CHAPTER III

BOOLEAN ALGEBRA

BOOLEAN VALUES

INTRODUCTION

- Boolean algebra is a form of algebra that deals with single digit binary values and variables.
- Values and variables can indicate some of the following binary pairs of values:
    - ON / OFF
    - TRUE / FALSE
    - HIGH / LOW
    - CLOSED / OPEN
    - 1 / 0

BOOL. OPERATIONS

FUNDAMENTAL OPERATORS

- Three fundamental operators in Boolean algebra
  - **NOT**: unary operator that complements represented as $\overline{\mathbf{A}}$, $\mathbf{A}'$, or $\sim \mathbf{A}$
  - **AND**: binary operator which performs logical multiplication
    - i.e. **A** ANDed with **B** would be represented as **AB** or $\mathbf{A} \cdot \mathbf{B}$
  - **OR**: binary operator which performs logical addition
    - i.e. **A** ORed with **B** would be represented as $\mathbf{A} + \mathbf{B}$

NOT

A	$\overline{A}$
0	1
1	0

AND

A	B	AB
0	0	0
0	1	0
1	0	0
1	1	1

OR

A	B	A + B
0	0	0
0	1	1
1	0	1
1	1	1

BOOL. OPERATIONS

BINARY BOOLEAN OPERATORS

- Below is a table showing all possible Boolean functions $\mathbf{F_N}$ given the two-inputs **A** and **B**.

A	B	F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}
0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
1	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

- F_0: 0 — **Null**
- F_1: AB
- F_2, F_4: **Inhibition**
- F_3: A
- F_5: B
- F_6: $A \oplus B$
- F_7: $A + B$
- F_8: $\overline{A + B}$
- F_9: $\overline{A \oplus B}$
- F_{10}: $\overline{B}$
- F_{11}, F_{13}: **Implication**
- F_{12}: $\overline{A}$
- F_{14}: $\overline{AB}$
- F_{15}: 1 — **Identity**

BOOLEAN ALGEBRA

PRECEDENCE OF OPERATORS

- Boolean expressions must be evaluated with the following order of operator precedence
    - parentheses
    - NOT
    - AND
    - OR

Example:

$$F = (A(\overline{C + \bar{B}D}) + \overline{B\bar{C}})\bar{E}$$

$$F = \left(A \left(\overline{C + \bar{B}\, D} \right) + \overline{B\, \bar{C}} \right) \bar{E}$$

BOOLEAN ALGEBRA

FUNCTION EVALUATION

- Example 1:

Evaluate the following expression when $\mathbf{A} = \mathbf{1}, \mathbf{B} = \mathbf{0}, \mathbf{C} = \mathbf{1}$

$$\mathbf{F} = \mathbf{C} + \overline{\mathbf{C}}\mathbf{B} + \mathbf{B}\overline{\mathbf{A}}$$

- Solution

$$\mathbf{F} = \mathbf{1} + \overline{\mathbf{1}} \cdot \mathbf{0} + \mathbf{0} \cdot \overline{\mathbf{1}} = \mathbf{1} + \mathbf{0} + \mathbf{0} = \mathbf{1}$$

- Example 2:

Evaluate the following expression when $\mathbf{A} = \mathbf{0}, \mathbf{B} = \mathbf{0}, \mathbf{C} = \mathbf{1}, \mathbf{D} = \mathbf{1}$

$$\mathbf{F} = \mathbf{D}(\mathbf{B}\overline{\mathbf{C}}\mathbf{A} + \overline{(\mathbf{A}\overline{\mathbf{B}} + \mathbf{C})} + \mathbf{C})$$

- Solution

$$\mathbf{F} = \mathbf{1} \cdot (\mathbf{0} \cdot \overline{\mathbf{1}} \cdot \mathbf{0} + \overline{(\mathbf{0} \cdot \overline{\mathbf{0}} + \mathbf{1})} + \mathbf{1}) = \mathbf{1} \cdot (\mathbf{0} + \overline{\mathbf{1}} + \mathbf{1}) = \mathbf{1} \cdot \mathbf{1} = \mathbf{1}$$

