Simple Digital Logic Design (H-Bridge)

Georgia Institute of Technology

CS 3651 – Prototyping Intelligent Appliances

Simple Digital Logic Design

- The basic steps in designing a simple digital circuit are:
  - Step 1: Define the problem
    - Truth tables
  - Step 2: Translate truth tables into combinatorial logic circuit
    - Boolean Algebra
    - Minterms
    - Sum of Products (or Product of Sums)
  - Step 3: Optimization
    - Boolean Identities
    - DeMorgan's Law
    - Karnaugh Maps (K-Maps)
  - Step 4: Build It!
    - Protoboard and Integrated Circuits.

    - Warning: This is a lot of information if it is your first exposure to circuits!

Step 1: Define the Problem

- Digital logic circuits can contain multiple inputs and outputs.
- The combinations of inputs and outputs can be represented in a table form (called truth tables).
- Truth tables should list ALL the combinations of inputs and outputs.

Example: Inverter

Input	**Output**
0	1
1	0

Our Problem: H-bridge

- We want to build a device called an H-Bridge.
  - An H-bridge is a simple motor controller that is used to provide 4 functions to an electric motor: Forward, Reverse, Brake, and Coast. The functions are selected with 2 input lines.
  - The H-bridge is built with 4 switches, and allows voltage to be applied across the motor in either direction.

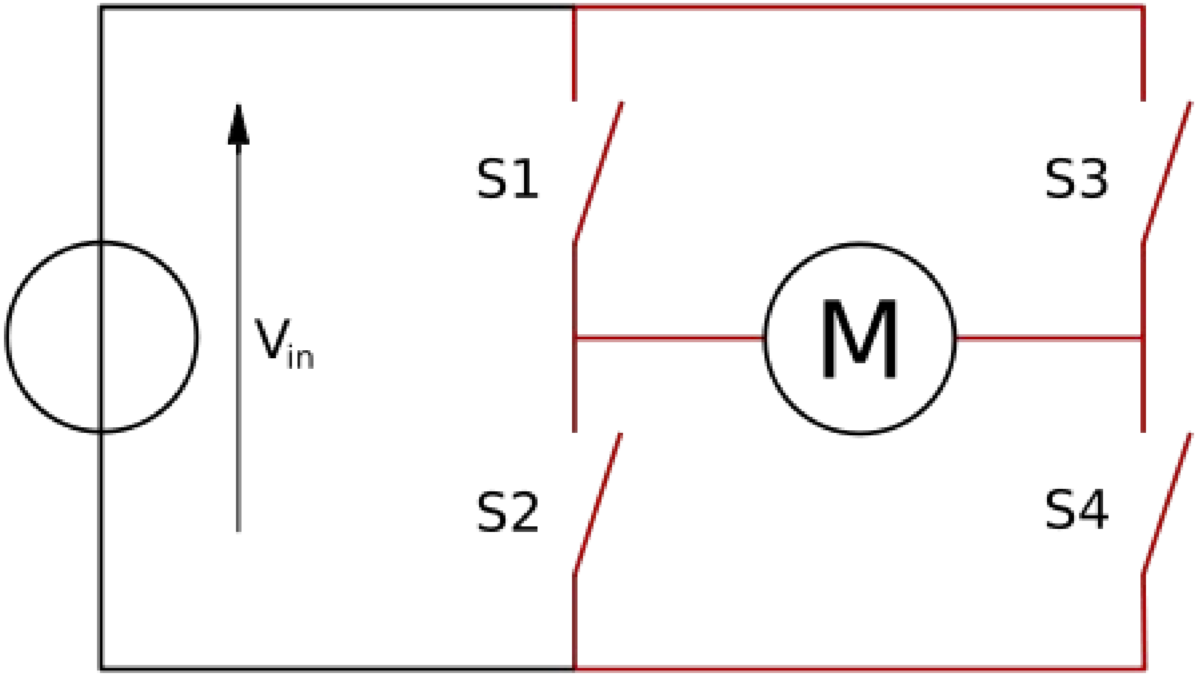


Photo courtesy of Wikipedia

H-Bridge Truth Table

- H-Bridge input table H-Bridge output table

IN 2	IN 1	Function
0	0	Coast
0	1	Forward
1	0	Reverse
1	1	Brake

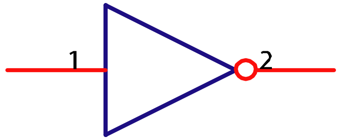
Function	SW1	SW2	SW3	SW4
Coast	0	0	0	0
Forward	1	0	0	1
Reverse	0	1	1	0
Brake	1	0	1	0

