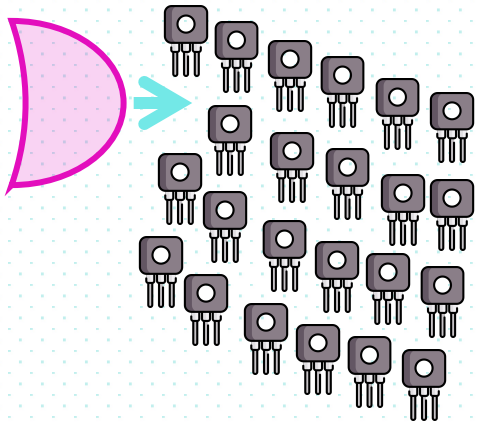
Logic Optimization



Guest Lecturer:

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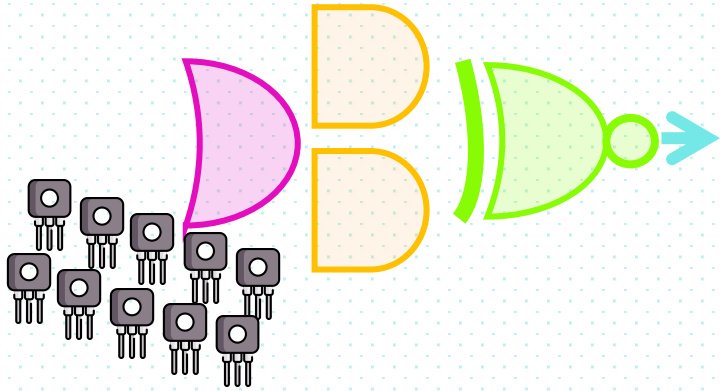
(PhD Candidate at UCSD)



Course Calendar: Where We Are Now

Week	Date	Topic	Activities	Resources
1	Monday – March 31	Course Overview – Basic and Combinational Logic	Exit Tickets 1, 2 Discussion 1 (Basic logic, Boolean Algebra, Truth Tables, SOP, POS) HW 1	Mano's Chapter 1
	Wednesday – April 2	Logic minimization (Algebraic Logic Minimization, Karnaugh Map)		
2	Monday – April 7	Logic minimization (Re-cap, Multi-level Minimization)	Exit Tickets 3, 4 Discussion 2 (Logic minimization practice, Quine–McCluskey) HW 2	Mano's Chapter 3.1-3.5 Tinder's Chapter 4
	Wednesday – April 9	Logic minimization (Re-cap, Multi-level Minimization)		
3	Monday – April 14	Number Systems	Exit Tickets 5, 6 Discussion 3 (Vivado Design Suite, Verilog) HW 3	
	Wednesday – April 16	Transistors to Gates		
4	Monday – April 21	Transistors to Gates	Exit Tickets 7, 8 Discussion 4 (Vivado Design Suite, Verilog) HW 4	
	Wednesday – April 23	Universal Gates		
5	Monday – April 28	Universal Gates	Exit Tickets 9, 10 Discussion 5 (Vivado Design Suite, Verilog, project) HW 5	
	Wednesday – April 30	RTL Combinatorial Components		
6	Monday – May 5	RTL Combinatorial Components	Exit Tickets 11, 12 Discussion 5 (Vivado Design Suite, Verilog, project) Mini-project proposal due	
	Wednesday – May 7	Programmable Logic Devices		
7	Monday – May 12	Programmable Logic Devices	Exit Tickets 13, 14 Discussion 7 (Vivado Design Suite, Verilog, project) HW 6	
	Wednesday – May 14	Memory Element Structures		
8	Monday – May 19	Controllers for RTL	Exit Tickets 15, 16 Discussion 8 (Vivado Design Suite, Verilog, project) HW 7	
	Wednesday – May 21	Controllers for RTL		
9	Monday – May 26	RTL Methodology	Exit Tickets 17, 18 Discussion 9 (Vivado Design Suite, Verilog, project) HW 8	
	Wednesday – May 28	RTL Methodology		
10	Monday – June 2	Standard Sequential Modules	Exit Tickets 19, 20 Projects Presentation	
	Wednesday – June 4	System Design		
Final			Final Exam	

Today's Learning Goals: Logic Optimization

- Recap of Algebraic Logic Optimization and Karnaugh Maps
- Multi-Level Optimization

Useful Links / Resources

- Chapter # in Morris Mano's Digital Design: 3.1-3.5 (Algebraic Logic Optimization and Karnaugh Maps)
- Chapter # in Tinder's Engineering Digital Design: 4 (Multi-level Optimization, Efficient Sharing of Logic)
- GitHub (slides) : https://github.com/Fasgarinejad/DigitalDesign

Prerequisites:

Basic Logic and Boolean Algebra: Backup Slides: 1-3

Truth Tables: Backup Slides: 4-6

Algebraic Logic Optimization: Recap Slides

Karnaugh Maps: Recap Slides

QR CODE FOR SLIDES

Circuits (Seven Segment Display)

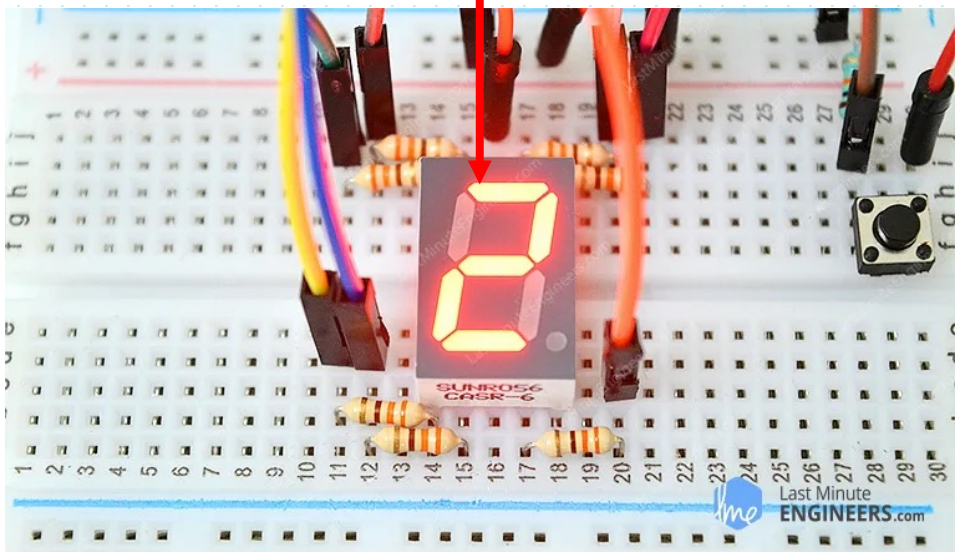
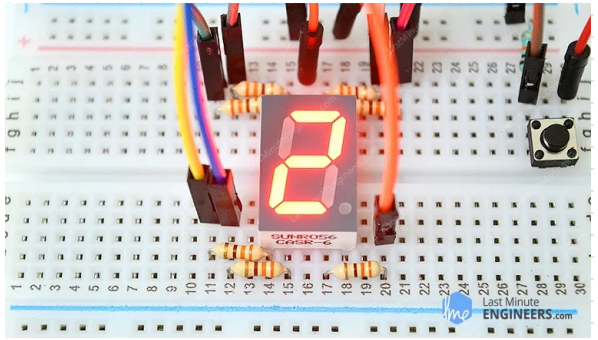
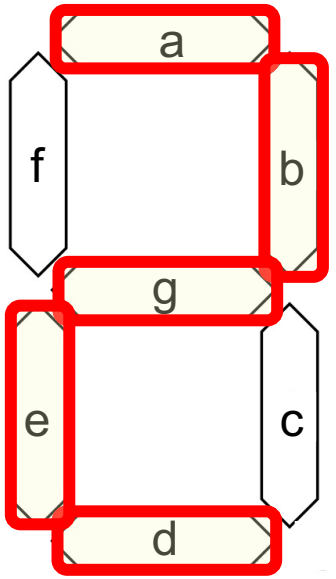


image from https://www.nutsvolts.com/ and https://lastminuteengineers.com/

Seven Segment Display Truth Table

	inputs				*outputs*						
Digit	**A**	**B**	**C**	**D**	**a**	**b**	**c**	**d**	**e**	**f**	**g**
0	0	0	0	0	1	1	1	1	1	1	0
1	0	0	0	1	0	1	1	0	0	0	0
2	0	0	1	0	1	1	0	1	1	0	1
3	0	0	1	1	1	1	1	1	0	0	1
4	0	1	0	0	0	1	1	0	0	1	1
5	0	1	0	1	1	0	1	1	0	1	1
6	0	1	1	0	1	0	1	1	1	1	1
7	0	1	1	1	1	1	1	0	0	0	0
8	1	0	0	0	1	1	1	1	1	1	1
9	1	0	0	1	1	1	1	1	0	1	1



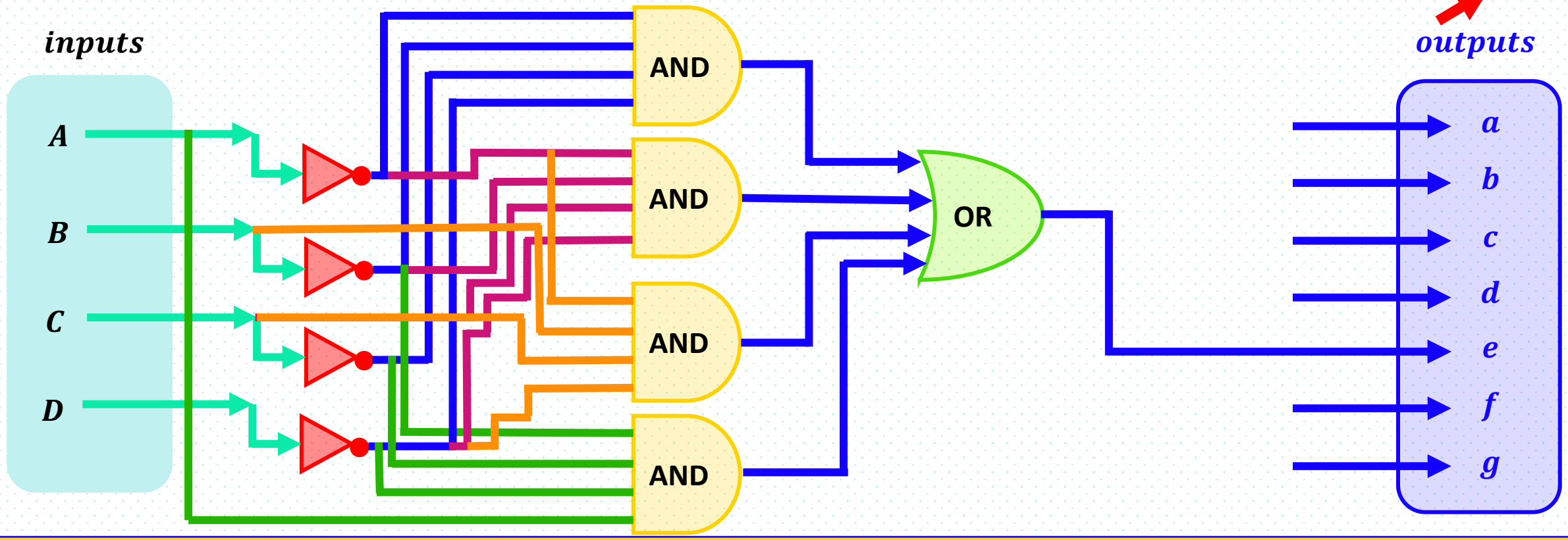


7-Segment Display Logical Circuit

with Two Levels

$$e = \bar{A}\bar{B}\bar{C}\bar{D} + \bar{A}\bar{B}CD + \bar{A}BC\bar{D} + A\bar{B}\bar{C}\bar{D}$$ SOP (Sum of Products)

