

Intro to Digital Design

Karnaugh Maps

Instructor: Chris Thachuk

Teaching Assistants:

Eujean Lee

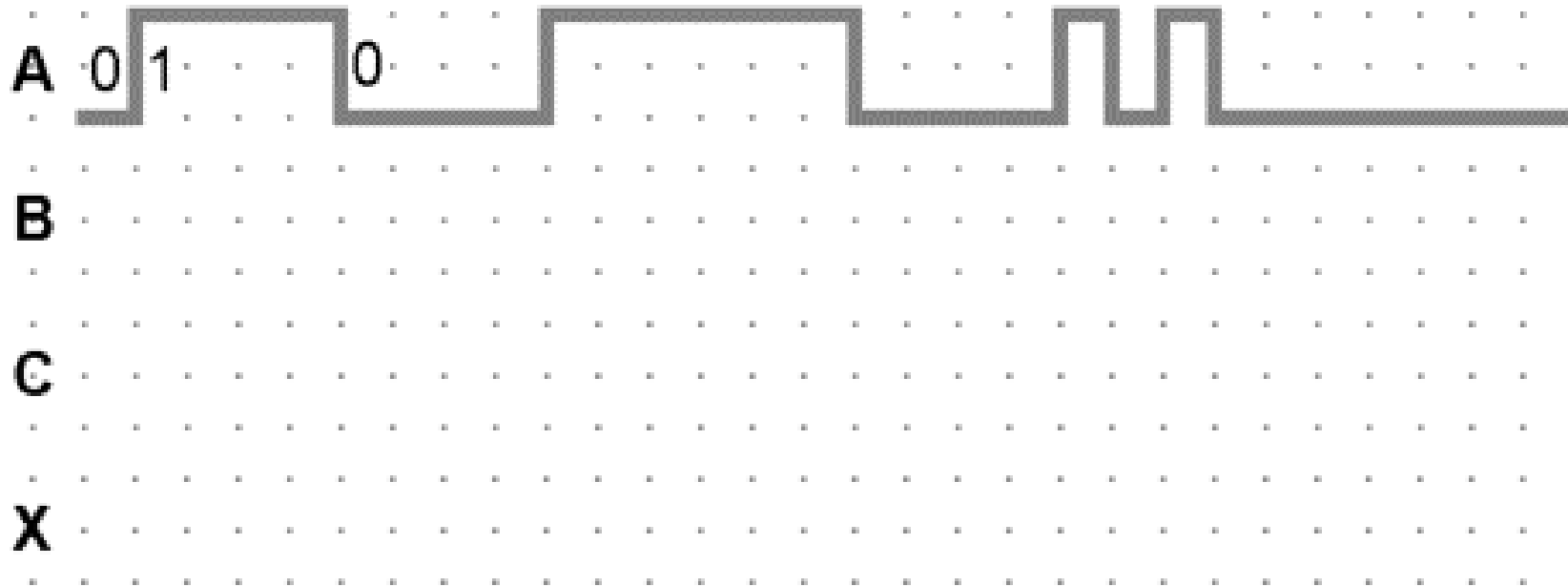
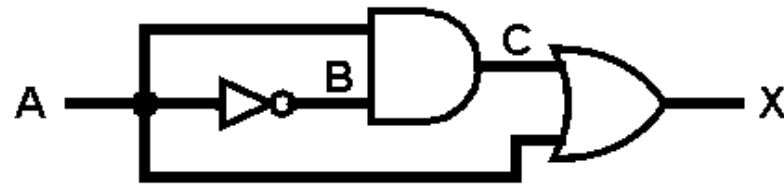
Nandini Talukdar

Stephanie Osorio-Tristan

Wen Li

Question:

- ❖ Let the CL delays be 1 tick (NOT) and 3 ticks (AND, OR). How many ticks is the signal X high?