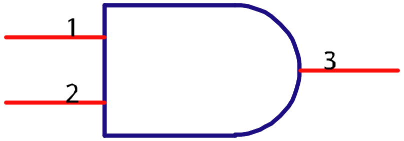
- H-Bridge full combinatorial logic full truth table

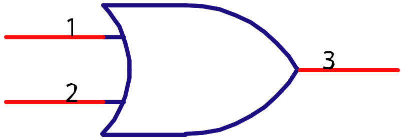
IN2	IN1	SW1	SW2	SW3	SW4	Function
0	0	0	0	0	0	Coast
0	1	1	0	0	1	Forward
1	0	0	1	1	0	Reverse
1	1	1	0	1	0	Brake

Step 2: Translate truth table into circuit

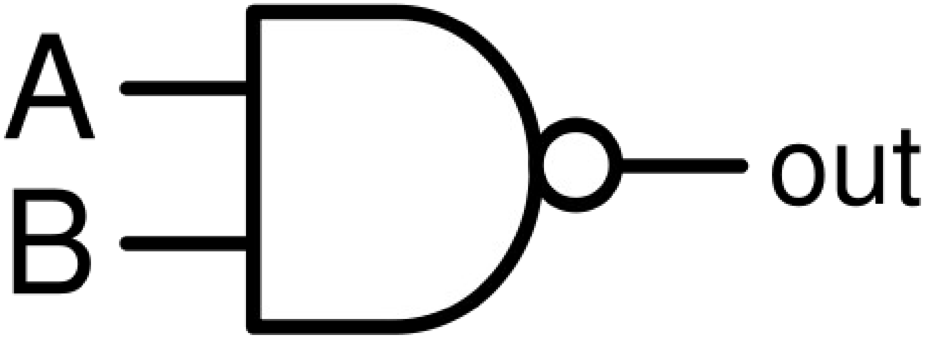
- All digital circuits can be built with some combination of AND, OR, and NOT gates.
- Depending on what gates you have available, you can redesign your circuit to use different types of gates (using DeMorgan's Law).
- NAND gates are widely used.