Digit	A	B	C	D	a	b	c	d	e	f	g
0	0	0	0	0	1	1	1	1	1	1	0
1	0	0	0	1	0	1	1	0	0	0	0
2	0	0	1	0	1	1	0	1	1	0	1
3	0	0	1	1	1	1	1	1	0	0	1
4	0	1	0	0	0	1	1	0	0	1	1
5	0	1	0	1	1	0	1	1	0	1	1
6	0	1	1	0	1	0	1	1	1	1	1
7	0	1	1	1	1	1	1	0	0	0	0
8	1	0	0	0	1	1	1	1	1	1	1
9	1	0	0	1	1	1	1	1	0	1	1



Algebraic Logic Optimization with Two Levels

$e = \bar{A}\bar{B}\bar{C}\bar{D} + \bar{A}\bar{B}CD + \bar{A}BC\bar{D} + A\bar{B}\bar{C}\bar{D}$

Complement $C + \bar{C} = 1$

$\bar{A}\bar{B}\bar{D}(\bar{C} + C) + \bar{A}BC\bar{D} + A\bar{B}\bar{C}\bar{D} =$

$\bar{A}\bar{B}\bar{D} + \bar{A}BC\bar{D} + A\bar{B}\bar{C}\bar{D} =$

$\bar{A} + A\bar{C} = \bar{A}(1 + \bar{C}) + A\bar{C} =$
$\bar{A} + \bar{A}\bar{C} + A\bar{C} = \bar{A} + \bar{C}(\bar{A} + A)$
$= \bar{A} + \bar{C}$

$\bar{B}\bar{D}(\bar{A} + A\bar{C}) + \bar{A}BC\bar{D} =$

$\bar{B}\bar{D}(\bar{A} + \bar{C}) + \bar{A}BC\bar{D} =$

$\bar{A}\bar{B}\bar{D} + \bar{B}\bar{C}\bar{D} + \bar{A}BC\bar{D} =$

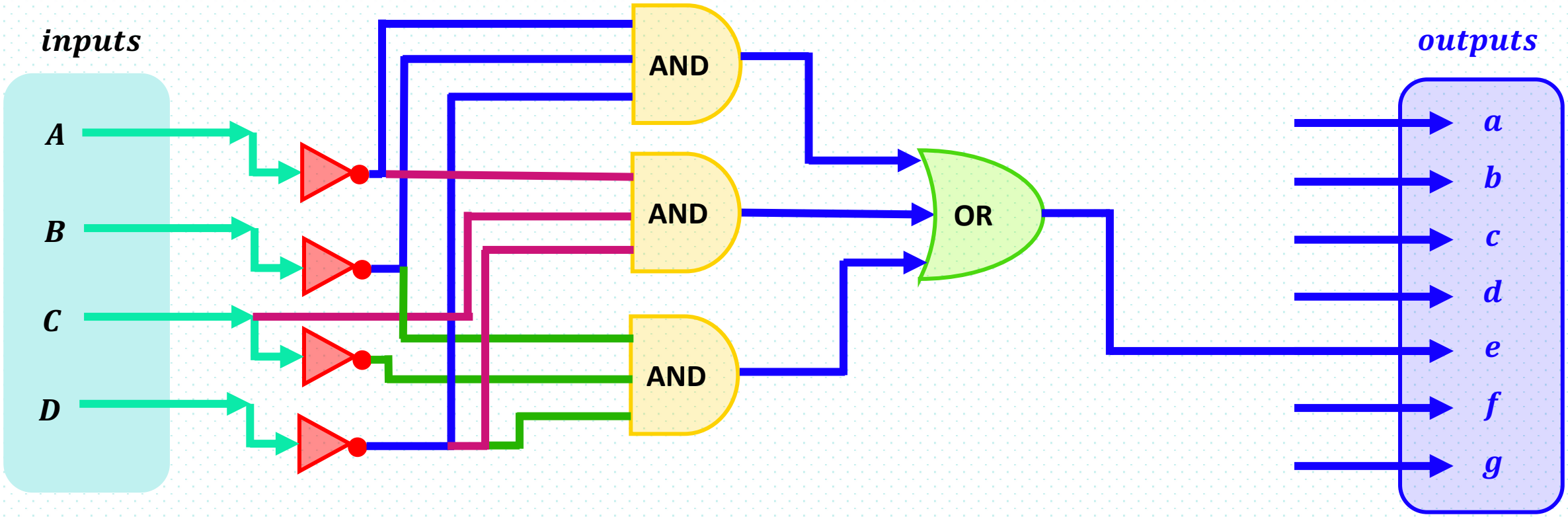
$\bar{A}\bar{D}(\bar{B} + BC) + \bar{B}\bar{C}\bar{D} =$

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

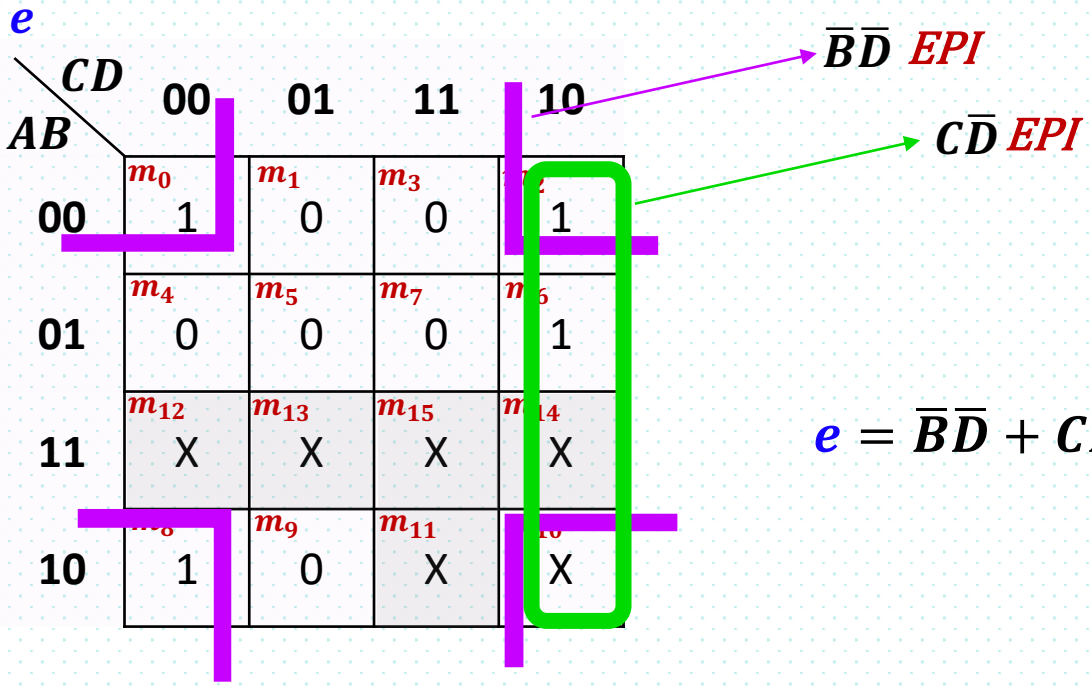
$\bar{A}\bar{B}\bar{D} + \bar{A}C\bar{D} + \bar{B}\bar{C}\bar{D}$ Reduced Sum of Products

Algebraic Logic Optimization with Two Levels

$e = \overline{A}\overline{B}\overline{D} + \overline{A}C\overline{D} + \overline{B}\overline{C}\overline{D}$ Reduced Sum of Products



7-Segment Display Karnaugh Map



Digit	A	B	C	D	a	b	c	d	e	f	g
0	0	0	0	0	1	1	1	1	1	1	0
1	0	0	0	1	0	1	1	0	0	0	0
2	0	0	1	0	1	1	0	1	1	0	1
3	0	0	1	1	1	1	1	1	0	0	1
4	0	1	0	0	0	1	1	0	0	1	1
5	0	1	0	1	1	0	1	1	0	1	1
6	0	1	1	0	1	0	1	1	1	1	1
7	0	1	1	1	1	1	1	0	0	0	0
8	1	0	0	0	1	1	1	1	1	1	1
9	1	0	0	1	1	1	1	1	0	1	1