Relevant Course Information

- ❖ Lab 1 & 2 Demos due during your assigned demo slots
 - Don't forget to submit your lab materials *before* Wednesday at 2:30 pm, regardless of your demo time
- ❖ Lab 3 – Logic simplification in Verilog
 - Get practice with K-maps
 - Full credit for minimal logic
- ❖ Quiz #1 – 10/29 during lecture time

Lecture Outline

- ❖ **Karnaugh Maps (K-maps)**
- ❖ Design Examples

On and Off Sets

❖ *On Set* is the set of input patterns where the function is TRUE

■ Here on set = $\{\bar{A}\bar{B}C, \bar{A}BC, A\bar{B}\bar{C}, A\bar{B}C\}$

❖ *Off Set* is the set of input patterns where the function is FALSE

■ Here off set = $\{\bar{A}\bar{B}\bar{C}, \bar{A}B\bar{C}, A\bar{B}\bar{C}, ABC\}$

❖ **Recall:** Use the On Set for *Sum of Products (SoP)* and the Off Set for *Product of Sums (PoS)*

■ Considered **two-level** Boolean expressions

A	B	C	F
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	0

Two-Level Simplification

- ❖ Using Sum of Products, “neighboring” input combinations simplify
 - “Neighboring”: inputs that differ by a single signal
 - *The Uniting Theorem*: $A(\bar{B} + B) = A$
 - *e.g.*, $AB + \bar{A}B = B$, $\bar{A}BC + \bar{A}B\bar{C} = \bar{A}B$
- ❖ **Goal**: Find neighboring subsets of the On Set to eliminate variables and simplify the expression
- ❖ **Idea**: Let’s write out our Truth Table such that the neighbors become apparent!
 - Need a Karnaugh map for *EACH* output

Karnaugh Maps

- ❖ A **K-map** is a method of representing a truth table that helps visualize adjacencies in ≤ 4 dimensions
 - For more dimensions, computer-based methods are needed
- 1) Split inputs into 2 *evenly-sized* groups
 - One group will have an extra if an odd # of inputs
- 2) Write out all combinations of each group on each axis Group of n inputs $\rightarrow 2^n$ combinations
 - **Successive combinations change only 1 input (Gray code)**

2 Inputs:

		B	
		0	1
A	0		
	1		

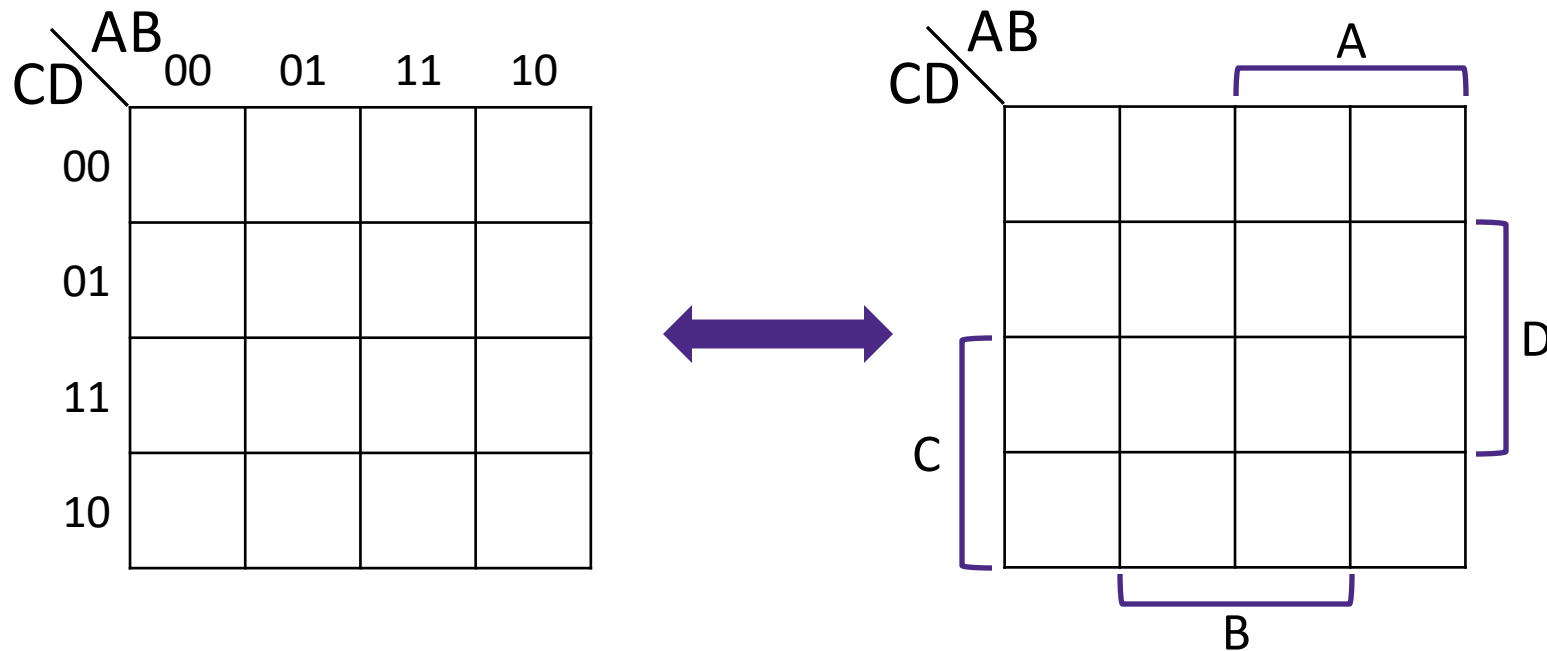
3 Inputs:

