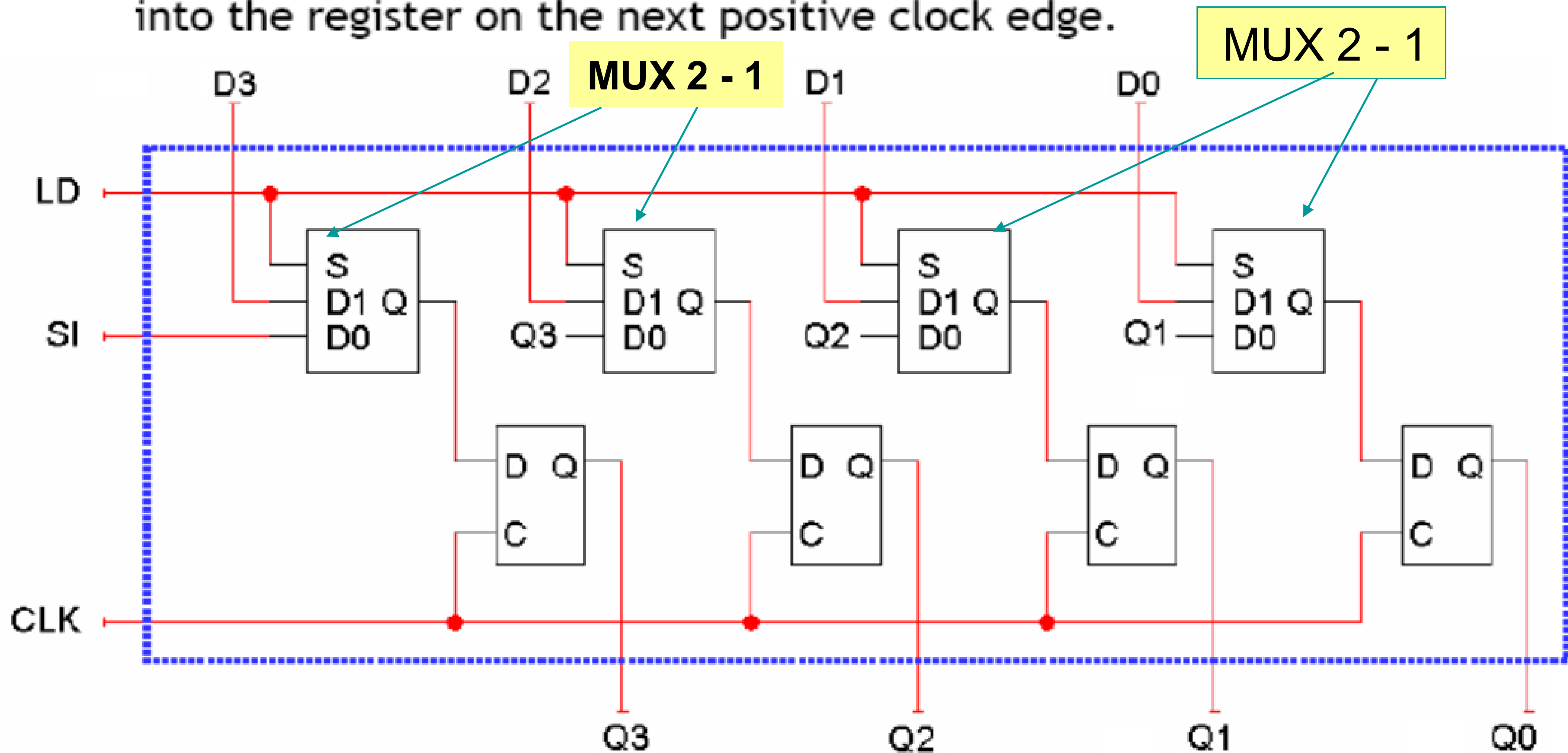
- The current Q0 (0 in this example) will be lost on the next cycle.

Shift registers with parallel load

- We can add a parallel load operation, just as we did for regular registers.

