Chapter # 1: Introduction

Contemporary Logic Design

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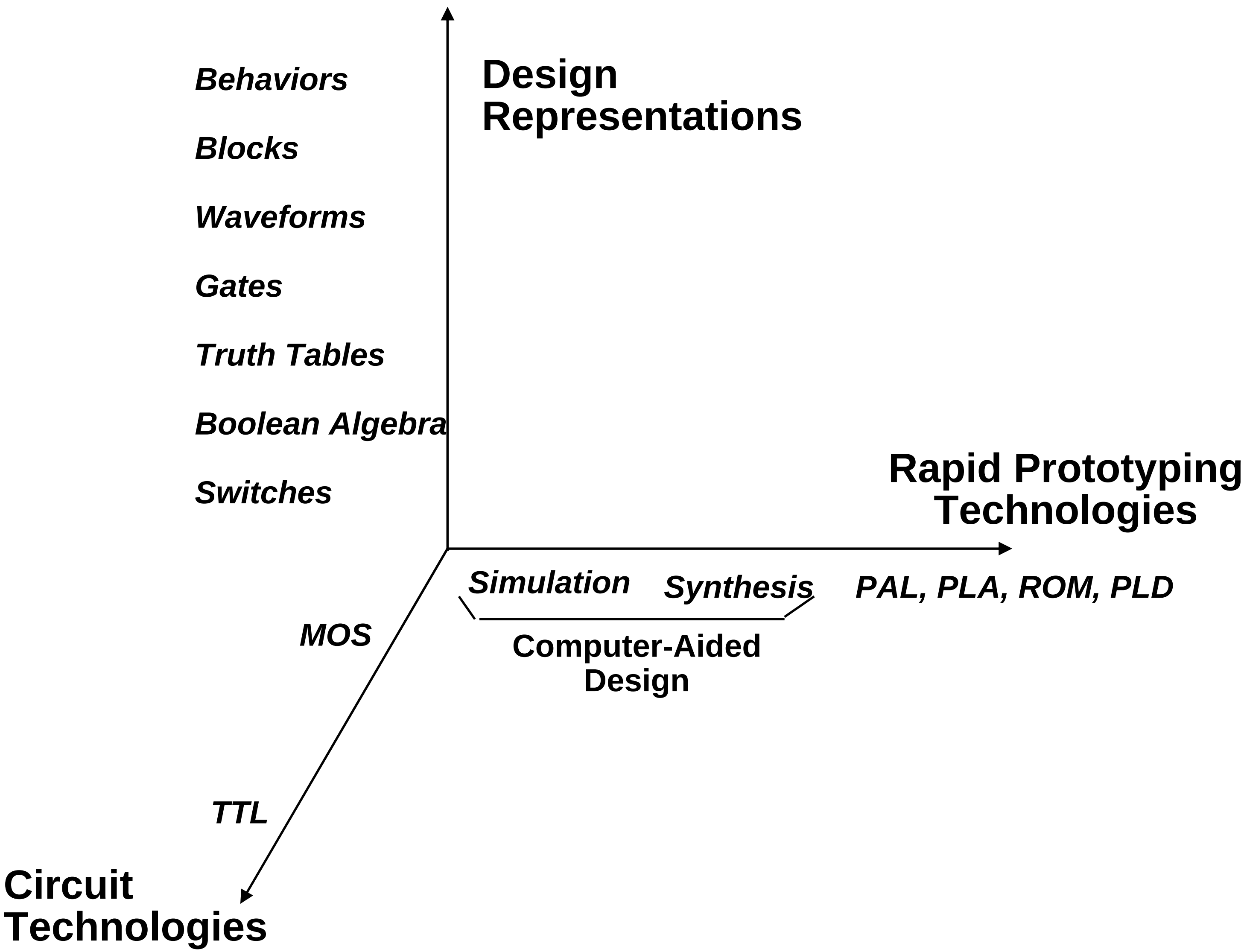
The Elements of Modern Design

Representations, Circuit Technologies, Rapid Prototyping



The Process of Design

Bottom Up Assembly

Primitives composed to build more and more complex assemblies

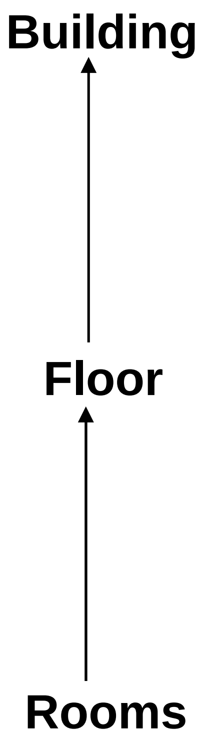
e.g., a group of rooms form a floor

e.g., a group of floors form a bldg.