		AB			
		00	01	11	10
C	0				
	1				

Karnaugh Maps

❖ Also see visualization with brackets for “asserted” simplifications:

4 Inputs:



K-map Example: Majority Circuit

- ❖ Filling in a Karnaugh map:

A	B	C	F
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

		AB			
		00	01	11	10
C	0				
	1				

- ❖ Each row of truth table corresponds to ONE cell of Karnaugh map
- ❖ Note the jump when you go from input 011 to 100
(*most mistakes made here*)

K-map Example: Majority Circuit

- ❖ Filling in alternate Karnaugh map:

A	B	C	F
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

		BC			
		00	01	11	10
A	0				
	1				

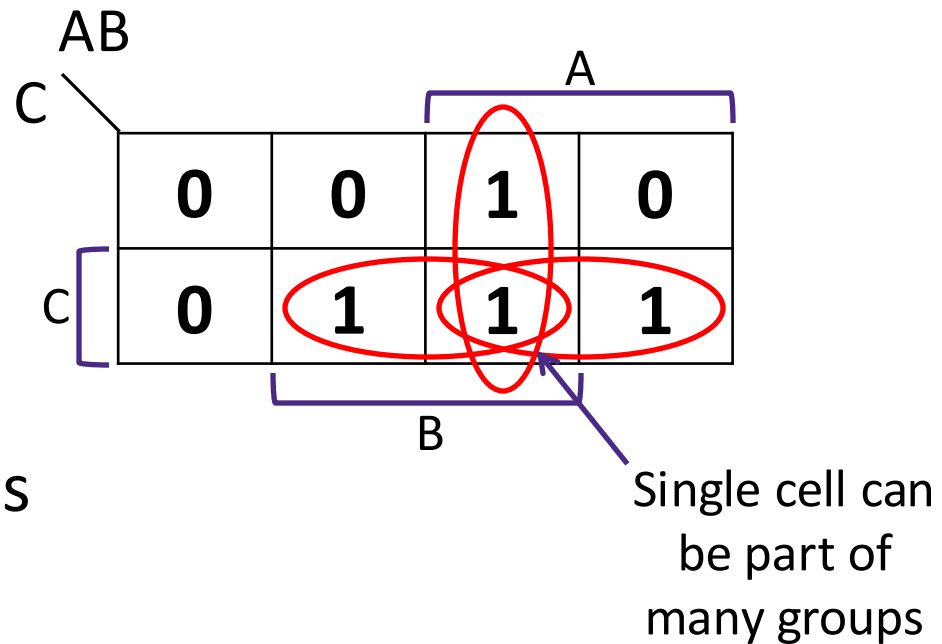
- ❖ Each row of truth table corresponds to ONE cell of Karnaugh map
- ❖ Note the jump when you go from input 001 to 010 and 101 to 110
(*most mistakes made here*)