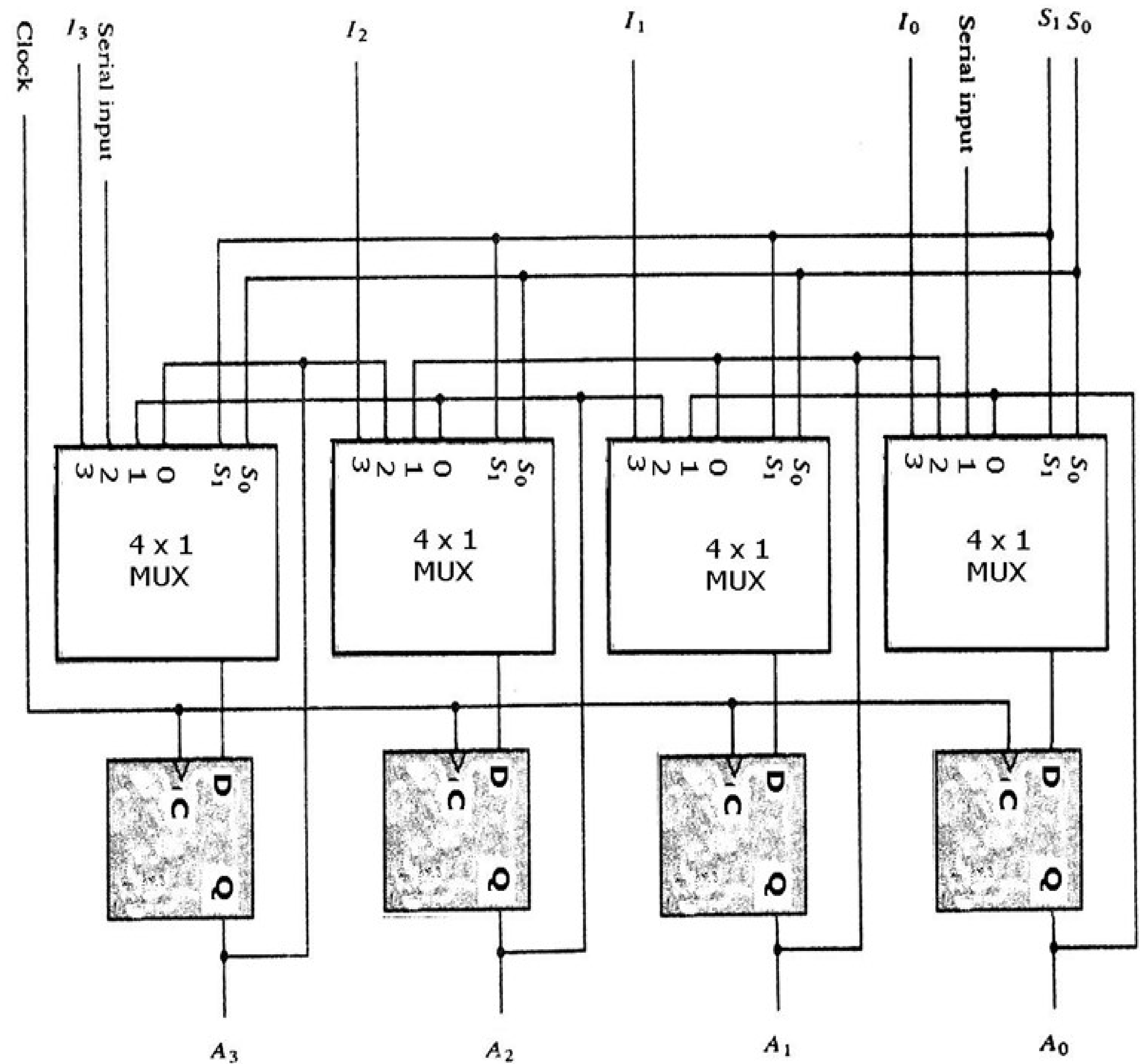
Serial
  - When LD = 0 the flip-flop inputs will be SIQ3Q2Q1, so the register will shift on the next positive clock edge.

Parallel
  - When LD = 1, the flip-flop inputs are D0-D3, and a new value is loaded into the register on the next positive clock edge.