BOOLEAN ALGEBRA

BASIC IDENTITIES

$X + 0 = X$	$X \cdot 1 = X$	Identity
$X + 1 = 1$	$X \cdot 0 = 0$	
$X + X = X$	$X \cdot X = X$	Idempotent Law
$X + X' = 1$	$X \cdot X' = 0$	Complement
$(X')' = X$		Involution Law
$X + Y = Y + X$	$XY = YX$	Commutativity
$X + (Y + Z) = (X + Y) + Z$	$X(YZ) = (XY)Z$	Associativity
$X(Y + Z) = XY + XZ$	$X + YZ = (X + Y)(X + Z)$	Distributivity
$X + XY = X$	$X(X + Y) = X$	Absorption Law
$X + X'Y = X + Y$	$X(X' + Y) = XY$	Simplification
$(X + Y)' = X'Y'$	$(XY)' = X' + Y'$	DeMorgan's Law
$XY + X'Z + YZ = XY + X'Z$	$(X + Y)(X' + Z)(Y + Z) = (X + Y)(X' + Z)$	Consensus Theorem

BOOLEAN ALGEBRA

DUALITY PRINCIPLE

- **Duality principle:**
  - States that a Boolean equation remains valid if we take the dual of the expressions on both sides of the equals sign.
  - The dual can be found by interchanging the **AND** and **OR** operators along with also interchanging the **0**'s and **1**'s.
  - This is evident with the duals in the basic identities.
    - For instance: DeMorgan's Law can be expressed in two forms

$$(\mathbf{X}+\mathbf{Y})' = \mathbf{X}'\mathbf{Y}' \quad \text{as well as} \quad (\mathbf{X}\mathbf{Y})' = \mathbf{X}'+\mathbf{Y}'$$

BOOLEAN ALGEBRA

FUNCTION MANIPULATION (1)

- Example: Simplify the following expression

$$\mathbf{F} = \mathbf{BC} + \mathbf{B\overline{C}} + \mathbf{BA}$$

- Simplification

$$\mathbf{F} = \mathbf{B}(\mathbf{C} + \overline{\mathbf{C}}) + \mathbf{BA}$$

$$\mathbf{F} = \mathbf{B} \cdot \mathbf{1} + \mathbf{BA}$$

$$\mathbf{F} = \mathbf{B}(\mathbf{1} + \mathbf{A})$$

$$\mathbf{F} = \mathbf{B}$$

BOOLEAN ALGEBRA

FUNCTION MANIPULATION (2)

- Example: Simplify the following expression

$$F = A + \overline{A}B + \overline{A}\,\overline{B}C + \overline{A}\,\overline{B}\,\overline{C}D + \overline{A}\,\overline{B}\,\overline{C}\,\overline{D}E$$

- Simplification

$$F = A + \overline{A}(B + \overline{B}C + \overline{B}\,\overline{C}D + \overline{B}\,\overline{C}\,\overline{D}E)$$

$$F = A + B + \overline{B}C + \overline{B}\,\overline{C}D + \overline{B}\,\overline{C}\,\overline{D}E$$

$$F = A + B + \overline{B}(C + \overline{C}D + \overline{C}\,\overline{D}E)$$

$$F = A + B + C + \overline{C}D + \overline{C}\,\overline{D}E$$

$$F = A + B + C + \overline{C}(D + \overline{D}E)$$

$$F = A + B + C + D + \overline{D}E$$

$$F = A + B + C + D + E$$

BOOLEAN ALGEBRA

FUNCTION MANIPULATION (3)

- Example: Show that the following equality holds

$$\overline{A(\overline{B}\,\overline{C} + BC)} = \overline{A} + (B + C)(\overline{B} + \overline{C})$$