K-map Simplification

- ❖ Group neighboring 1's so all are accounted for:
 - Each group of neighbors becomes a product term in the output

- ❖ $F = BC + AB + AC$

- ❖ Larger groups become smaller terms
 - The single 1 in top row $\rightarrow ABC\bar{C}$
 - Vertical group of two 1's $\rightarrow AB$
 - If entire lower row was 1's $\rightarrow C$



General K-map Rules

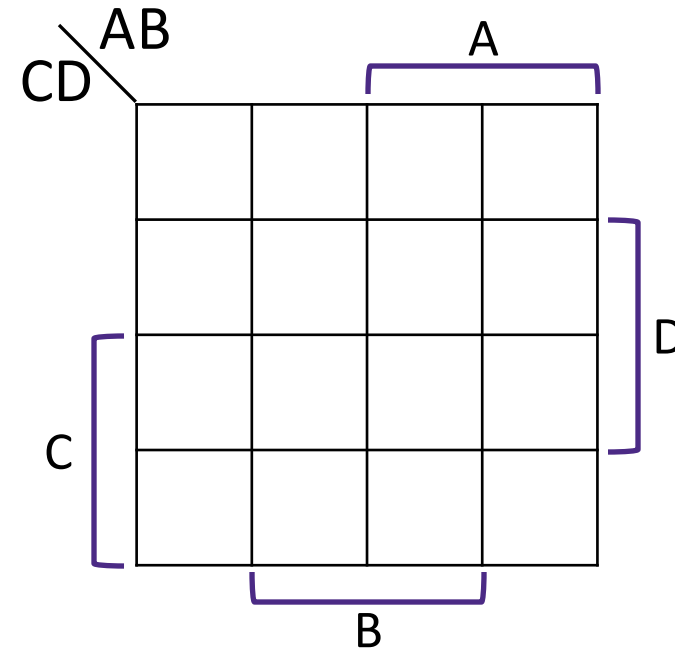
- ❖ Only group in powers of 2
 - Grouping should be of size $2^i \times 2^j$
 - Applies for both directions
- ❖ Wraps around in all directions
 - “Corners” case is extreme example
- ❖ Always choose largest groupings possible
 - Avoid single cells whenever possible
- ❖ $F = BD + \overline{B}\overline{D} + ACD$

		AB			
		00	01	11	10
CD	00	1	0	0	1
	01	0	1	1	0
	11	0	1	1	1
	10	1	0	0	1

- 1) NOT a valid group
- 2) IS a valid group
- 3) IS a valid group
- 4) “Corners” case
- 5) 1 of 2 good choices here