$e = \bar{B}\bar{D} + C\bar{D}$ More Reduced SOP

7-Segment Display Karnaugh Map

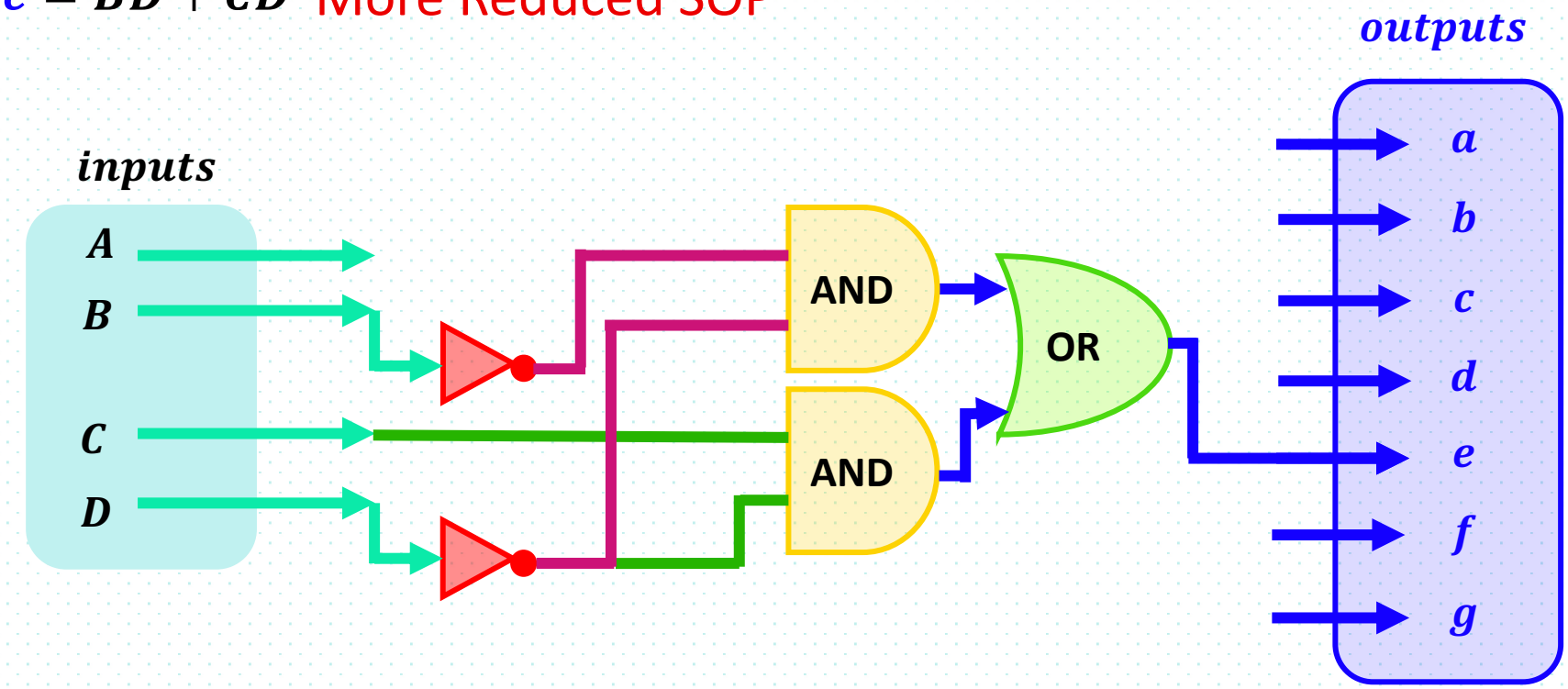
e

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

$\bar{B}\bar{D}$ *EPI*

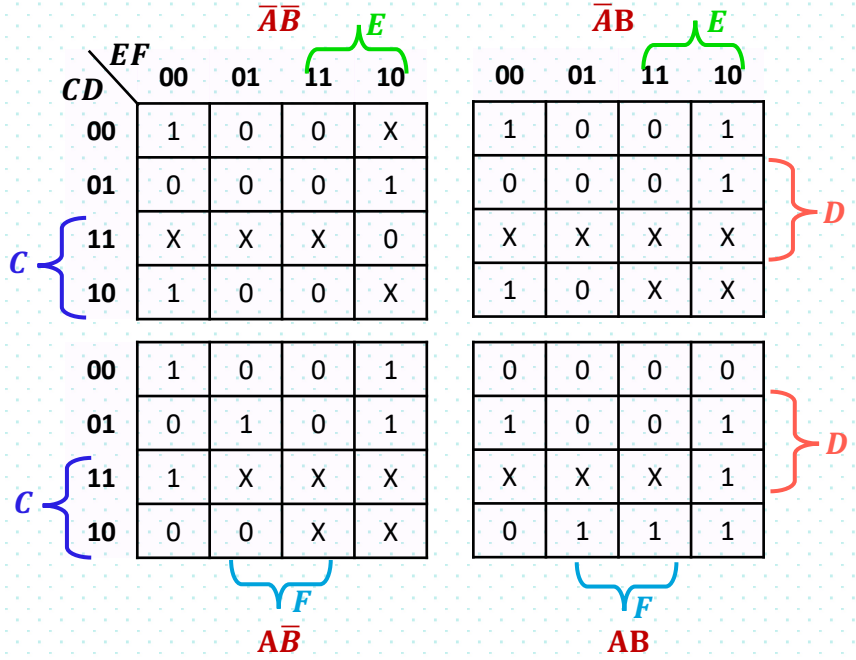
$C\bar{D}$ *EPI*

$e = \bar{B}\bar{D} + C\bar{D}$ More Reduced SOP



Logic Minimization with Two Levels

Note: 6-Variable K-Map



In SOP form:

Minimize number of products (reduce gates) and ✓

Minimize literals (reduce gate inputs) ✓

In POS form:

Minimize number of sums (reduce gates) and

Minimize literals (reduce gate inputs)

$$e = \bar{A}\bar{B}\bar{C}\bar{D} + \bar{A}\bar{B}C\bar{D} + \bar{A}BC\bar{D} + A\bar{B}\bar{C}\bar{D} \longrightarrow e = \bar{B}\bar{D} + C\bar{D}$$

How many minterms does a 6 variable K-Map have?

Karnaugh Maps or Manual Logic Optimization are impractical, Error-Prone and Tedious for Complex Logic with Various Inputs

Better Logic Minimization Techniques with Two Levels

Quine–McCluskey (further study Chapter #4.8.1 in Tinder's, backup slides 7,8)

- ✓ Algorithmic and suitable for computer implementation
- ✓ Less error-prone compared to humans
- ✓ Handles more variables than Karnaugh Maps
- ✓ Like Karnaugh Maps find the optimal logic

  Impractical beyond 10-15 variables (modern digital systems have hundreds of variables)

Espresso (further study Chapter #4.8.3 in Tinder's)

Is Heuristic and finds a near-optimal solution, but it is good enough in many logic synthesis systems (e.g., Intel and AMD use Espresso-based logic minimization)

- ✓ Handles more variables than Quine–McCluskey

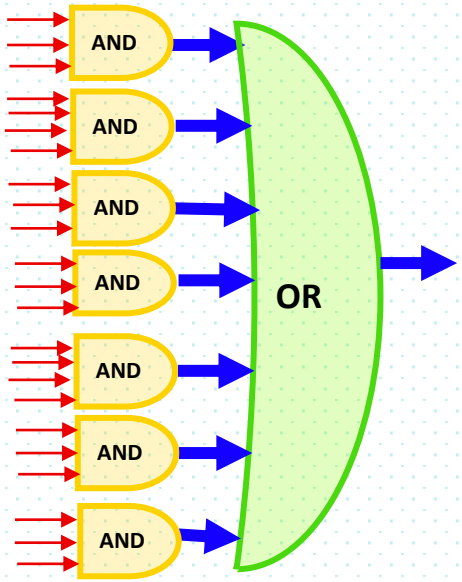
Two level Logic Optimization is simple but impedes re-use of shared logic between different functions and have **large fan-in gates** and wires, leading to slower and larger circuits

Multi-Level Logic Minimization

Consider the minimized SOP five-variable function F:

$$F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$$

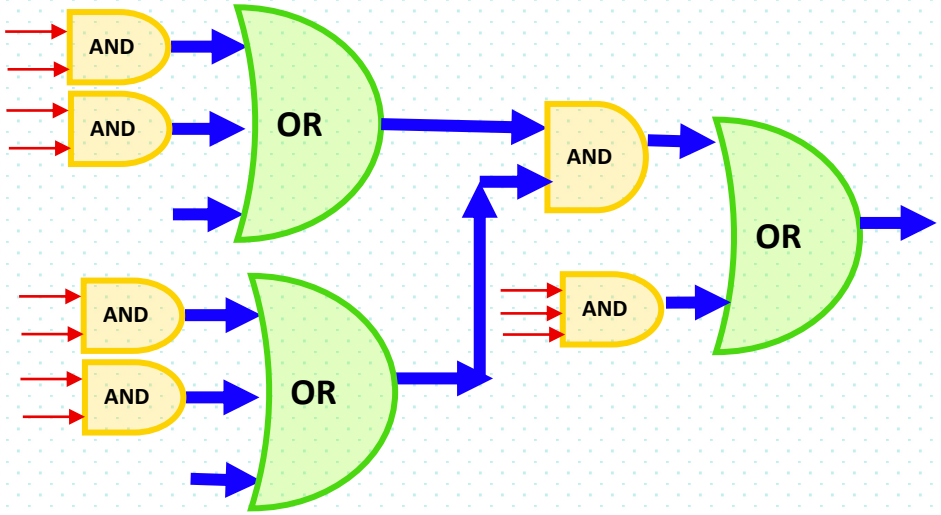
SOP using K_MAP



With using a multi – level logic minimization, we can get:

$$F = (AB + CD + E)(\overline{AB} + \overline{CD} + \overline{E}) + \overline{A}\overline{C}\overline{E}$$

Multi-Level Minimization using Resubstitution Method



Multi-Level Logic Minimization: Resubstitution

Boolean resubstitution method generates multilevel functions that have improved fan-in (hence improved area) requirements.

Our function: $F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$

1. Choose some **P** based on the common terms in your product-terms in F and sum them
2. And each $p - term\ i$ with the chosen **P** and find Q_i
3. Factor out **P** from all of the p-terms (call the coefficient **Q**) and sum remaining terms as **R**

$$F = \mathbf{P}.\mathbf{Q} + \mathbf{R} = \mathbf{P}\sum Q_i + \sum \boldsymbol{R_i}$$

Multi-Level Logic Minimization: Resubstitution

$$F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$$

1. Choose some **P** based on the common terms in your product-terms in F and sum them:

   Common terms in above p-terms are AB(2 times), $\bar{E}$(2 times), $\bar{C}\bar{D}$(2 times), $\bar{A}\bar{B}$ (2 times), CD(two times) and E(two times)

   We arbitrary choose $AB + CD + E$ and set **P** equal to that:

   $$\mathbf{P} = \boldsymbol{AB + CD + E}$$

Multi-Level Logic Minimization: Resubstitution

$$F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$$

2. And each $p-term\ i$ with the chosen **P** and find Q_i that makes that $p-term$

$\mathrm{AB}\bar{\mathrm{E}} = \mathrm{P}.\mathrm{Q}_1 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_1 \rightarrow \mathrm{Q}_1 = \bar{\mathrm{E}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{E}} = \mathrm{AB}\bar{\mathrm{E}} + \mathrm{CD}\bar{\mathrm{E}} + \mathrm{E}\bar{\mathrm{E}}$

$\mathrm{AB}\bar{\mathrm{C}}\bar{\mathrm{D}} = \mathrm{P}.\mathrm{Q}_2 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_2 \rightarrow \mathrm{Q}_2 = \bar{\mathrm{C}}\bar{\mathrm{D}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{C}}\bar{\mathrm{D}} = \mathrm{AB}\bar{\mathrm{C}}\bar{\mathrm{D}} + \mathrm{CD}\bar{\mathrm{C}}\bar{\mathrm{D}} + \mathrm{E}\,\bar{\mathrm{C}}\bar{\mathrm{D}}$

$\mathrm{CD}\bar{\mathrm{E}} = \mathrm{P}.\mathrm{Q}_3 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_3 \rightarrow \mathrm{Q}_3 = \bar{\mathrm{E}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{E}} = \mathrm{AB}\bar{\mathrm{E}} + \mathrm{CD}\bar{\mathrm{E}} + \mathrm{E}\bar{\mathrm{E}}$

$\bar{\mathrm{A}}\bar{\mathrm{C}}\bar{\mathrm{E}} = \mathrm{P}.\mathrm{Q}_4 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_4 \rightarrow R_4 = \bar{\mathrm{A}}\bar{\mathrm{C}}\bar{\mathrm{E}}$

$\bar{\mathrm{A}}\bar{\mathrm{B}}\mathrm{CD} = \mathrm{P}.\mathrm{Q}_5 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_5 \rightarrow \mathrm{Q}_5 = \bar{\mathrm{A}}\,\bar{\mathrm{B}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{A}}\,\bar{\mathrm{B}} = \mathrm{AB}\bar{\mathrm{A}}\,\bar{\mathrm{B}} + \mathrm{CD}\,\bar{\mathrm{A}}\,\bar{\mathrm{B}} + \mathrm{E}\bar{\mathrm{A}}\,\bar{\mathrm{B}}$

$\bar{\mathrm{A}}\bar{\mathrm{B}}\mathrm{E} = \mathrm{P}.\mathrm{Q}_6 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_6 \rightarrow \mathrm{Q}_6 = \bar{\mathrm{A}}\,\bar{\mathrm{B}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{A}}\,\bar{\mathrm{B}} = \mathrm{AB}\bar{\mathrm{A}}\,\bar{\mathrm{B}} + \mathrm{CD}\,\bar{\mathrm{A}}\,\bar{\mathrm{B}} + \mathrm{E}\bar{\mathrm{A}}\,\bar{\mathrm{B}}$

$\bar{\mathrm{C}}\bar{\mathrm{D}}\mathrm{E} = \mathrm{P}.\mathrm{Q}_7 = (\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\mathrm{Q}_7 \rightarrow \mathrm{Q}_7 = \bar{\mathrm{C}}\bar{\mathrm{D}}$