- Simplification

$$\overline{A(\overline{B}\,\overline{C} + BC)} = \overline{A} + \overline{(\overline{B}\,\overline{C} + BC)}$$

$$= \overline{A} + (\overline{\overline{B}\,\overline{C}})(\overline{BC})$$

$$= \overline{A} + (B + C)(\overline{B} + \overline{C})$$

STANDARD FORMS

SOP AND POS

- Boolean expressions can be manipulated into many forms.
- Some standardized forms are required for Boolean expressions to simplify communication of the expressions.
  - **Sum-of-products** (**SOP**)
    - Example:

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}) = \mathbf{AB} + \overline{\mathbf{B}}\mathbf{C}\overline{\mathbf{D}} + \mathbf{AD}$$

  - **Products-of-sums** (**POS**)
    - Example:

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}, \mathbf{D}) = (\mathbf{A} + \mathbf{B})(\overline{\mathbf{B}} + \mathbf{C} + \overline{\mathbf{D}})(\mathbf{A} + \mathbf{D})$$

STANDARD FORMS

MINTERMS

- The following table gives the minterms for a **three-input** system

			m_0	m_1	m_2	m_3	m_4	m_5	m_6	m_7
A	**B**	**C**	$\overline{A}\,\overline{B}\,\overline{C}$	$\overline{A}\,\overline{B}C$	$\overline{A}B\overline{C}$	$\overline{A}BC$	$A\overline{B}\,\overline{C}$	$A\overline{B}C$	$AB\overline{C}$	ABC
0	0	0	1	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0	0	0	0
0	1	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	1	0	0	0	0
1	0	0	0	0	0	0	1	0	0	0
1	0	1	0	0	0	0	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0
1	1	1	0	0	0	0	0	0	0	1

STANDARD FORMS

SUM OF MINTERMS

- **Sum-of-minterms** standard form expresses the Boolean or switching expression in the form of a **sum of products** using **minterms**.
  - For instance, the following Boolean expression using minterms

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \overline{\mathbf{A}}\,\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \overline{\mathbf{A}}\,\overline{\mathbf{B}}\mathbf{C} + \mathbf{A}\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \mathbf{A}\overline{\mathbf{B}}\mathbf{C}$$

could instead be expressed as

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = m_0 + m_1 + m_4 + m_5$$

or more compactly

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \sum m(0, 1, 4, 5) = \textit{one-set}(0, 1, 4, 5)$$

STANDARD FORMS

MAXTERMS

- The following table gives the maxterms for a **three-input** system

A	B	C	M_0 $A + B + C$	M_1 $A + B + \overline{C}$	M_2 $A + \overline{B} + C$	M_3 $A + \overline{B} + \overline{C}$	M_4 $\overline{A} + B + C$	M_5 $\overline{A} + B + \overline{C}$	M_6 $\overline{A} + \overline{B} + C$	M_7 $\overline{A} + \overline{B} + \overline{C}$
0	0	0	0	1	1	1	1	1	1	1
0	0	1	1	0	1	1	1	1	1	1
0	1	0	1	1	0	1	1	1	1	1
0	1	1	1	1	1	0	1	1	1	1
1	0	0	1	1	1	1	0	1	1	1
1	0	1	1	1	1	1	1	0	1	1
1	1	0	1	1	1	1	1	1	0	1
1	1	1	1	1	1	1	1	1	1	0

STANDARD FORMS

PRODUCT OF MAXTERMS

- **Product-of-maxterms** standard form expresses the Boolean or switching expression in the form of **product of sums** using **maxterms**.
  - For instance, the following Boolean expression using maxterms

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = (\mathbf{A} + \mathbf{B} + \overline{\mathbf{C}})(\overline{\mathbf{A}} + \mathbf{B} + \mathbf{C})(\overline{\mathbf{A}} + \overline{\mathbf{B}} + \overline{\mathbf{C}})$$

could instead be expressed as

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = M_1 \cdot M_4 \cdot M_7$$

or more compactly as

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \prod M(1, 4, 7) = \textit{zero-set}(1, 4, 7)$$

STANDARD FORMS

MINTERM AND MAXTERM EXP.