K-Map Example

$$\diamond F = \bar{A}D + BD + \bar{B}C + A\bar{B}D$$

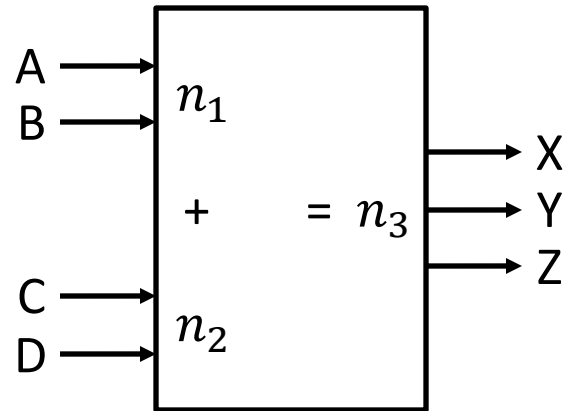


Lecture Outline

- ❖ Karnaugh Maps (K-maps)
- ❖ **Design Examples**

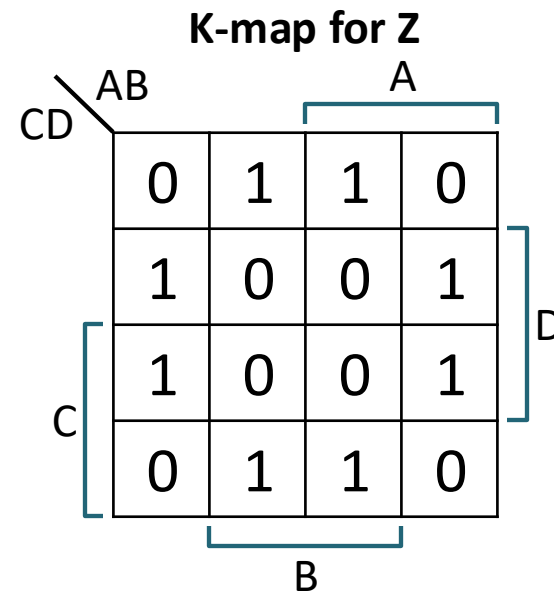
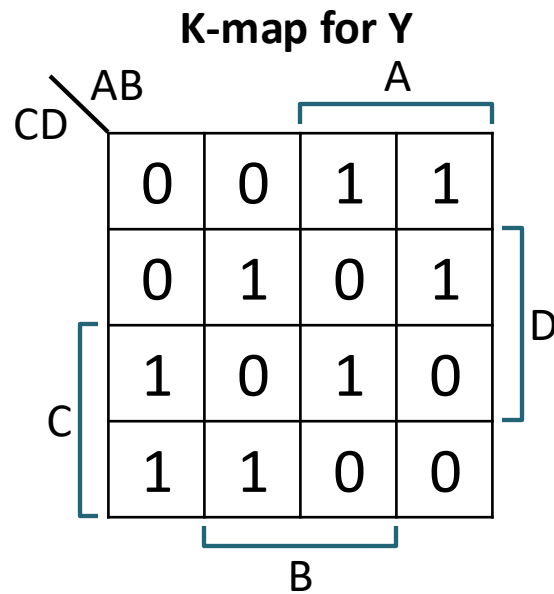
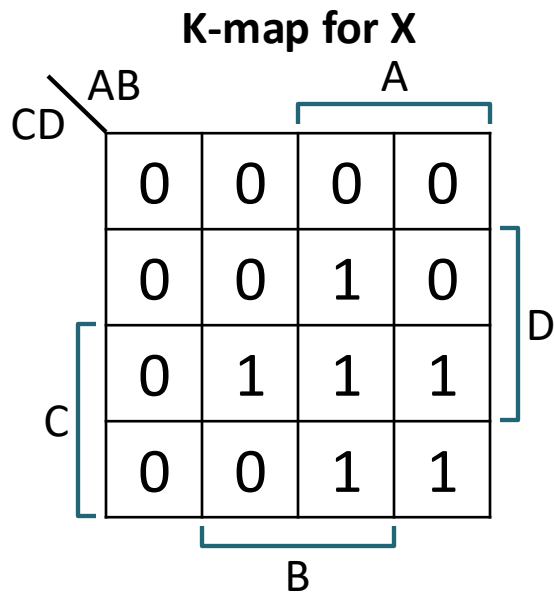
Design Example: 2-bit Adder

- ❖ Block Diagram and Truth Table:



A	B	C	D	X	Y	Z
0	0	0	0	0	0	0
0	0	0	1	0	0	1
0	0	1	0	0	1	0
0	0	1	1	0	1	1
0	1	0	0	0	0	1
0	1	0	1	0	1	0
0	1	1	0	0	1	1
0	1	1	1	1	0	0
1	0	0	0	0	1	0
1	0	0	1	0	1	1
1	0	1	0	1	0	0
1	0	1	1	1	0	1
1	1	0	0	0	1	1
1	1	0	1	1	0	0
1	1	1	0	1	0	1
1	1	1	1	1	1	0

Design Example: 2-bit Adder



X =

Y =

Z =

Technology Break

Don't Cares

- ❖ Use symbol 'X' to mean it can be either a 0 or 1
 - Make choice to simplify final expression

	AB		A		
CD	0	0	X	0	
	1	1	X	1	D
	1	1	0	0	
C	0	X	0	0	
	B				

Let all X = 0:

F =

	AB		A		
CD	0	0	X	0	
	1	1	X	1	D
	1	1	0	0	
C	0	X	0	0	
	B				

Let all X = 1:

F =

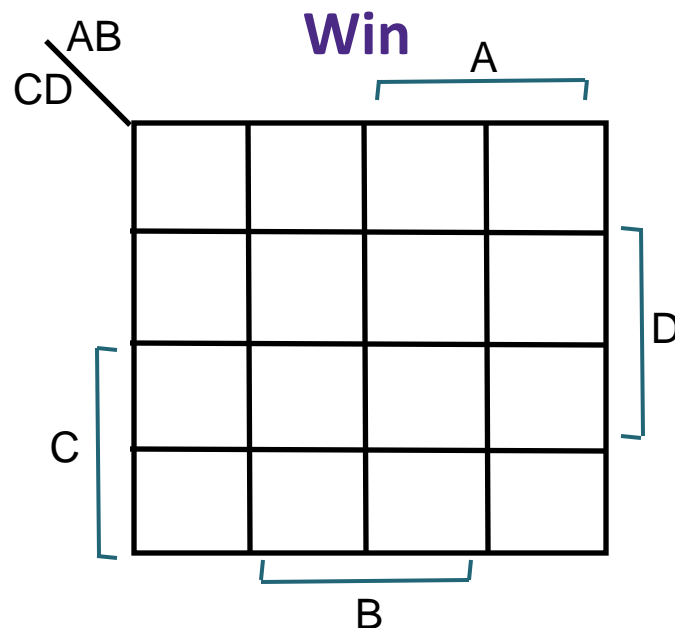
	AB		A		
CD	0	0	X	0	
	1	1	X	1	D
	1	1	0	0	
C	0	X	0	0	
	B				

Choose wisely:

F =

Design Example: Rock-Paper-Scissors

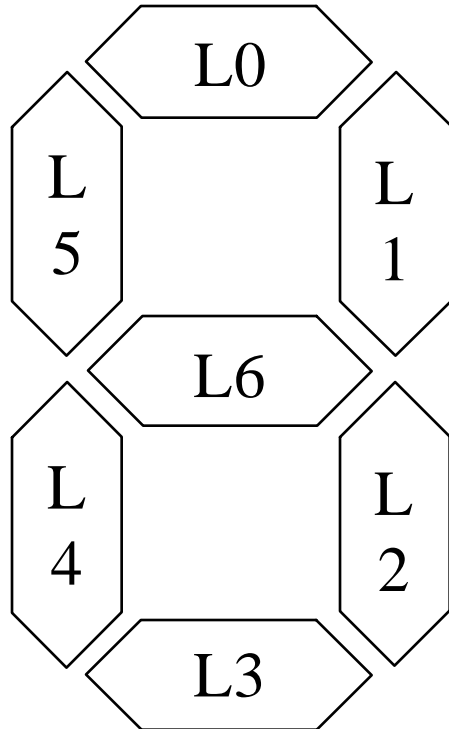
- ❖ Rock (00), Paper (01), Scissors (10) for two players P0 and P1
- ❖ **Output:** Win = Winner's ID (0/1)
Tie = 1 if Tie, 0 else



P1		P0		Win	Tie
A	B	C	D		
0	0	0	0		
0	0	0	1		
0	0	1	0		
0	0	1	1		
0	1	0	0		
0	1	0	1		
0	1	1	0		
0	1	1	1		
1	0	0	0		
1	0	0	1		
1	0	1	0		
1	0	1	1		
1	1	0	0		
1	1	0	1		
1	1	1	0		
1	1	1	1		