$(\mathrm{AB} + \mathrm{CD} + \mathrm{E}).\bar{\mathrm{C}}\bar{\mathrm{D}} = \mathrm{AB}\bar{\mathrm{C}}\bar{\mathrm{D}} + \mathrm{CD}\bar{\mathrm{C}}\bar{\mathrm{D}} + \mathrm{E}\bar{\mathrm{C}}\bar{\mathrm{D}}$

Multi-Level Logic Minimization: Resubstitution

3 Factor out **P** from all of the p-terms (call the coefficient **Q**) and isolate remaining terms as **R**

$AB\overline{E} = P.Q_1 = P.\overline{E}$

$AB\overline{C}\,\overline{D} = P.Q_2 = P.\overline{C}\,\overline{D}$

$CD\overline{E} = P.Q_3 = P.\overline{E}$

$\overline{A}\,\overline{C}\,\overline{E} = P.Q_4 = 0.$ $\quad R_4 = \overline{A}\,\overline{C}\,\overline{E}$

$\overline{A}\,\overline{B}CD = P.Q_5 = P.\overline{A}\,\overline{B}$

$\overline{A}\,\overline{B}E = P.Q_6 == P.\overline{A}\,\overline{B}$

$\overline{C}\,\overline{D}E = P.Q_7 = P.\overline{C}\,\overline{D}$

$$\sum \boldsymbol{Q_i} = (\overline{E} + \overline{C}\,\overline{D} + \overline{A}\,\overline{B})$$

$$\sum \boldsymbol{R_i} = \overline{A}\,\overline{C}\,\overline{E}$$

$$\boldsymbol{P} = (\boldsymbol{AB} + \boldsymbol{CD} + \boldsymbol{E})$$

$$F = \mathbf{P}\sum \boldsymbol{Q_i} + \sum \boldsymbol{R_i} = (\boldsymbol{AB} + \boldsymbol{CD} + \boldsymbol{E}).(\overline{E} + \overline{C}\,\overline{D} + \overline{A}\,\overline{B}) + \overline{A}\,\overline{C}\,\overline{E}$$

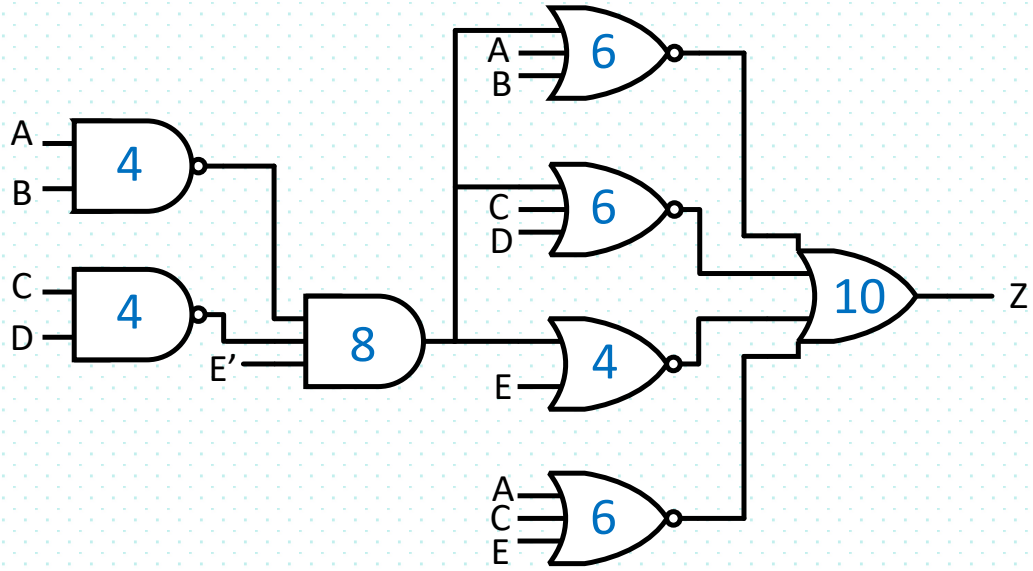
An Enhanced Resubstitution Algorithm for Area-Oriented Logic Optimization

Andrea Costamagna, *EPFL*, *Lausanne, Switzerland*
Alan Mishchenko, *U.C.Berkley*, *Berkley, California*
Satrajit Chatterjee, *Kepler AI*, Palo Alto, California
Giovanni De Micheli, *EPFL*, *Lausanne, Switzerland*

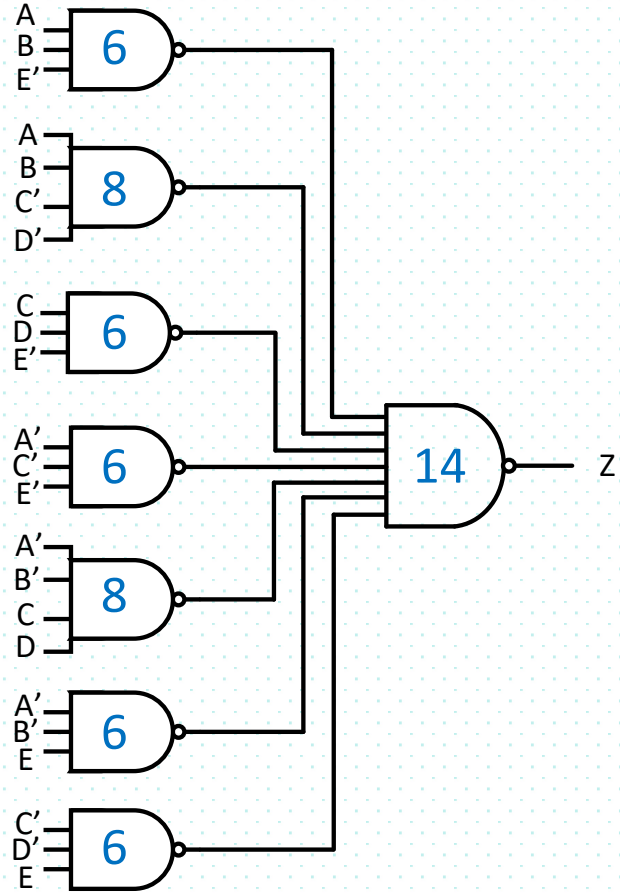
ISCAS, 2024

Multi-Level Logic Minimization: Resubstitution

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



Area = 4×3 + 6×3 + 8 + 10 + 2 = 50
(1 inverters for E')
Literals = 13



Area = 6×5 + 8×2 + 14 + 2×5 = 70
(5 inverters for A', B', C', D', E')
Literals = 23

Sharing of Logic in 7-Segment Display

e

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

$$e = \bar{B}\bar{D} + C\bar{D}$$
$$= (\bar{B} + C)\bar{D}$$

g

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

$$g = A + \bar{B}\bar{D} + \bar{B}C + C\bar{D} + B\bar{C}D$$
$$= (\bar{B} + C)\bar{D} + \bar{B}C + B\bar{C}D + A$$

Bonus Exit Ticket

AB \ CD	00	01	11	10
00	m_0 1	m_1 1	m_3 1	m_2 1
01	1			
11				
10				

$$F(A,B,C,D) = \sum m(0,1,2,3,4,9,10,11,13,14,15)$$

Using Resubstitution multi-level logic minimization, write F in terms of **P**. **Q** + **R**, and draw the logic circuit.

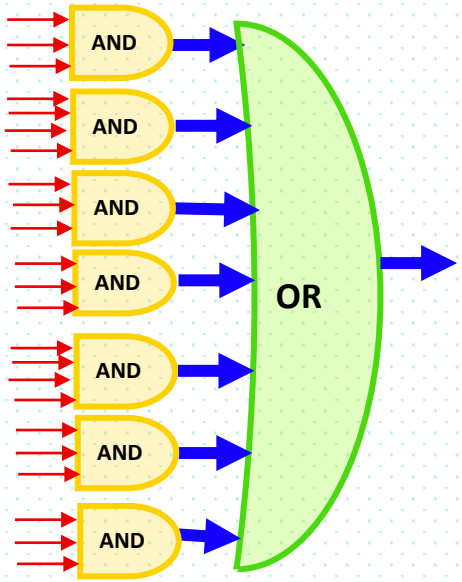
1) Fill in the K-Map
2) Write F in terms of reduced SOP based on K-Map.
   Hint: You will be using more than used/visible PIs in 3.
3) Hint: Choose **P** $= \bar{A} + C + D$ and find **Q** and **R**.
4) Draw the corresponding circuit

Multi-Level Logic Minimization

Consider the minimized SOP five-variable function F:

$$F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$$

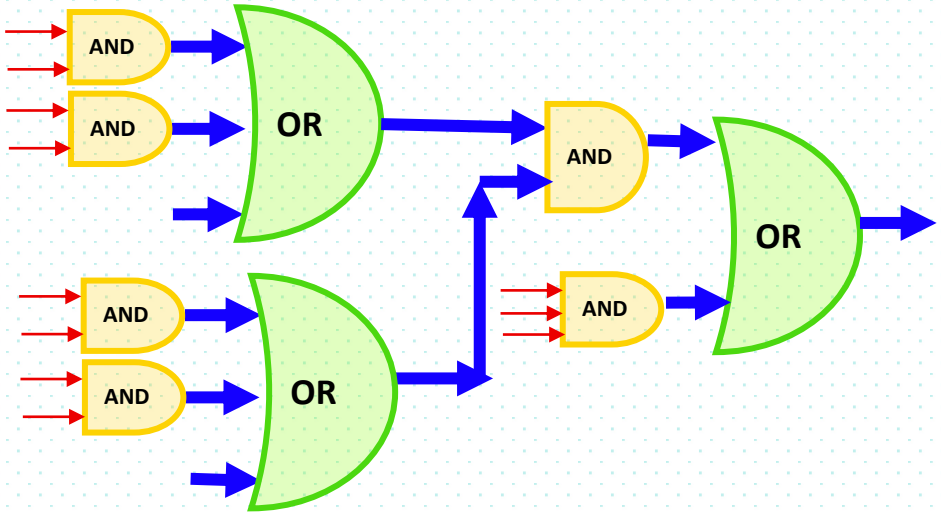
SOP using K_MAP



With using a multi – level logic minimization, we can get:

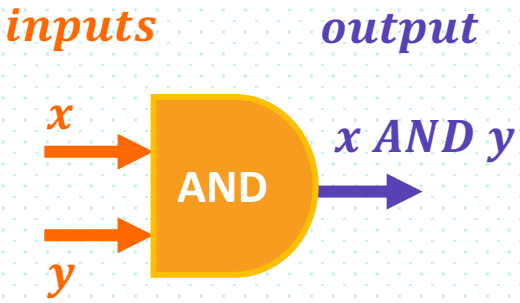
$$F = (AB + CD + E)(\overline{AB} + \overline{CD} + \overline{E}) + \overline{A}\overline{C}\overline{E}$$

Multi-Level Minimization using Resubstitution Method

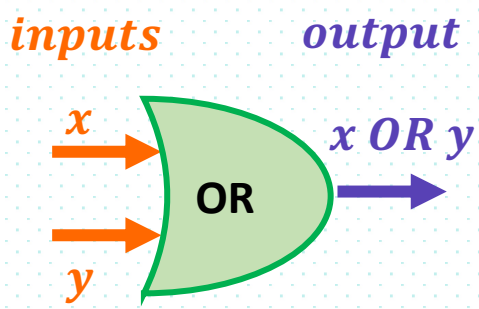


Backup: Circuits (AND, OR, NOT, XOR Gates)