A Bidirectional Shift Register with parallel load

S1	S0	Operation
0	0	No change
0	1	Shift left
1	0	Shift right
1	1	Parallel load

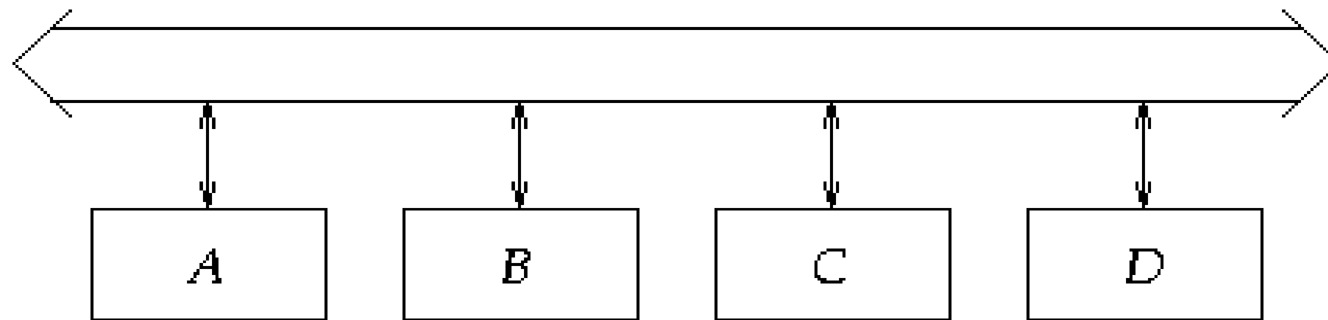


Other types of shift registers

- Logical shifts – Standard shifts like we just saw. In the absence of a SI input, 0 occupies the vacant position.
  - Left: 0110 -> 1100
  - Right: 0110 -> 0011
- Circular shifts (also called ring counters or rotates) – The shifted out bit wraps around to the vacant position.
  - Left: 1001 -> 0011
  - Right: 1001 -> 1100
- Switch-tail ring counter (aka Johnson counter) – Similar to the ring counter, but the serial input is the complement of the serial output.
  - Left: 1001 -> 0010
  - Right: 1001 -> 0100
- Arithmetical shifts – Left shifting is the same as a logical shift. Right shifting however maintains the MSB.
  - Left: 0110 -> 1100
  - Right: 0110 -> 0011;   1011 -> 1101

Bus-based Data transfers

- The computer need several registers
  - Bus is the Path for data transfer among registers
  - A bus consists of a set of parallel data lines



Multiplexer-based bus construction

Figure 4-3 Bus system for four registers.