- Given an arbitrary Boolean function, such as

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \mathbf{AB} + \overline{\mathbf{B}}(\overline{\mathbf{A}} + \overline{\mathbf{C}})$$

how do we form the canonical form for:

- **sum-of-minterms**
  - Expand the Boolean function into a sum of products. Then take each term with a missing variable $\mathbf{X}$ and **AND** it with $\mathbf{X} + \overline{\mathbf{X}}$.
- **product-of-maxterms**
  - Expand the Boolean function into a product of sums. Then take each factor with a missing variable $\mathbf{X}$ and **OR** it with $\mathbf{X}\overline{\mathbf{X}}$.

STANDARD FORMS

FORMING SUM OF MINTERMS

- Example

$$F(A, B, C) = AB + \bar{B}(\bar{A} + \bar{C}) = AB + \bar{A}\bar{B} + \bar{B}\bar{C}$$
$$= AB(C + \bar{C}) + \bar{A}\bar{B}(C + \bar{C}) + (A + \bar{A})\bar{B}\bar{C}$$
$$= \bar{A}\bar{B}\bar{C} + \bar{A}\bar{B}C + A\bar{B}\bar{C} + AB\bar{C} + ABC$$
$$= \sum m(0, 1, 4, 6, 7)$$

A	B	C	F	
0	0	0	1	← 0
0	0	1	1	← 1
0	1	0	0	
0	1	1	0	
1	0	0	1	← 4
1	0	1	0	
1	1	0	1	← 6
1	1	1	1	← 7

Minterms listed as 1s in Truth Table

STANDARD FORMS

FORMING PROD OF MAXTERMS

- Example

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \mathbf{AB} + \overline{\mathbf{B}}(\overline{\mathbf{A}} + \overline{\mathbf{C}}) = \mathbf{AB} + \overline{\mathbf{A}}\overline{\mathbf{B}} + \overline{\mathbf{B}}\overline{\mathbf{C}}$$

$$= (\mathbf{A} + \overline{\mathbf{B}})(\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{C}})(\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}}) \quad \text{(using distributivity)}$$

$$= (\mathbf{A} + \overline{\mathbf{B}} + \mathbf{C}\overline{\mathbf{C}})(\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{C}})(\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}})$$

$$= (\mathbf{A} + \overline{\mathbf{B}} + \mathbf{C})(\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{C}})(\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}})$$

$$= \prod M(2, 3, 5)$$

A	B	C	F	
0	0	0	1	
0	0	1	1	
0	1	0	0	← 2
0	1	1	0	← 3
1	0	0	1	
1	0	1	0	← 5
1	1	0	1	
1	1	1	1	

Maxterms listed as 0s in Truth Table

STANDARD FORMS

CONVERTING MIN AND MAX

- Converting between sum-of-minterms and product-of-maxterms
  - The two are complementary, as seen by the truth tables.
  - To convert interchange the $\sum$ and $\prod$, then use missing terms.
    - Example: The example from the previous slides

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \sum m(0, 1, 4, 6, 7)$$

is re-expressed as

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \prod M(2, 3, 5)$$

where the numbers 2, 3, and 5 were missing from the minterm representation.

SIMPLIFICATION

KARNAUGH MAPS

- Often it is desired to simplify a Boolean function. A quick graphical approach is to use Karnaugh maps.