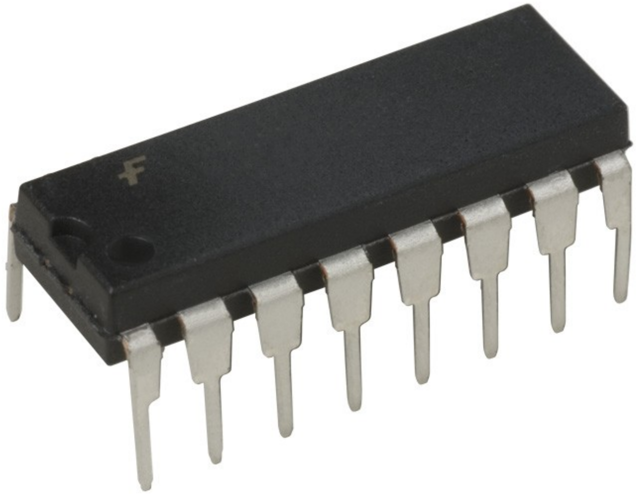


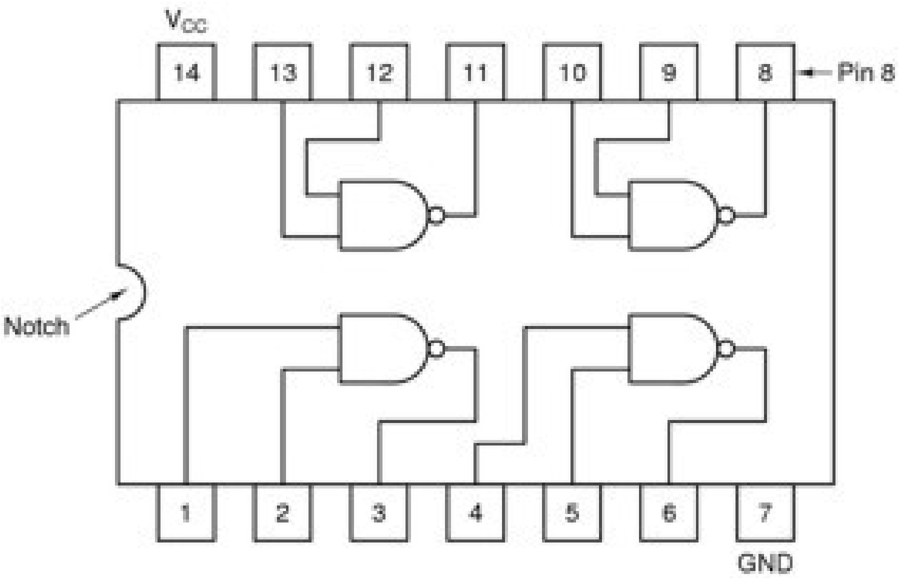
A	B	OUT
0	0	1
0	1	1
1	0	1
1	1	0



Step 2 cont.: Translate truth table into circuit

- These gates are available in integrated circuits that you can buy at electronics stores (RadioShack, Fry's, etc.)





Step 2 cont.: Translate truth table into circuit

- There are a couple different ways to translate a truth table into a physical circuit.
- One easy was is the Sum of Products method (SOP), another way is the Product of Sums (POS) method.
- These methods create a working circuit that is NOT optimized.
- Uses Boolean algebra (not the same as regular algebra)
  - A=B+C A=B OR C
  - A=B*C A=B AND C
  - A=BC A=B AND C
  - $A=\overline{B}$ A=NOT(B)

Sum of Products

- Select the rows that generate a TRUE output, and then combine the terms with an OR gate.
- You do this separately for each output value (sw1. . .sw4).

IN2	IN1	SW1	SW2	SW3	SW4	Function
0	0	0	0	0	0	Coast
0	1	1	0	0	1	Forward
1	0	0	1	1	0	Reverse
1	1	1	0	1	0	Brake