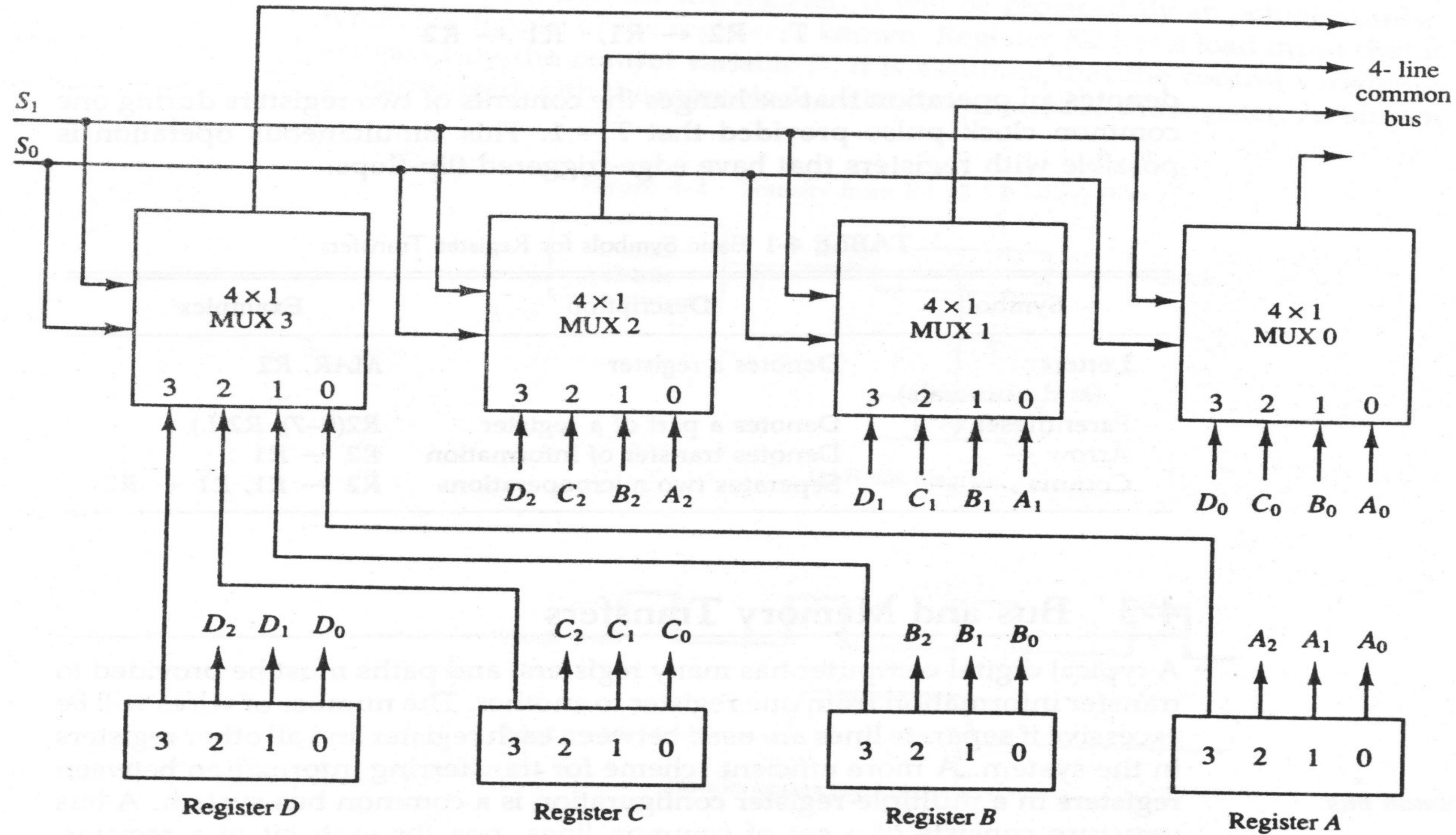
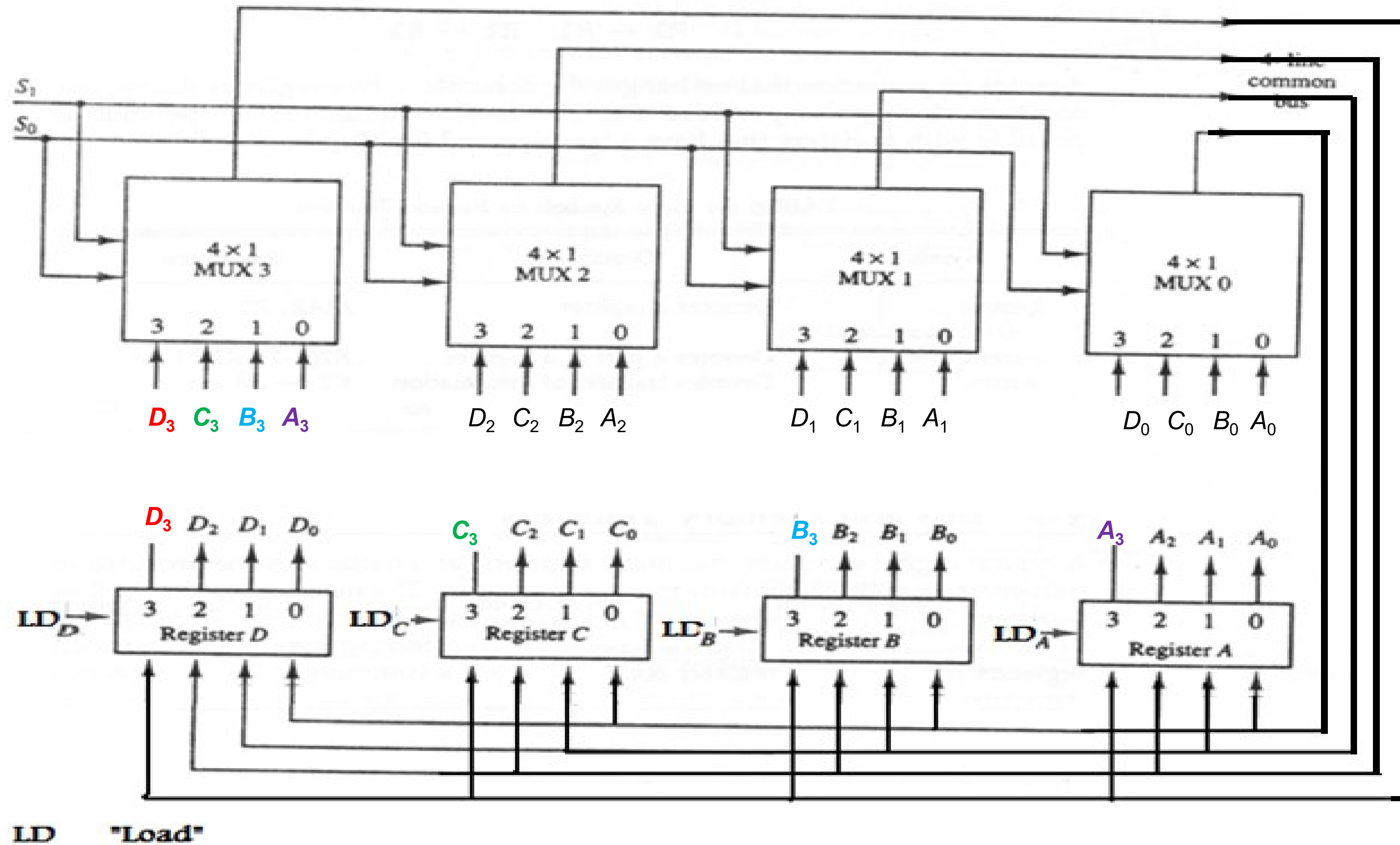