2-variable Karnaugh map

A \ B	0	1
0	0	0
1	0	1

$F = AB$

3-variable Karnaugh map

A \ BC	00	01	11	10
0	0	1	1	0
1	0	1	1	1

$F = AB + C$

4-variable Karnaugh map

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

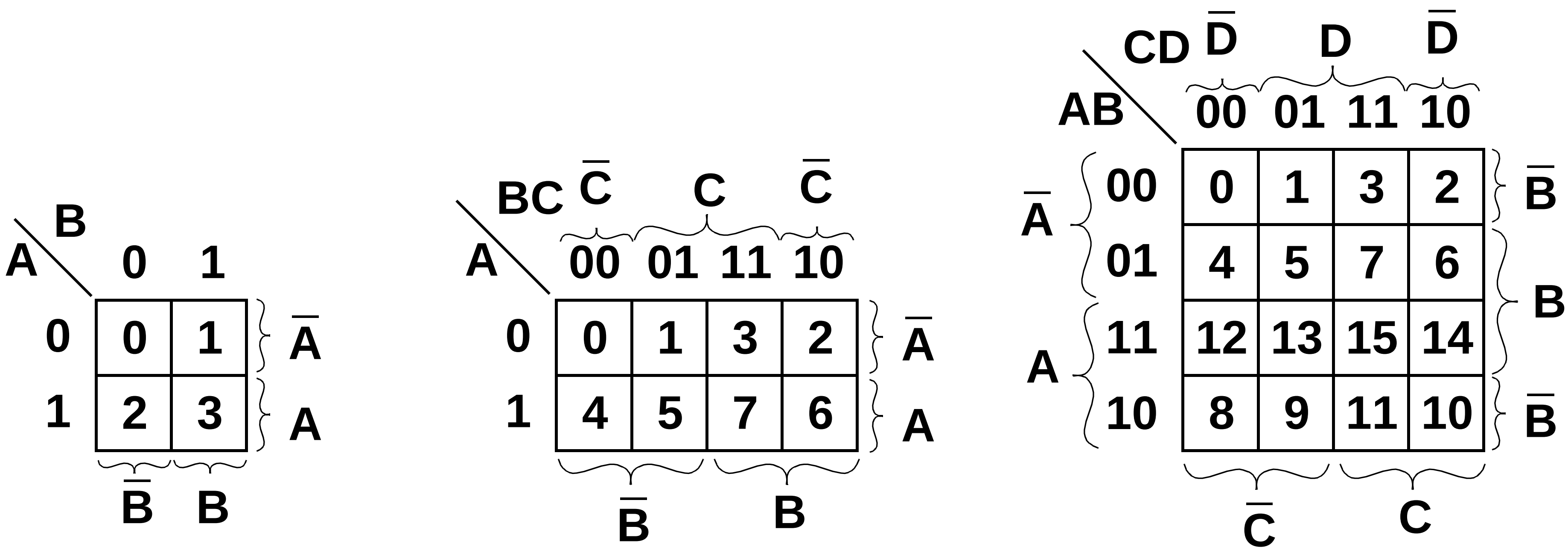
$F = AB + \overline{C}D$

SIMPLIFICATION

KARNAUGH MAP ORDERING

- Notice that the ordering of cells in the map are such that moving from one cell to an adjacent cell only changes one variable.

2-variable Karnaugh map | **3-variable Karnaugh map** | **4-variable Karnaugh map**