IN2	IN1	SW1
0	0	0
0	1	1
1	0	0
1	1	1

IN2	IN1	SW2
0	0	0
0	1	0
1	0	1
1	1	0

IN2	IN1	SW3
0	0	0
0	1	0
1	0	1
1	1	1

IN2	IN1	SW4
0	0	0
0	1	1
1	0	0
1	1	0

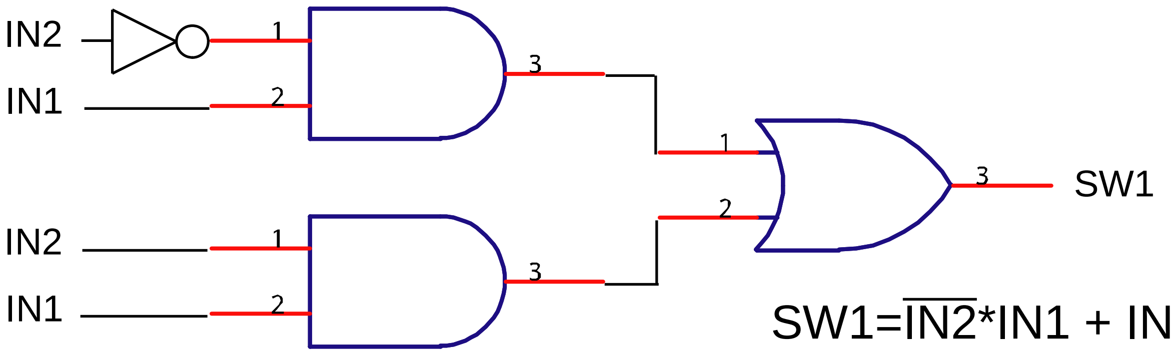
SW1= $\overline{IN2}*IN1 + IN2*IN1$

SW2= $IN2*\overline{IN1}$

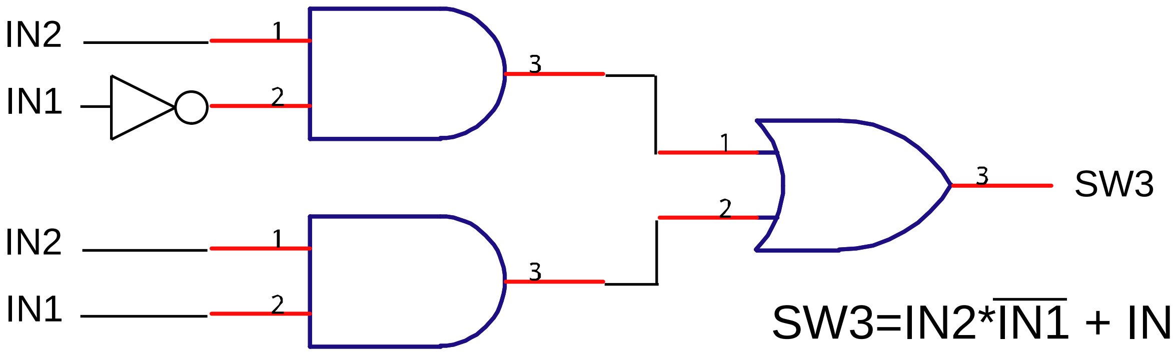
SW3= $IN2*\overline{IN1} + IN2*IN1$

SW4= $\overline{IN2}*IN1$

Sum of Products

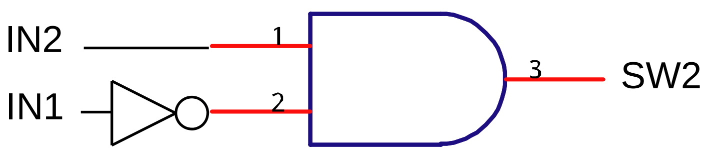


SW1=$\overline{IN2}$*IN1 + IN2*IN1

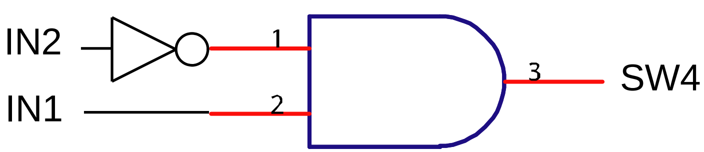


SW3=IN2*$\overline{IN1}$ + IN2*IN1

Do you see any unnecessary gates?



SW2=IN2*$\overline{IN1}$



SW4=$\overline{IN2}$*IN1

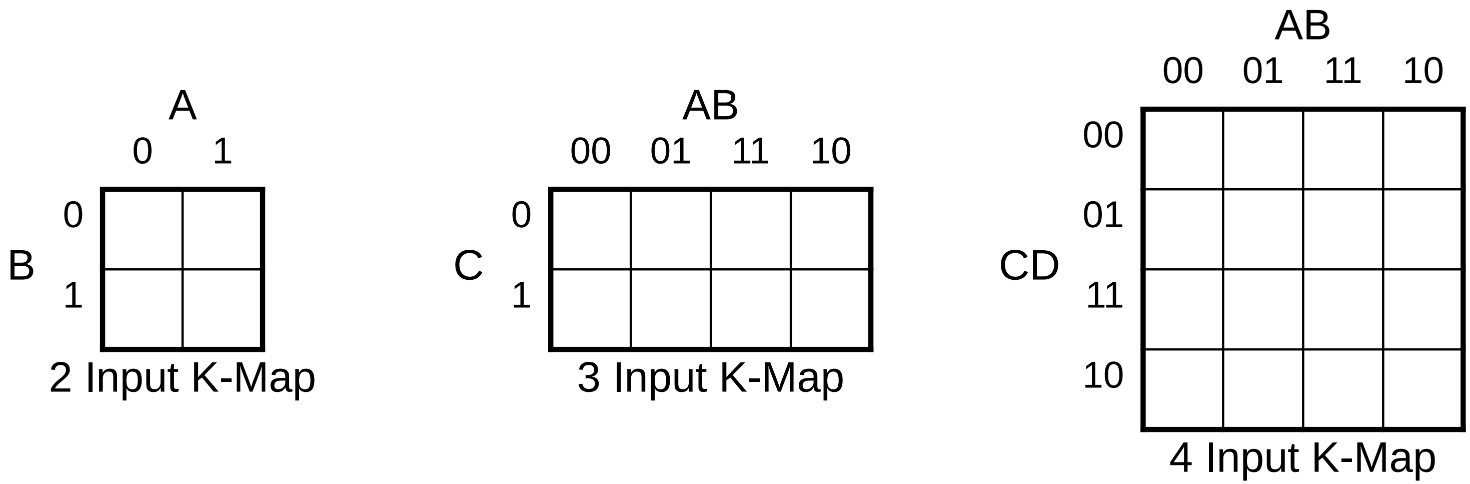
Step 3: Optimization – Boolean Identities

- Using Boolean identities, the circuit can be simplified.