TABLE 4-2 Function Table for Bus of Fig. 4-3

S_1	S_0	Register selected
0	0	*A*
0	1	*B*
1	0	*C*
1	1	*D*

Bus-based transfers for multiple registers



To transfer data using a bus:

- connect the output of the source register to the bus;
- connect the input of the target register to the bus;
- when the clock pulse arrives, the transfer occurs

Examples: Bus-based transfers

S1	S0	LD_A	LD_B	LD_C	LD_D	Operation
0	0	0	1	0	0	Register B ← Register A
1	1	1	0	0	0	Register A ← Register D
0	0	0	1	1	0	Register B ← Register A; Register C ← Register A

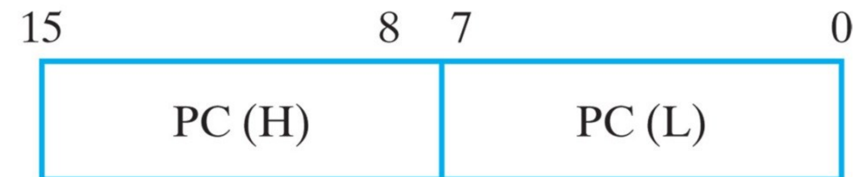
Register Transfer Language

- **Micro operations** (micro-ops) are operations on data stored in registers
- **Register transfer language (RTL)** is a concise and precise means of describing those operations
- **RTL expressions** are made up of elements which describe the registers being manipulated, and the micro-ops being performed on them
- Registers are denoted by uppercase letters (sometimes followed by numbers) that indicate the function of the register
  - e.g. R0, R1, AR, PC, MAR, et al.
  - The individual bits can be denoted using parenthesis and bit numbers or labels
    - e.g. R0(0), R0(7:0), PC(L), PC(H)

(a) Register R

(b) Individual bits of 8-bit register

(c) Numbering of 16-bit register



(d) Two-part 16-bit register

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Register Transfer Language

TABLE 6-1
Basic Symbols for Register Transfers

Symbol	Description	Examples
Letters (and numerals)	Denotes a register	$AR, R2, DR, IR$
Parentheses	Denotes a part of a register	$R2(1), R2(7:0), AR(L)$
Arrow	Denotes transfer of data	$R1 \leftarrow R2$
Comma	Separates simultaneous transfers	$R1 \leftarrow R2, R2 \leftarrow R1$
Square brackets	Specifies an address for memory	$DR \leftarrow M[AR]$

Destination register ← Source register:

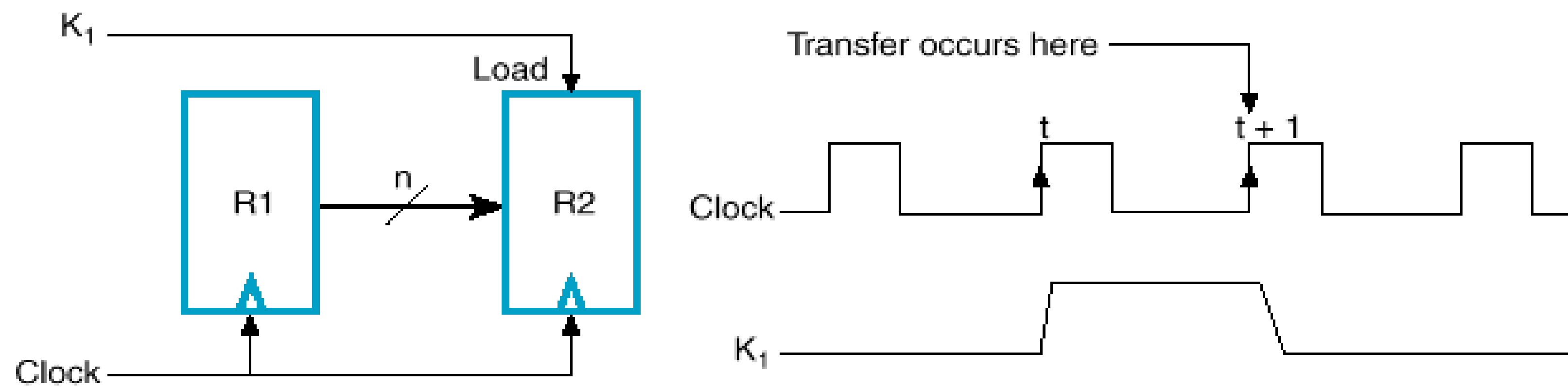
- Data in source register does not change
- A datapath are available from the outputs of the source register to the inputs of the destination register
- The destination register has a parallel load capability
- All RTL statements occur in response to a **clock tick**
- Normally we want a given transfer to occur not for every clock pulse, but only for specific values of the control signals