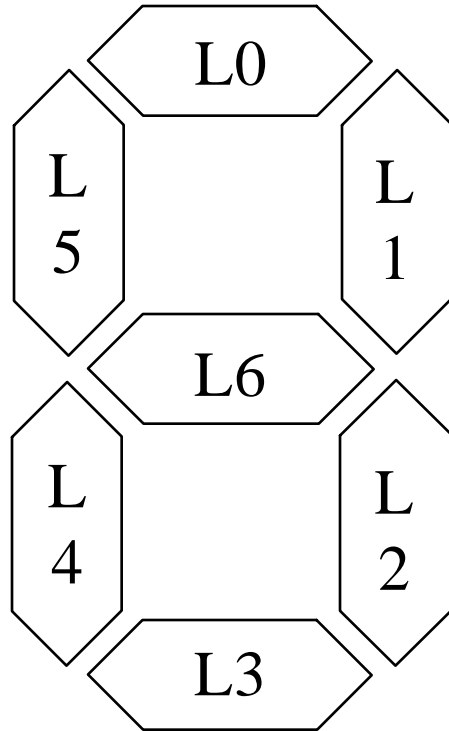
Case Study: Seven-Segment Display

- ❖ Chip to drive digital display

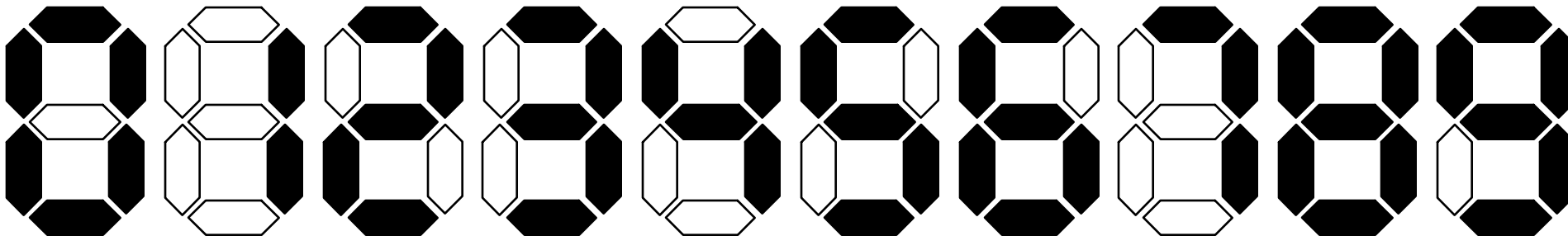


B3	B2	B1	B0
0	0	0	0
0	0	0	1
0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0

Case Study: Seven-Segment Display



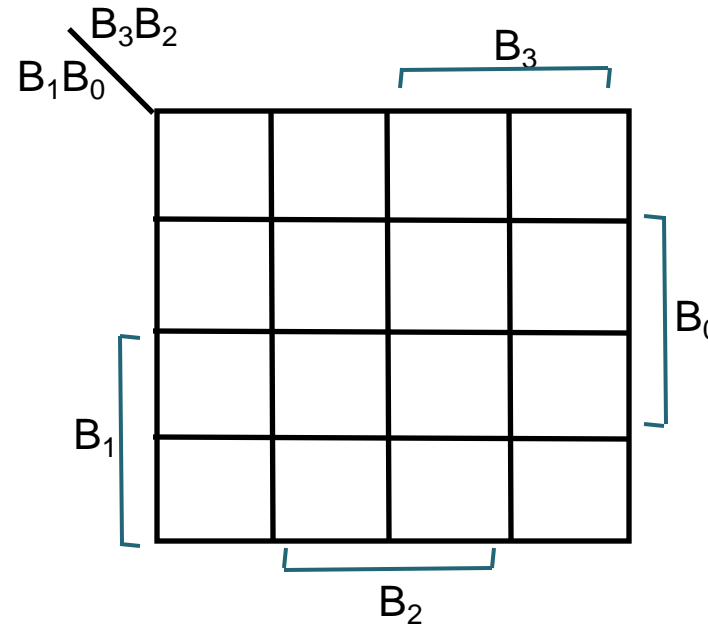
B3	B2	B1	B0	Val	L0	L1	L2	L3	L4	L5	L6
0	0	0	0	0	1	1	1	1	1	1	0
0	0	0	1	1	0	1	1	0	0	0	0
0	0	1	0	2	1	1	0	1	1	0	1
0	0	1	1	3	1	1	1	1	0	0	1
0	1	0	0	4	0	1	1	0	0	1	1
0	1	0	1	5	1	0	1	1	0	1	1
0	1	1	0	6	1	0	1	1	1	1	1
0	1	1	1	7	1	1	1	0	0	0	0
1	0	0	0	8	1	1	1	1	1	1	1
1	0	0	1	9	1	1	1	1	0	1	1



Case Study: Seven-Segment Display

❖ Implement L5:

B3	B2	B1	B0	L5
0	0	0	0	1
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	0
1	0	0	0	1
1	0	0	1	1



7-Seg Display in Verilog

```
module seg7 (bcd, leds);
  input  logic [3:0] bcd;
  output logic [6:0] leds;

  always_comb
    case (bcd)
      // 3210           6543210
      4'b0000: leds = 7'b0111111;
      4'b0001: leds = 7'b0000110;
      4'b0010: leds = 7'b1011011;
      4'b0011: leds = 7'b1001111;
      4'b0100: leds = 7'b1100110;
      4'b0101: leds = 7'b1101101;
      4'b0110: leds = 7'b1111101;
      4'b0111: leds = 7'b0000111;
      4'b1000: leds = 7'b1111111;
      4'b1001: leds = 7'b1101111;
      default: leds = 7'bX;
    endcase
endmodule
```

Procedural Blocks

- ❖ `assign`: continuous assignment
 - Used with wires
 - *e.g.*, `assign F = ~((A & B) | (C & D));`
- ❖ `initial`: executes once at time zero
 - Set initial values (**generally simulation only!!!**)
 - Define testbench waveforms (and monitor)
 - *e.g.*, `initial`

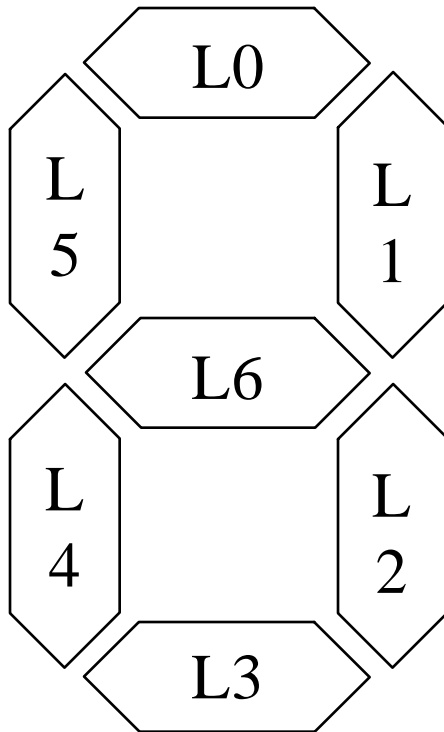
```
    for (i = 0; i < 8; i = i+1) begin
        {SEL, I, J} = i;    #10;
    end
```


Procedural Blocks

- ❖ `always`: loop to execute over and over again
 - Block gets triggered by a *sensitivity list*
 - Any object that is assigned a value in an `always` statement must be declared as a variable (`reg/logic`).
 - Examples:
 - `always @ (a or b or c) ↔ always @ (a, b, c)`
 - `always @ (*)` implicitly contains all read signals within the block
- ❖ `always_comb`: special SystemVerilog for CL
 - Similar to `always @ (*)`, but generally more robust
 - *Only for use with combinational logic!!!*

Verilog: Extend 7-Seg to Hex

- ❖ Show “A” on 0b1010 (ten) to “F” on 0b1111 (fifteen)



```
module seg7 (bcd, leds);
  input logic [3:0] bcd;
  output logic [6:0] leds;

  always_comb
    case (bcd)
      // 3210           6543210
      4'b0000: leds = 7'b0111111;
      4'b0001: leds = 7'b0000110;
      4'b0010: leds = 7'b1011011;
      4'b0011: leds = 7'b1001111;
      4'b0100: leds = 7'b1100110;
      4'b0101: leds = 7'b1101101;
      4'b0110: leds = 7'b1111101;
      4'b0111: leds = 7'b0000111;
      4'b1000: leds = 7'b1111111;
      4'b1001: leds = 7'b1101111;
      default: leds = 7'bX;
    endcase
endmodule
```

Circuit Implementation Techniques

- ❖ **Truth Tables** – “Black box” circuit description
- ❖ **Boolean Algebra** – Math form for optimization
 - *K-Maps* – Alternate simplification technique
- ❖ **Circuit Diagrams** – TTL Implementations
- ❖ **Verilog** – Simulation & mapping to FPGAs