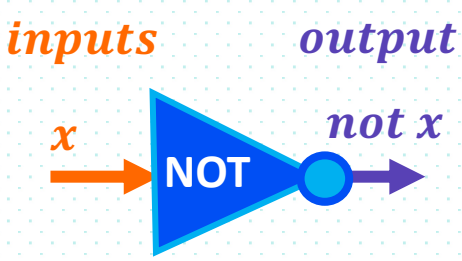
inputs x	inputs y	output x AND y
1	1	1
1	0	0
0	1	0
0	0	0



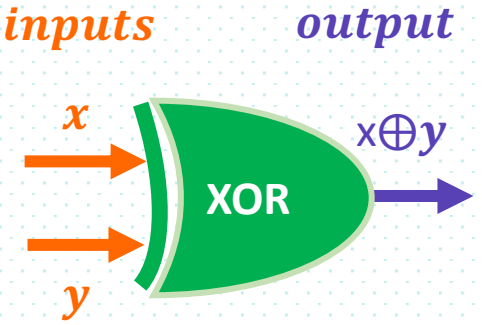
inputs x	inputs y	output x OR y
1	1	1
1	0	1
0	1	1
0	0	0



inputs x	output NOT x
0	1
1	0



inputs x	inputs y	output x XOR y = x⊕y
1	1	0
1	0	1
0	1	1
0	0	0



Backup: Logical operators aka propositional connectives

Conjunction AND ∧ ($\land$ *in latex*) 2 inputs

Evaluates to T ($True$ *or* 1) exactly when **both** inputs are T ($True$ *or* 1)

Exclusive or XOR ⊕ ($\oplus$ *in latex*) 2 inputs

Evaluates to T ($True$ *or* 1) exactly when **exactly one** inputs is T ($True$ *or* 1)

Disjunction OR ∨ ($\lor$ *in latex*) 2 inputs

Evaluates to T ($True$ *or* 1) exactly when **at least one** inputs is T ($True$ *or* 1)

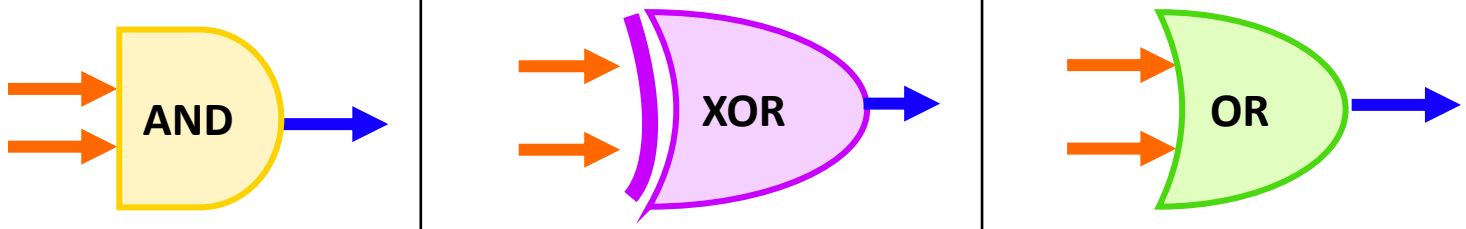
Negation NOT ¬ ($\lnot$ *in latex*) 1 input

Evaluates to T ($True$ *or* 1) exactly when its input is F ($False$ *or* 0)

Backup: Truth tables

Input-output tables where we use T (1) and F (0)

inputs		*output*		
p	q	$p \wedge q$	$p \oplus q$	$p \vee q$
1	1	1	0	1
1	0	0	1	1
0	1	0	1	1
0	0	0	0	0



Backup: Truth tables

Given a truth table, how do we find an expression using the input variables and logical operators that outputs corresponding output specified in this table?

Application: design a circuit given a desired input-output relationship.

p	q	$output\ 1$	$output\ 2$
T	T	T	F
T	F	T	F
F	T	F	F
F	F	T	T

Expressions that represents output of $output1$: $(p \wedge q) \vee (p \wedge \neg q) \vee (\neg p \wedge \neg q)$

Expressions that represents output of $output2$: $(\neg p \wedge \neg q)$

Backup: DNF (SOP) and CNF (SOP)

Definition: An expression built of variables and logical operators is in **Disjunctive Normal Form (DNF)** means that it is an OR of ANDS.

Definition: An expression built of variables and logical operators is in **Conjunctive Normal Form (CNF)** means that it is an AND of ORs.

Example: An expression that has **output ?** is:

Input			Output
p	q	r	?
T	T	T	T
T	T	F	T
T	F	T	F
T	F	F	T
F	T	T	F
F	T	F	F
F	F	T	T
F	F	F	F

DNF: $(p \wedge q \wedge r) \vee (p \wedge q \wedge \neg r) \vee (p \wedge \neg q \wedge \neg r) \vee (\neg p \wedge \neg q \wedge r)$

CNF: $(\neg p \vee q \vee \neg r) \wedge (p \vee \neg q \vee \neg r) \wedge (p \vee \neg q \vee r) \wedge (p \vee q \vee r)$

Backup: Quine-McCluskey

$$F(a,b,c,d) = \sum m(7,9,12,13,14,15) + dont\ cares(4,11)$$

Column 1			Column 2		Column 2	
Group 1:	4	0 1 0 0 ✓	(4, 12)	_ 1 0 0	(9, 11, 13, 15)	1_ _1
Group 2:	9	1 0 0 1 ✓	(9, 11)	10_1 ✓	(9, 13, 11, 15)	1_ _1
	12	1 1 0 1 ✓	(9, 13)	1_01 ✓	(12, 13, 14, 15)	11_ _
			(12, 13)	110_ ✓	(12, 14, 13, 15)	11_ _
Group 3:	7	0 1 1 1 ✓	(12, 14)	11_0 ✓		
	11	1 0 1 1 ✓			List of PIs: $b\bar{c}\bar{d}$, bcd, ad, ab	
	13	1 1 0 1 ✓	(7, 15)	_111		
	14	1 1 1 0 ✓	(11, 15)	1_11 ✓		
			(13, 15)	11_1 ✓		
Group 5:	15	1 1 1 1 ✓	(14, 15)	111_ ✓		

Backup: Quine-McCluskey

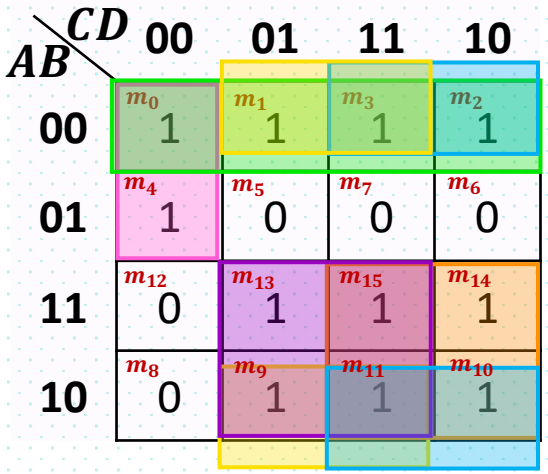
List of PIs: $b\bar{c}\bar{d}$, bcd, ad, ab

	7	9	12	13	14	15	4	11
$b\bar{c}\bar{d}$			X				X	
bcd	X					X		
ad		X		X		X		X
ab			X	X	X	X		

EPI

EPI

$$F = bcd + ad + ab$$



Exit Ticket

$$F(A,B,C,D) = \sum m(0,1,2,3,4,9,10,11,13,14,15)$$

Using Resubstitution multi-level logic minimization, write F in terms of **P. Q + R**, and draw the logic circuit.

P $= \bar{A} + C + D$ and find **Q** and **R**.

$$F = \bar{A}\bar{C}\bar{D} + AD + AC + \bar{A}\bar{B} + \bar{B}D + \bar{B}C$$

$$\bar{A}\bar{C}\bar{D} = \mathrm{P}.\mathrm{Q}_1 = (\bar{A} + C + D)\,.\,\mathrm{Q}_1 = P.\bar{C}\bar{D}$$

$$AD = \mathrm{P}.\mathrm{Q}_2 = (\bar{A} + C + D)\,.\,\mathrm{Q}_2 = P.A$$

$$AC = \mathrm{P}.\mathrm{Q}_3 = (\bar{A} + C + D)\,.\,\mathrm{Q}_3 = P.A$$

$$\bar{A}\bar{B} = \mathrm{P}.\mathrm{Q}_4 = (\bar{A} + C + D)\,.\,\mathrm{Q}_4 = P.\bar{B}$$

$$F = \mathbf{P.Q + R} = \mathbf{P}\sum Q_i + \sum R_i = (\bar{A} + C + D)\,.\,(A + \bar{C}\bar{D} + \bar{B})$$

Number of CMOS Transistors needed for different Gates

Table 1. Gate types, Gate ID, corresponding CMOS transistors [17]

Gate Type Code	Gate Symbol	Area (µm)	Number Of Transistors
0		0	0
1		1728	2
2		2880	6
3		2880	6
4		2304	4
5		2304	4
6		4608	9
7		5184	9

Multi-Level Logic Minimization

Example logical function $F(A,B,C,D,E) = \sum m(0,1,2,3,5,6,7,8,9,10,18,21,24,25,26,28,29)$

Simplification using 5-Variable K-Map

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

	00	01	11	10
00	0	0	0	1
01	0	1	0	0
11	1	1	0	0
10	1	1	0	1

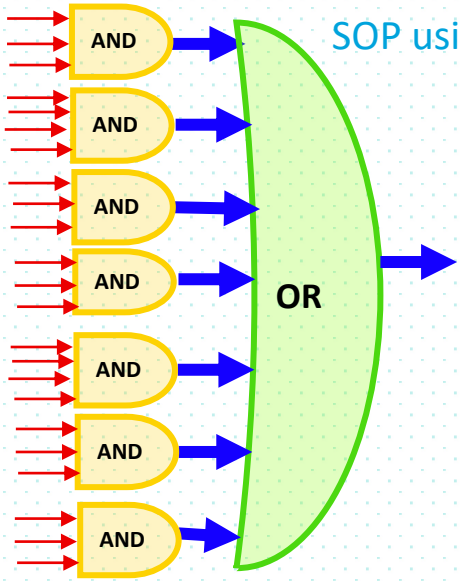
$Based\ on\ above\ K-Map$:

$F = AB\bar{E} + AB\bar{C}\bar{D} + CD\bar{E} + \bar{A}\bar{C}\bar{E} + \bar{A}\bar{B}CD + \bar{A}\bar{B}E + \bar{C}\bar{D}E$

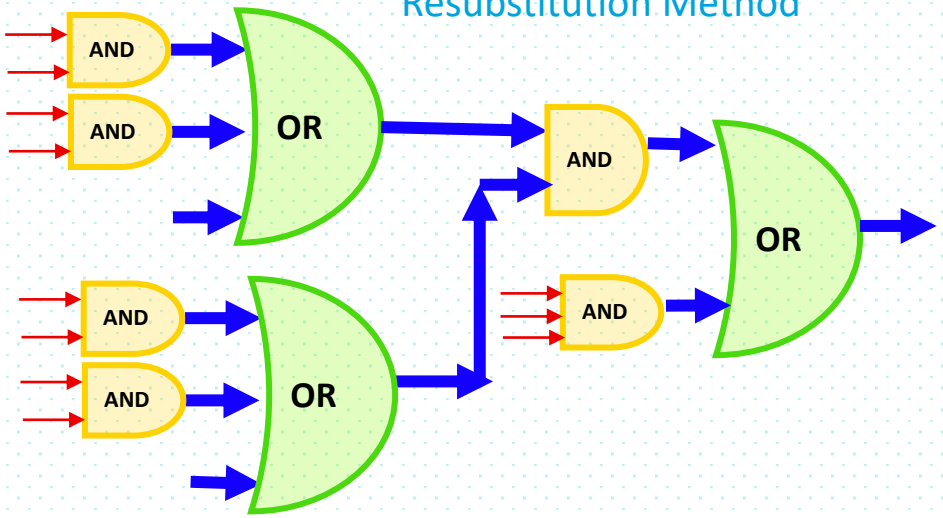
$With\ using\ a\ multi-level\ logic\ minimization, we\ can\ get$:

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

SOP using K_MAP



Multi-Level Minimization using Resubstitution Method



How do I fit into

Department of Electrical and Computer Engineering

as Assistant Teaching Professor

Fatemeh Asgarinejad

PhD candidate at UC San Diego

Teaching Experiences as Instructor/TA

Computer Science and Engineering, UC San Diego

Summer 2024
Discrete Mathematics for Computer Science
Instructor | Syllabus | Course website

Winter 2025
Discrete Mathematics for Computer Science
Teaching Assistant | Miles Jones

Fall 2024
Mathematics for Algorithms and Systems Analysis
Teaching Assistant | Miles Jones

Spring 2024
Mathematics for Algorithms and Systems Analysis
Teaching Assistant | Miles Jones

Winter 2024
Mathematics for Algorithms and Systems Analysis
Teaching Assistant | Miles Jones

Summer 2023
Design and Analysis of Algorithms
Teaching Assistant | Jor-El Briones

Spring 2023
Discrete Mathematics for Computer Science
Teaching Assistant | Jor-El Briones

Winter 2023
Discrete Mathematics for Computer Science
Teaching Assistant | Miles Jones

Summer 2022
Discrete Mathematics for Computer Science
Teaching Assistant | Jor-El Briones

Spring 2022
Discrete Mathematics for Computer Science
Teaching Assistant | Miles Jones

Summer 2021
Discrete Mathematics for Computer Science
Teaching Assistant | Miles Jones

Data Science, UC San Diego

Fall 2023
Data Science Programming
Teaching Assistant | Duncan Watson-Parris

Summer 2023
Theoretical Foundations of Data Science
Teaching Assistant | Rod Albuyeh

San Diego State University

Fall 2021
First Year Seminars
Instructor, four sections

UC San Diego Extension

Aug 2019 - Sep 2020
Fundamentals of Machine Learning
Teaching Assistant | Sanjoy Dasgupta

Teaching Experiences as Instructor/TA

Rating: 92.3%

Summer 2024 Discrete Mathematics for Computer Science at UCSD CSE
Instructor | Syllabus | Course Website

Enrollment: 19

- Developed the course content based on materials from previous quarters /recorded lectures accessible in UCSD podcasts
- Held office hours and one-on-one meetings
- Created several assignments, quizzes and exams
- Led a staff of 3 TA/tutors.

Ongoing	100%	93.8%	81.25%	87.5%	75%	100%	
Spring 2025	Winter 2025	Spring 2023	Winter 2023	Summer 2022	Spring 2022	Summer 2021	Teaching Assista
Enrollment: 240	**240**	**279**	**281**	**22**	**339**	**78**	

- Taught discussion sections
- Held office hours and one-on-ones
- Helped in creating and proofreading assignments and exams
- Created grade rubrics and helped in grading
- Delivered review sessions
- Helped manage a staff of often over 10
- Question answering in piazza, etc.

Teaching Experiences as Instructor/TA

100%	100%	92.3%	
Fall 2024	Spring 2024	Winter 2024	Mathematics for Algorithms and Systems Analysis at UCSD CSE
Enrollment: 340	**193**	**246**	Teaching Assistant

- Taught discussion sections
- Held office hours and one-on-ones
- Helped in creating and proofreading assignments and exams
- Created grade rubrics and helped in grading
- Delivered review sessions
- Helped manage a staff of over 10
- Question answering in piazza, etc.

Teaching Experiences as Instructor/TA

100%

Summer 2023 — Design and Analysis of Algorithms at UCSD CSE
Teaching Assistant | Jor-El Briones

Enrollment: 36

- Taught discussion sections
- Held office hours and one-on-ones
- Helped in proofreading assignments and exams
- Created grade rubrics and helped in grading
- Delivered review sessions
- Question answering in piazza, etc.

85.7%

Fall 2023 — Data Science Programming at UCSD DSC
Teaching Assistant | Duncan Watson-Parris

Enrollment: 56

- Held office hours
- Helped in creating and proofreading assignments and exams
- Designed midterm exam
- Created grade rubrics and helped in grading
- Question answering in piazza, etc.

92.6%

Summer 2023 — Theoretical Foundations of Data Science at UCSD DSC
Teaching Assistant | Rod Albuyeh

Enrollment: 28

- Taught discussion sections
- Held office hours
- Helped in proofreading assignments and exams
- Created grade rubrics and helped in grading
- Question answering in piazza, etc.

Teaching Experiences as Instructor/TA

Fall 2021

First Year Seminars at SDSU
Instructor, four sections

- Created and led lectures and activities on topics including resume creating, building a sense of community, well-being and mental health awareness, preparation for internships and academic success strategies (time and stress management)

Aug 2019 - Sep 2020

Fundamentals of Machine Learning at UCSD Extension
Teaching Assistant | Sanjoy Dasgupta

- Question answering (online)
- Developed solution manual of HomeWorks and quizzes

Teaching Experiences as Instructor/TA: Challenges and Ideas

Discrete Mathematics for Computer Science

Students are often used to “plug-and-chug” and “watch-and-repeat” in mathematics specifically in their first year.

What to do: Discuss the difference between “math” (what they know) and “math” (what is being taught) and promote ”**growth mindset**”

Find the roots to the following quadratic equation:

$$x^2 - 2x + 3 = 0$$

$x = \frac{-b \pm \sqrt[2]{b^2-4ac}}{2a}$ and $a = 1, b = -2$ *and* $c = 3$

Hence, $x = \frac{-(-2) \pm \sqrt[2]{(-2)^2-4(1)(-3)}}{2(1)} \rightarrow x = 3$ *and* -1

VS

Are the following statements consistent? (can all of them be true without leading to contradiction)

1. $p \rightarrow (r \vee s)$
2. $q \rightarrow s$
3. $p \leftrightarrow q$
4. $\neg u$

Teaching Experiences as Instructor/TA: Challenges and Ideas

Lack of student motivation as a result of finding materials **too abstract, difficult to understand** or **not interesting to follow or uncertain about their use cases**

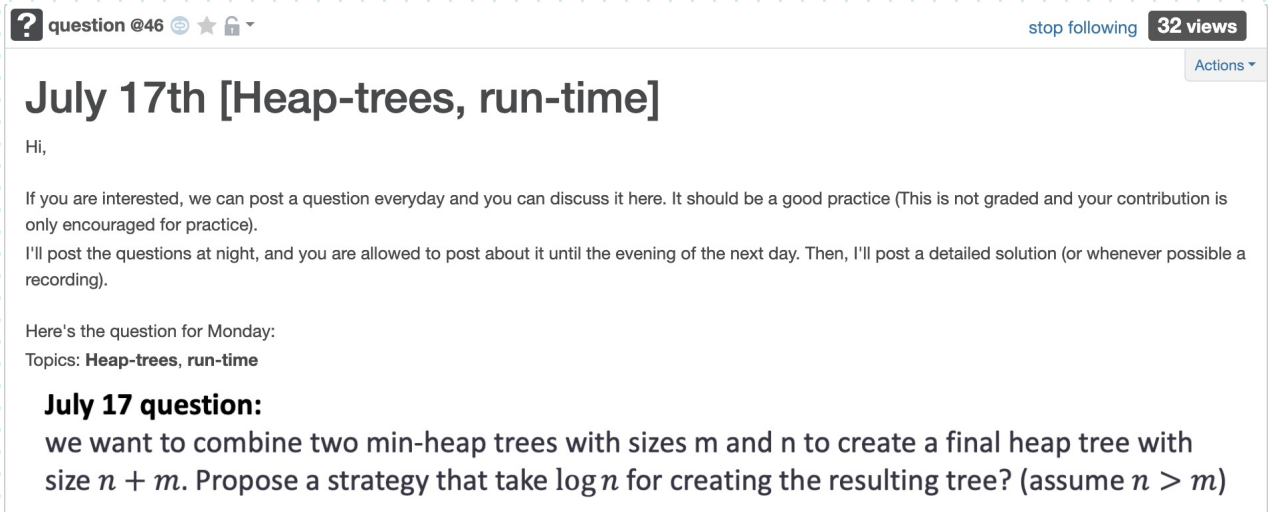
What to do: Connecting the course to real-world and interesting application

What to do: E.g. mentioning the ongoing research in a field, application of different methods in the industry: multi-level minimization techniques are used in Intel and AMD and there is ongoing research in this field.

Teaching Experiences as Instructor/TA: Challenges and Ideas

Students take some classes with different level of prepared-ness, talents and backgrounds and sometimes prejudices

What to do: Effectively support and engage all students using one-on-ones and challenging questions



question @46 ☆ stop following 32 views

Actions

July 17th [Heap-trees, run-time]

Hi,

If you are interested, we can post a question everyday and you can discuss it here. It should be a good practice (This is not graded and your contribution is only encouraged for practice).
I'll post the questions at night, and you are allowed to post about it until the evening of the next day. Then, I'll post a detailed solution (or whenever possible a recording).

Here's the question for Monday:
Topics: **Heap-trees**, **run-time**

July 17 question:
we want to combine two min-heap trees with sizes m and n to create a final heap tree with size $n + m$. Propose a strategy that take $\log n$ for creating the resulting tree? (assume $n > m$)

More challenging questions for students who aspire to further deepen their understanding
From CSE 101 class

Encouraging struggling students to join one-on-one sessions

24	**Tuesday**						
25	Time	TA/Tutor	Location/Zoom Link	Student Name	Student Email	What would you like help with? (Cannot be homework help)	Additional Comments (Optional)
26	11-11:30a	Joey	https://ucsd.zoom.us/my/jrdek				
27	11-11:30a	Joey	https://ucsd.zoom.us/my/jrdek				
28	4 - 4:30	Fatemeh	CSE 2140 or Zoom				
29	4:30 - 5	Fatemeh	CSE 2140 or Zoom				

Training/Teaching/Mentoring beyond a TA/Instructor

Experiences

Summer 2024

Mentor for PRISM Center High School Research Program led by Professor Tajana Rosing and Professor Niema Moshiri at UCSD

- 6-week fully remote program for educating students about real-world biomedical problem-solving within computing
  - Students worked on a biology-inspired machine learning project, completed a Massive Open Online Course (MOOC) for Introduction to Computation Science and OOP in python, attended UCSD faculty talks (e.g. talk by Prof. Rob Knight), learned about university applications and scholarships, and joined daily sessions and office hours
- Supported by a grant from the Semiconductor Research Corporation (SRC) through the PRISM Center
- **14 High School students, 12 from underrepresented racial or ethnic backgrounds, seven of the students had no prior computing experience and 64% were women**

I was one of the **panelists** and speakers in 2024 PRISM Annual review

I have been invited to **co-lead 2025 PRISM High School Research Program** (Jun-July)