Register Transfer Language

- RTL conditional statements:
  - e.g. If (K1 = 1) Then (R2 ← R1)

Control function notation (Colon, :)

  - e.g. K1: R2 ← R1



Register transfer operations

- We can apply arithmetic operations to registers.

$$R1 \leftarrow R2 + R3$$
$$R3 \leftarrow R1 - 1$$

- **Every RTL statement** written in register-transfer notation presupposes a hardware construct for implementing the transfer.

TABLE 6-3
Arithmetic Microoperations

Symbolic Designation	Description
$R0 \leftarrow R1 + R2$	Contents of $R1$ plus $R2$ transferred to $R0$
$R2 \leftarrow \overline{R2}$	Complement of the contents of $R2$ (1s complement)
$R2 \leftarrow \overline{R2} + 1$	2s complement of the contents of $R2$
$R0 \leftarrow R1 + \overline{R2} + 1$	$R1$ plus 2s complement of $R2$ transferred to $R0$ (subtraction)
$R1 \leftarrow R1 + 1$	Increment the contents of $R1$ (count up)
$R1 \leftarrow R1 - 1$	Decrement the contents of $R1$ (count down)

Register Transfer Language

Bitwise operations:

- Most computers also support logical operations like AND, OR and NOT, but extended to multi-bit words instead of just single bits.
- To apply a logical operation to two words X and Y, apply the operation on each pair of bits X_i and Y_i:

```
     1 0 1 1          1 0 1 1          1 0 1 1
 AND 1 1 1 0      OR  1 1 1 0      XOR 1 1 1 0
 -----------      -----------      -----------
     1 0 1 0          1 1 1 1          0 1 0 1
```

- Single operand logical operation: "complementing" all the bits in a number.

```
 NOT 1 0 1 1
 -----------
     0 1 0 0
```

TABLE 6-4
Logic Microoperations

Symbolic Designation	Description
$R0 \leftarrow \overline{R1}$	Logical bitwise NOT (1s complement)
$R0 \leftarrow R1 \wedge R2$	Logical bitwise AND (clears bits)
$R0 \leftarrow R1 \vee R2$	Logical bitwise OR (sets bits)
$R0 \leftarrow R1 \oplus R2$	Logical bitwise XOR (complements bits)

Bitwise operations in programming

- Languages like C, C++ and Java provide bitwise logical operations:

  & (AND) | (OR) ^ (XOR) ~ (NOT)

- These operations treat each integer as a bunch of individual bits:

  13 & 25 = 9 because 01101 & 11001 = 01001

- They are *not* the same as the operators &&, || and !, which treat each integer as a single logical value (0 is false, everything else is true):

  13 && 25 = 1 because true && true = true

- Bitwise operators are often used in programs to set a bunch of Boolean options, or flags, with one argument.
- Easy to represent sets of fixed universe size with bits:
  - 1: is member, 0 not a member. Unions: OR, Intersections: AND

Register transfer operations

- Finally, we can shift values left or right by one bit. The source register is not modified, and we assume that the shift input is always 0.

TABLE 6-5
Examples of Shifts

		Eight-Bit Examples	
Type	**Symbolic Designation**	**Source $R2$**	**After Shift: Destination $R1$**
Shift left	$R1 \leftarrow \text{sl } R2$	10011110	00111100
Shift right	$R1 \leftarrow \text{sr } R2$	11100101	01110010