1.	Law of Identity	$A = A$ $\overline{A} = \overline{A}$
2.	Commutative Law	$A \cdot B = B \cdot A$ $A + B = B + A$
3.	Associative Law	$A \cdot (B \cdot C) = A \cdot B \cdot C$ $A + (B + C) = A + B + C$
4.	Idempotent Law	$A \cdot A = A$ $A + A = A$
5.	Double Negative Law	$\overline{\overline{A}} = A$
6.	Complementary Law	$A \cdot \overline{A} = 0$ $A + \overline{A} = 1$
7.	Law of Intersection	$A \cdot 1 = A$ $A \cdot 0 = 0$
8.	Law of Union	$A + 1 = 1$ $A + 0 = A$
9.	DeMorgan's Theorem	$\overline{AB} = \overline{A} + \overline{B}$ $\overline{A + B} = \overline{A}\,\overline{B}$
10.	Distributive Law	$A \cdot (B + C) = (A \cdot B) + (A \cdot C)$ $A + (BC) = (A + B) \cdot (A + C)$
11.	Law of Absorption	$A \cdot (A + B) = A$ $A + (AB) = A$
12.	Law of Common Identities	$A \cdot (\overline{A} + B) = AB$ $A + (\overline{A}B) = A + B$

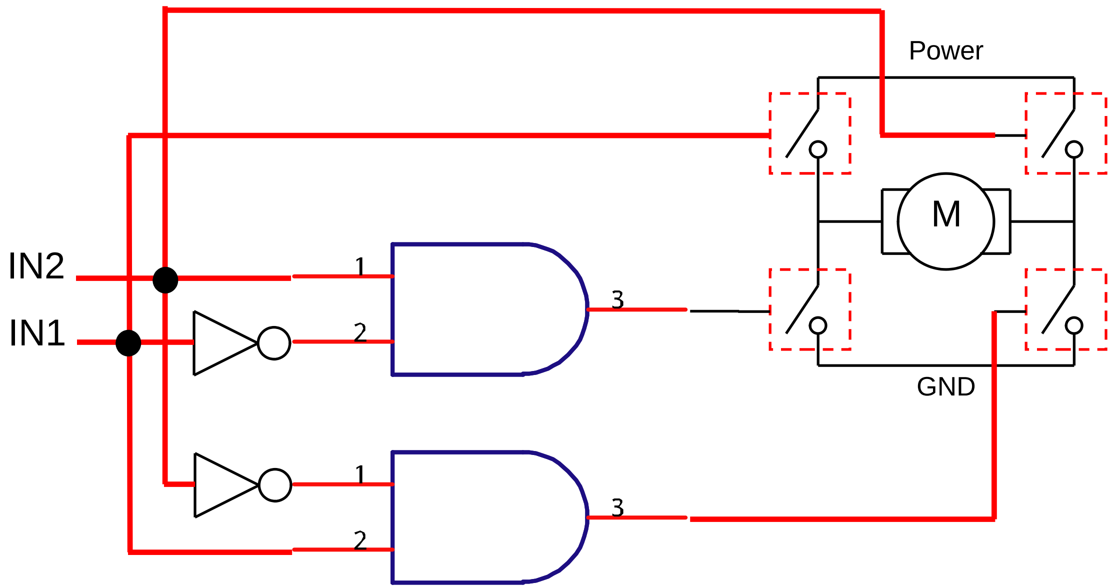
Step 3: Optimization – K Maps

- Karnaugh Maps are a graphical way to optimize circuits.
- It involves populating the K-map tables from the truth tables with the correct vales, and then grouping rectangles of 1’s together according to certain rules.



Step 4: Build it!

Final Circuit



Conclusion

- This method is great for prototyping because
  - 1) It is really cheap. Each discrete logic chip is about 10 cents.
  - 2) It is reliable, the chips do what you want them to do as soon as you get them. No programming necessary.
- The catch: it does not scale well for anything more than a simple circuit.
- It does not have any delays built in to compensate for the switching times of the H-Bridge!
- FPGA (field programmable gate arrays) are used for more complex circuits, and require the user to program the chips.