Processing with Intelligent Storage and Memory

PRISM

Training/Teaching/Mentoring beyond a TA/Instructor

Experiences

Summer 2023

Mentor and content creation team member for Algorithmic Creativity and Python Programming Summer School Course for underserved high school students in Iran, Sharif University of Technology

- Helped in content creation and held office hours
- **+6,200 students enrolled in online version of the course to date**
- The algorithm creativity and python programming questions are based on engaging Bebras Challenges and games. No need for laptops, platform could be run on a smart phone

2022-present

HKN honor society of UC San Diego outreach program

- **Underserved middle school and high school students** are targeted for **promoting interest in STEM**
- These programs are often hands-on problem-solving activities, such as designing a simple practical circuit

Training/Teaching/Mentoring beyond a TA/Instructor

Experiences

Sep 2024 - present

Mentor for Women In Computing at UC San Diego

- Helping with navigating academic and more specifically research path for incoming graduate students

Women In Computing is also involved in:

- Familiarizing undergraduate students with general paradigm of research
- Mentoring programs and Milestone projects and workshops
- Networking with industry

Training/Teaching/Mentoring beyond a TA/Instructor

Experiences

2023 - present

Mentor of undergraduate students in System Energy Efficiency lab in UC San Diego

- Directly mentoring **4 undergraduate and 1 high school student** (most **reached out in my office hours for the courses I served as TA**)
- Resulted in one publication so far:
  - M. Gaddi, F. Ponzina, F. Asgarinejad, B. Aksanli, T. Rosing, “HyperECG: ECG Signal Inference from Radar with Hyperdimensional Computing”, BIBE, 2024.
- Ongoing projects in addressing catastrophic forgetting (Jiaying Yang and A.J Olivares) and LLM prompt engineering (Matilda Gaddi and Amir Kiadi) using Hyperdimensional Computing

Experiences

Apr 2025 - present

Chair of IEEE Student Activities San Diego Section

- Foster students engagement in opportunities to enhance their academic and professional careers

E.g. on April 17th there will be a tour for San Diego Students for Qualcomm headquarters' museum tour and snapdragon demos

IEEE

see

Teaching Education Courses, Seminars and Peer-review Program

UC San Diego Student-Centered College Teaching & Course Design Certificate

- Preparing for planning a class session that engages, values and supports students, navigating teaching decisions
- Implementing strategies to create an equitable learning experience and applying frameworks of backward design
- Teaching for equity to create learner-centered course and syllabus

Leadership in Teaching: Graduate Peer Review of Instruction Program Certificate

- Practiced developing and **refining skills in collaborative leadership, mentoring, and reflective pedagogy**

Ongoing: Transparency in Learning and Teaching

- Practices for small but significant changes to enhance student learning and performance on assignments
- Promoting Transparency to bring to light the unwritten rules and unspoken expectations of higher education

Teaching/Training Goals

Existing students:

Increase resources to increase students success, graduation rate and GPA in their programs

- **Peer-mentor groups / one-on-one sessions** for discussing the homeworks and addressing issues with prerequisites, for students who feel behind in the class
  - Previous experience: Held one-on-one sessions for 10 courses at UCSD as TA / Instructor
  - Goal: Encouraging students for attending one-on-one sessions to keep up with the course pace
- **First year seminars for better transitioning undergraduate students from high school to university**
  - Previous experience: instructor of first year seminars
  - Goal: Helping with organizing programs for better transitioning of high school students to computer science

Teaching/Training Goals

Existing students:

Increase resources to increase students success, graduation rate and GPA in their programs

- **Certificate programs, workshops, hackathons, (or larger-scale event like data festivals! to attract wider audience)**
  - Previous experience: PRISM summer school and SUT summer Python programming
  - Goal: Helping student organizations and clubs for establishing and promoting workshops, hackathons and ML/DS festivals
- **Getting more students involved in research (in general)**
  - Previous experience: Mentoring 5 undergraduate and high school students in research projects
  - Goal: Teaching basics of paradigms of research
  - Goal: Holding paper reading groups
  - Goal: Independent and directed group study in data science and machine learning with supervision of research faculty

Teaching/Training Goals

Students not in the program / high school students:

- **Skill development workshops and certificate programs with engaging projects**
  - Previous experience: TA for Machine Learning Fundamentals at UCSD Extension targeting non-affiliated students
  - Goal: Helping with initiating certificate programs and holding summer programs

Educational Activities Goals Supported by Funding

Writing educational research proposals for NSF Funding

NSF provides funding for efforts to strengthen undergraduate STEM education, graduate education, broadening participation in STEM and research on education and learning

Improving Undergraduate STEM Education: Directorate for STEM Education (IUSE: EDU)

IUSE: EDU supports research programs that promote novel, creative, and transformative approaches to generating and using new knowledge about STEM teaching and learning to improve STEM education for undergraduate students

- The developed tools/creative approaches should be implemented to the program with the help of faculty as co-PIs.
- I maintain connections with UCSD and SDSU and opportunities for joint cross-regional proposals, student exchange programs and further collaborations

NSF Scholarships in Science, Technology, Engineering, and Mathematics Program (S-STEM)

S-STEM supports institutions of higher education to fund scholarships for academically talented low-income STEM majors and to study and implement a program of activities that support their recruitment, retention and graduation

- **Scholarships impact students decisions for enrollment**
- Invite students from local High School students and community colleges
- Targeting low-income students and under-represented communities

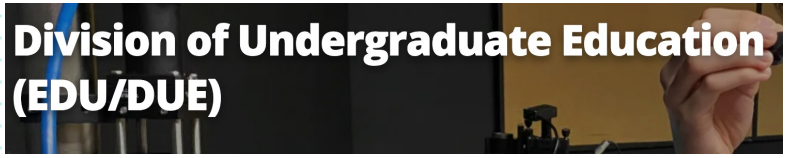
Educational Activities Goals Supported by Funding

Writing educational research proposals for NSF Funding

NSF provides funding for efforts to strengthen undergraduate STEM education, graduate education, broadening participation in STEM and research on education and learning

EHR Core Research supports activities that will advance STEM education research, including professional development for researchers, institutional training on the use of cutting-edge research techniques, and conferences.

- Funding could be used for small research-based project and workshop presentations by undergraduate students



DUE promotes STEM education through innovative curricula, faculty support and diversity initiatives to ensure student success in a changing STEM workforce

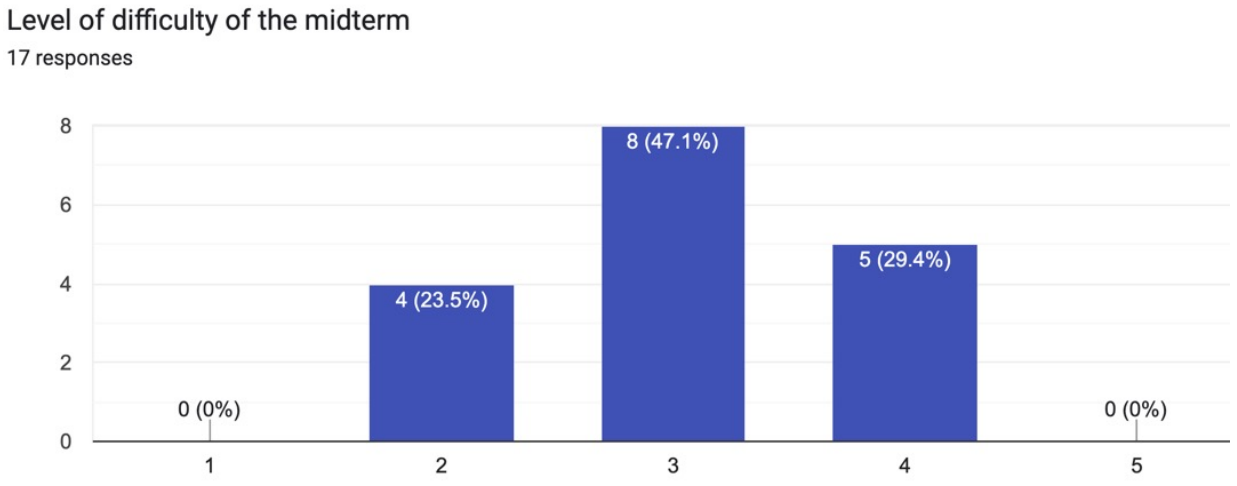
ExLENT supports hands-on learning opportunities for learners from nontraditional backgrounds, equipping them with skills for emerging technology fields and fostering workforce development through cross-sector partnerships.

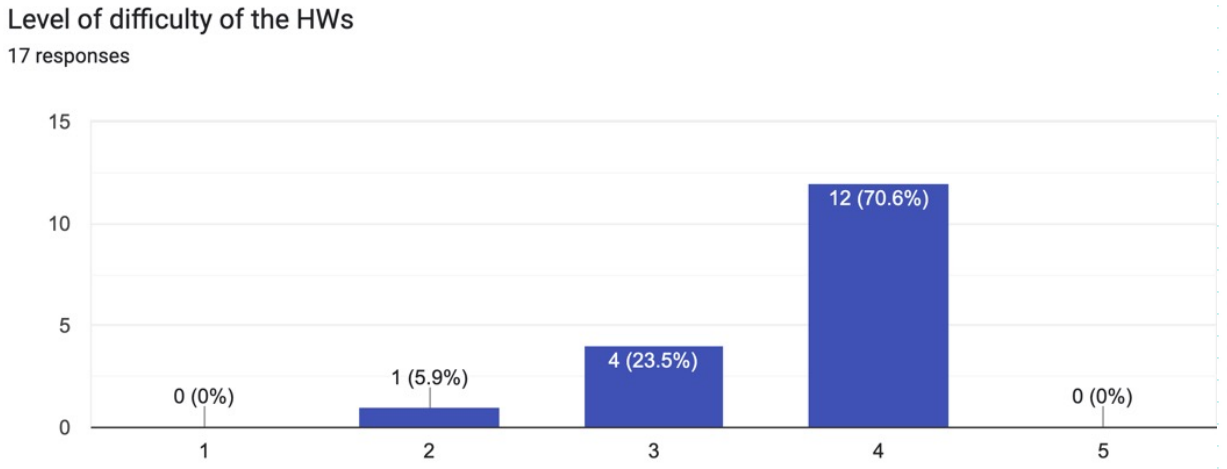
- Funding could be used for developing certificate programs, workshops and skill-building opportunities for non-STEM population

Teaching Philosophy: Feedback Mechanisms

Course feedback offers valuable teaching insights and makes students **feel heard**

Mid-quarter anonymous survey for CSE 20 at UCSD can be found here. The following are some of the results from 17 out of 19 students who participated in the survey:





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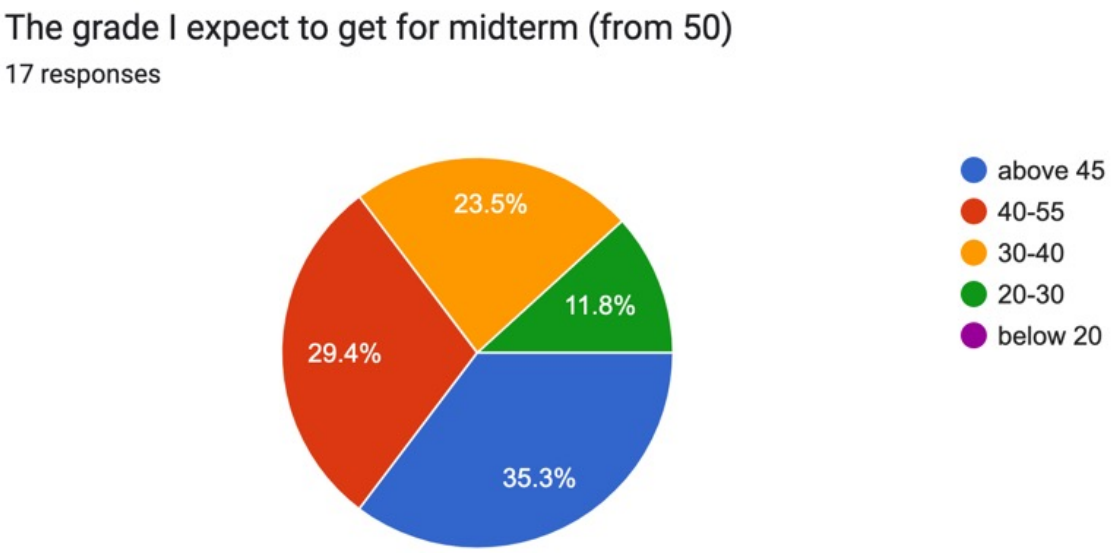
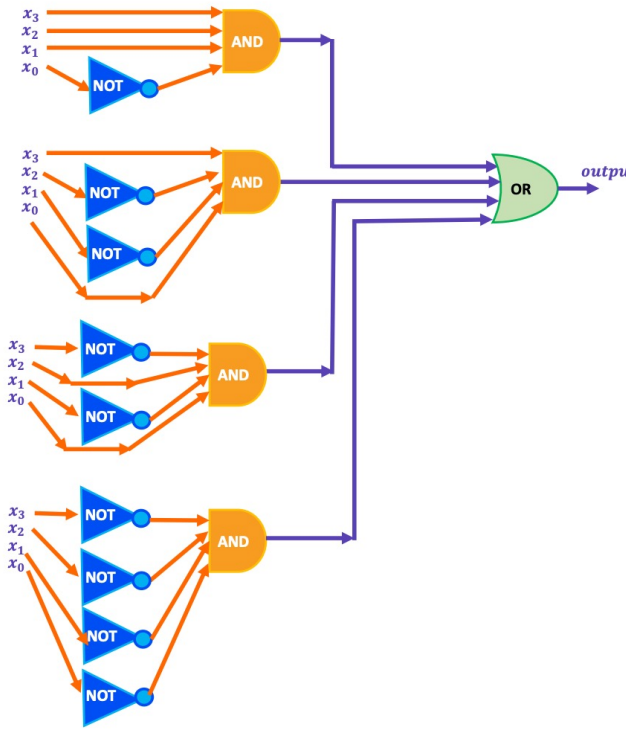


Teaching Philosophy: Well-structured, Polished and Organized Course Content / Logistics

If you invest energy and care and passion, you will cultivate care and enthusiasm



(a) $(q \wedge r) \vee \neg p$
(b) $(p \leftrightarrow r) \rightarrow (q \leftrightarrow p)$
(c) $(p \rightarrow q) \wedge (p \rightarrow r)$
(d) $((p \oplus q) \wedge (q \oplus r)) \rightarrow (p \oplus r)$

Answer

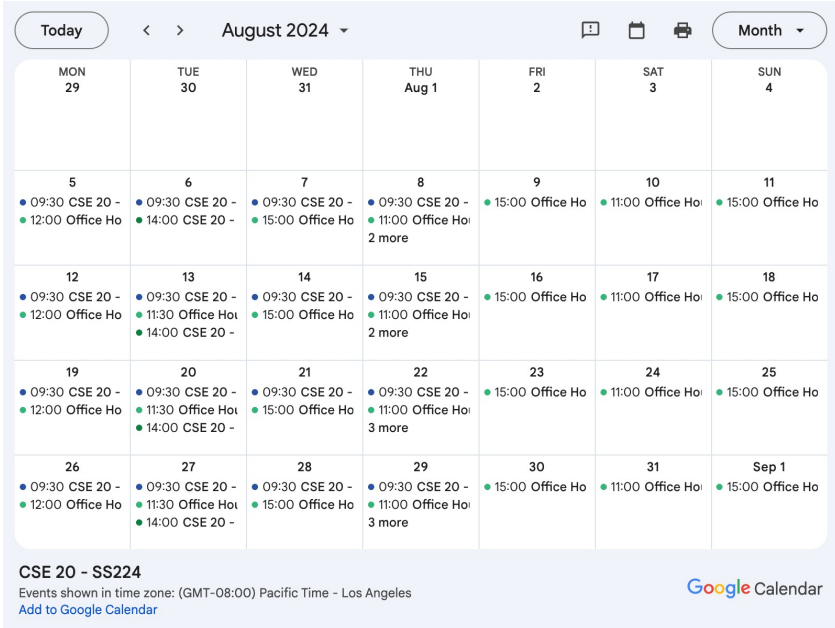
Simplification for showing (a) and (c) are logically equivalent
$(a)(q \wedge r) \vee \neg p$
$(c)(p \rightarrow q) \wedge (p \rightarrow r) = (\neg p \vee q) \wedge (\neg p \vee r)$ Using $x \rightarrow y = \neg x \vee y$
$= \neg p \vee (q \wedge r)$ Using distributive law This is equal to (a)

Using truth table for showing (b) and (d) are logically equivalent

$(b)(p \leftrightarrow r) \rightarrow (q \leftrightarrow p)$
$(d)((p \oplus q) \wedge (q \oplus r)) \rightarrow (p \oplus r)$

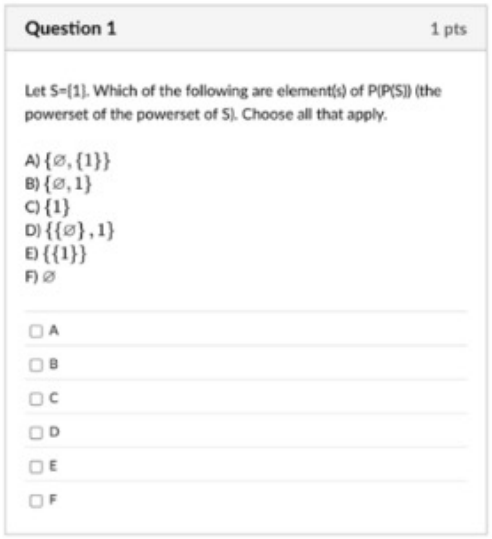
p	q	r	$p \oplus q$	$q \oplus r$	$(p \oplus q) \wedge (q \oplus r)$	$p \oplus r$	(d)	$p \leftrightarrow r$	$q \leftrightarrow p$	$(p \leftrightarrow r) \rightarrow (q \leftrightarrow p)$
T	T	T	F	F	F	F	T	T	T	T
T	T	F	F	T	F	T	T	F	T	T
T	F	T	T	T	T	F	F	T	F	F
T	F	F	T	F	F	T	T	F	F	T
F	T	T	T	F	F	T	T	F	F	T
F	T	F	T	T	T	F	F	T	F	F
F	F	T	F	F	F	T	T	F	T	T
F	F	F	F	F	F	F	T	T	T	T

(b) and (d) have the same outputs for any given set of inputs, thereby, they are logically equivalent.



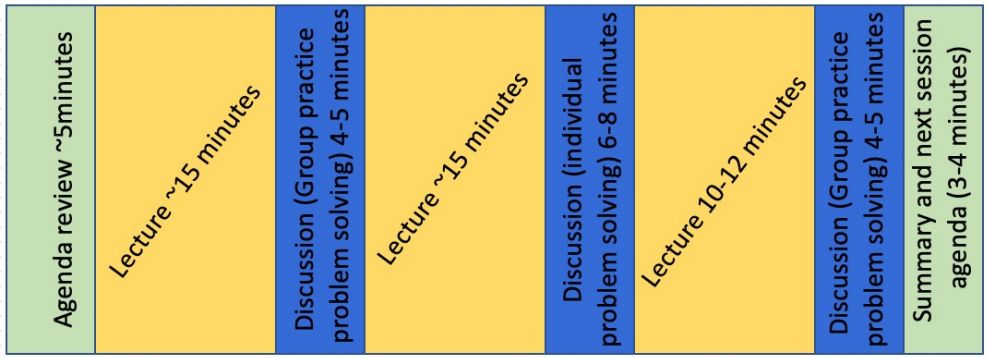
Teaching Philosophy: Active and Engaged Learning

Active Learning methods like group problem-solving exercises, group discussions, polls and daily exit tickets to enhance critical thinking and help deeper understanding of complex concepts and learn from each other



Exit Ticket

Observation: students tend to watch the recording of the lectures the day of the lecture if they were not present, helping to keep up with the course flow.



Group discussion example:

Can we use Master's Theorem in $T(n) = 2T\left(\frac{n}{2}\right) + O(n)$ to write the closed form of $T(n)$?

Teaching Philosophy: Cultivating Community in Class

Creating a sense of community involves encouraging collaboration through group projects and discussions while creating an environment where students feel comfortable asking questions or asking for help without fear of judgment

Group discussions, group projects and some group HW submissions

Practicing care and building a classroom where students feel a **sense of belonging** and **are not shy to ask for help**

Curriculum Development

Courses that could be added:

More CS/data analysis/Machine Learning courses

- Big Network Data (ECE 227) in UCSD (theoretical and empirical analysis on real data)
- Machine Learning for Physical Applications (ECE 228) (Gaussian probabilities, linear models, Kernel Methods, etc. for physical applications)
- idea: Seminar course for fine-tuning LLM for Logic design

More ML + Hardware courses:

- Machine Learning on Edge: Software Hardware Co-design
  - Stanford's Machine Learning on Embedded Systems (CS329E) link
  - MIT's TinyML and Efficient Deep Learning Computing (6.5940) link
  - UCSD's ECE 268. Security of Hardware Embedded Systems
- Hardware Accelerators for Deep Learning
  - Incorporating Professor Han's lab's ML for hardware and system's lab into desiging a ML+Hardware course link. E.g. One of their projects MCUNet does efficient neural architecture on microcontrollers

Project-based courses that use tools and CADs used in industry accompanied by discussions and guest lectures by industry experts

Course	Quarter	Roll	Rating (%)	Enrollment	Pages in misc. document
CSE 21 Math/Algorithm & Systems Analysis	Fall 2024	TA	Ongoing	340	Ongoing
CSE 20 Discrete Mathematics	Summer 2024	Instructor	12/13 (92.3%)	19	5 - 10
CSE 21 Math/Algorithm & Systems Analysis	Spring 2024	TA	10/10 (100%)	193	11 - 14
CSE 21 Math/Algorithm & Systems Analysis	Winter 2024	TA	12/13 (92.3%)	246	15 - 18
DSC 200 Data Science Programming	Fall 2023	TA	6/7 (85.7%)	56	19- 22
DSC 40A Theoretical Foundations of Data Science 1	Summer 2023	TA	11/12 (91.6%)	28	23 -26
CSE 101 Design & Analysis of Algorithm	Summer 2023	TA	10/10 (100%)	36	27 - 30
CSE 20 Discrete Mathematics	Spring 2023	TA	15/16 (93.8%)	279	31 - 35
CSE 20 Discrete Mathematics	Winter 2023	TA	13/16 (81.25%)	281	36 - 39
CSE 20 Discrete Mathematics	Summer 2022	TA	7/8 (87.5%)	22	40 - 43
CSE 20 Discrete Mathematics	Spring 2022	TA	3/4 (75%)	339	44 - 47
CSE 20 Discrete Mathematics	Summer 2021	TA	7/7 (100%)	78	48 - 51