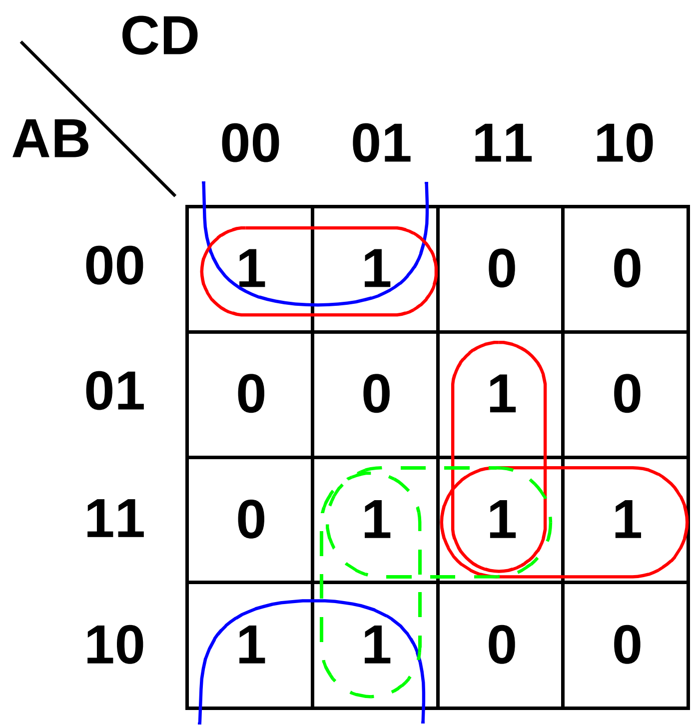


- This ordering allows for grouping of minterms/maxterms for simplification.

SIMPLIFICATION

IMPLICANTS

- **Implicant**
  - Bubble covering only **1**s (size of bubble must be a power of 2).
- **Prime implicant**
  - Bubble that is expanded as big as possible (but increases in size by powers of 2).
- **Essential prime implicant**
  - Bubble that contains a **1** covered only by itself and no other prime implicant bubble.
- **Non-essential prime implicant**
  - A **1** that can be bubbled by more then one prime implicant bubble.



SIMPLIFICATION

PROCEDURE FOR SOP

- **Procedure for finding the SOP from a Karnaugh map**
  - Step 1: Form the 2-, 3-, or 4-variable Karnaugh map as appropriate for the Boolean function.
  - Step 2: Identify all essential prime implicants for **1**s in the Karnaugh map
  - Step 3: Identify non-essential prime implicants for **1**s in the Karnaugh map.
  - Step 4: For each essential and one selected non-essential prime implicant from each set, determine the corresponding product term.
  - Step 5: Form a sum-of-products with all product terms from previous step.

SIMPLIFICATION

EXAMPLE FOR SOP (1)

- Simplify the following Boolean function

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \sum m(0, 1, 4, 5) = \bar{\mathbf{A}}\bar{\mathbf{B}}\bar{\mathbf{C}} + \bar{\mathbf{A}}\bar{\mathbf{B}}\mathbf{C} + \mathbf{A}\bar{\mathbf{B}}\bar{\mathbf{C}} + \mathbf{A}\bar{\mathbf{B}}\mathbf{C}$$

- Solution:

A \ BC	00	01	11	10
0	1	1	0	0
1	1	1	0	0

zero-set$(2, 3, 6, 7)$
one-set$(0, 1, 4, 5)$

- The essential prime implicants are $\bar{\mathbf{B}}$.
- There are no non-essential prime implicants.
- The sum-of-products solution is $\mathbf{F} = \bar{\mathbf{B}}$.

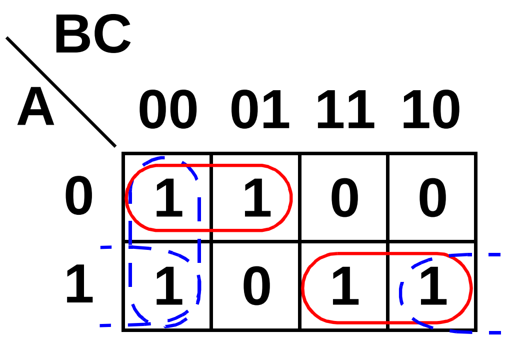
SIMPLIFICATION

EXAMPLE FOR SOP (2)

- Simplify the following Boolean function

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \sum m(0, 1, 4, 6, 7) = \overline{\mathbf{A}}\,\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \overline{\mathbf{A}}\,\overline{\mathbf{B}}\mathbf{C} + \mathbf{A}\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \mathbf{A}\mathbf{B}\overline{\mathbf{C}} + \mathbf{A}\mathbf{B}\mathbf{C}$$

- Solution:



zero-set$(2, 3, 5)$
one-set$(0, 1, 4, 6, 7)$

- The essential prime implicants are $\overline{\mathbf{A}}\,\overline{\mathbf{B}}$ and $\mathbf{AB}$.
- The non-essential prime implicants are $\overline{\mathbf{B}}\,\overline{\mathbf{C}}$ or $\mathbf{A}\overline{\mathbf{C}}$.
- The sum-of-products solution is

$$\mathbf{F} = \mathbf{AB} + \overline{\mathbf{A}}\,\overline{\mathbf{B}} + \overline{\mathbf{B}}\,\overline{\mathbf{C}} \text{ or } \mathbf{F} = \mathbf{AB} + \overline{\mathbf{A}}\,\overline{\mathbf{B}} + \mathbf{A}\overline{\mathbf{C}}.$$

SIMPLIFICATION

PROCEDURE FOR POS

- **Procedure for finding the SOP from a Karnaugh map**
  - Step 1: Form the 2-, 3-, or 4-variable Karnaugh map as appropriate for the Boolean function.
  - Step 2: Identify all essential prime implicants for **0**s in the Karnaugh map
  - Step 3: Identify non-essential prime implicants for **0**s in the Karnaugh map.
  - Step 4: For each essential and one selected non-essential prime implicant from each set, determine the corresponding sum term.
  - Step 5: Form a product-of-sums with all sum terms from previous step.

SIMPLIFICATION

EXAMPLE FOR POS (1)

- Simplify the following Boolean function

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \prod M(2, 3, 5) = (\mathbf{A} + \overline{\mathbf{B}} + \mathbf{C})(\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{C}})(\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}})$$

- Solution:

A \ BC	00	01	11	10
0	1	1	0	0
1	1	0	1	1

$zero\text{-}set(2, 3, 5)$

$one\text{-}set(0, 1, 4, 6, 7)$

- The essential prime implicants are $\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}}$ and $\mathbf{A} + \overline{\mathbf{B}}$.
- There are no non-essential prime implicants.
- The product-of-sums solution is $\mathbf{F} = (\mathbf{A} + \overline{\mathbf{B}})(\overline{\mathbf{A}} + \mathbf{B} + \overline{\mathbf{C}})$.

SIMPLIFICATION

EXAMPLE FOR POS (2)

- Simplify the following Boolean function

$$\mathbf{F}(\mathbf{A}, \mathbf{B}, \mathbf{C}) = \prod M(0, 1, 5, 7, 8, 9, 15)$$

- Solution:
  - The essential prime implicants are $\mathbf{B} + \mathbf{C}$ and $\overline{\mathbf{B}} + \overline{\mathbf{C}} + \overline{\mathbf{D}}$.
  - The non-essential prime implicants can be $\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{D}}$ or $\mathbf{A} + \mathbf{C} + \overline{\mathbf{D}}$.
  - The product-of-sums solution can be either

$$\mathbf{F} = (\mathbf{B} + \mathbf{C})(\overline{\mathbf{B}} + \overline{\mathbf{C}} + \overline{\mathbf{D}})(\mathbf{A} + \overline{\mathbf{B}} + \overline{\mathbf{D}})$$

or

$$\mathbf{F} = (\mathbf{B} + \mathbf{C})(\overline{\mathbf{B}} + \overline{\mathbf{C}} + \overline{\mathbf{D}})(\mathbf{A} + \mathbf{C} + \overline{\mathbf{D}})$$

zero-set(*0, 1, 5, 7, 8, 9, 15*)

one-set(*2, 3, 4, 6, 10, 11, 12, 13, 14*)

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

SIMPLIFICATION

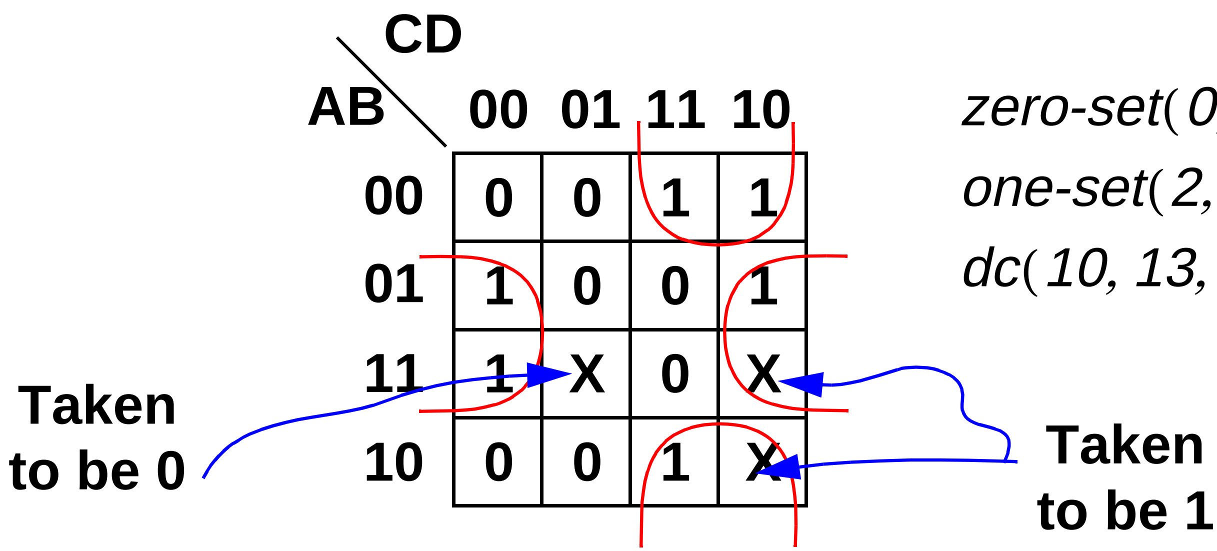
DON'T-CARE CONDITION

- Switching expressions are sometimes given as **incomplete**, or with **don't-care conditions**.
  - Having don't-care conditions can simplify Boolean expressions and hence simplify the circuit implementation.
  - Along with the *zero-set*( ) and *one-set*( ), we will also have *dc*( ).
  - Don't-cares conditions in Karnaugh maps
    - Don't-cares will be expressed as an "**X**" or "**-**" in Karnaugh maps.
    - Don't-cares can be bubbled along with the **1**s or **0**s depending on what is more convenient and help simplify the resulting expressions.

SIMPLIFICATION

DON'T-CARE EXAMPLE (1)

- Find the SOP simplification for the following Karnaugh map



zero-set(*0, 1, 5, 7, 8, 9, 15*)

one-set(*2, 3, 4, 6, 11, 12*)

dc(*10, 13, 14*)

- Solution:
  - The essential prime implicants are $B\bar{D}$ and $\bar{B}C$.
  - There are no non-essential prime implicants.
  - The sum-of-products solution is $F = \bar{B}C + B\bar{D}$.

SIMPLIFICATION

DON'T-CARE EXAMPLE (2)

- Find the POS simplification for the following Karnaugh map

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

Taken to be 0 (X in row 11, column 01)

Taken to be 1 (X in row 11, column 10 and row 10, column 10)

zero-set(*0, 1, 5, 7, 8, 9, 15*)

one-set(*2, 3, 4, 6, 11, 12*)

dc(*10, 13, 14*)

- Solution:
  - The essential prime implicants are $\mathbf{B} + \mathbf{C}$ and $\overline{\mathbf{B}} + \overline{\mathbf{D}}$.
  - There are no non-essential prime implicants.
  - The product-of-sums solution is $\mathbf{F} = (\mathbf{B} + \mathbf{C})(\overline{\mathbf{B}} + \overline{\mathbf{D}})$.