a group of transistors form a gate

a group of gates form an addition circuit

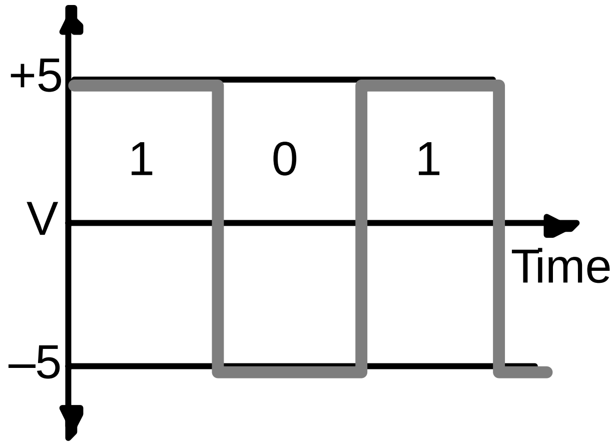
addition circuits plus storage circuits form a processor datapath

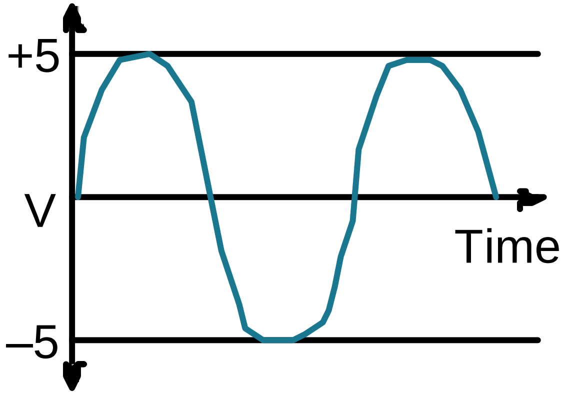


Digital Hardware Systems

Digital Systems

Digital vs. Analog Waveforms





Digital:
only assumes discrete values

Analog:
values vary over a broad range continuously

Digital Hardware Systems

Advantages of Digital Systems

Analog systems: slight error in input yields large error in output

Digital systems more accurate and reliable
Readily available as self-contained, easy to cascade building blocks

Computers use digital circuits internally

Interface circuits (i.e., sensors & actuators) often analog

This course is about logic design, not system design (processor architecture), not circuit design (transistor level)

Digital Hardware Systems

Digital Binary Systems

- ***Two discrete values:***
  yes, on, 5 volts, current flowing, magnetized North, "1"
  no, off, 0 volts, no current flowing, magnetized South, "0"

- ***Advantage of binary systems:***
  rigorous mathematical foundation based on logic

IF the garage door is open
AND the car is running
THEN the car can be backed out of the garage

both the door must be open and the car running before I can back out

IF N-S is green
AND E-W is red
AND 45 seconds has expired since the last light change
THEN we can advance to the next light configuration

the three preconditions must be true to imply the conclusion

Digital Hardware Systems

Boolean Algebra and Logical Operators

Algebra: **variables, values, operations**

In Boolean algebra, the values are the symbols 0 and 1
If a logic statement is false, it has value 0
If a logic statement is true, it has value 1

Operations: AND, OR, NOT

X	Y	X AND Y
0	0	0
0	1	0
1	0	0
1	1	1

X	Y	X OR Y
0	0	0
0	1	1
1	0	1
1	1	1

X	NOT X
0	1
1	0

Hardware Systems and Logical Operators

IF the garage door is open
AND the car is running
THEN the car can be backed out of the garage

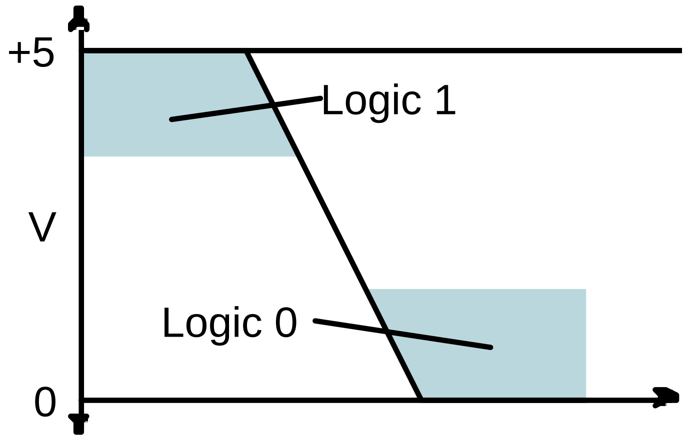
door open?	car running?	back out car?
false/0	false/0	false/0
false/0	true/1	false/0
true/1	false/0	false/0
true/1	true/1	TRUE/1

Digital Hardware Systems

The Real World

Physical electronic components are continuous, not discrete!

These are the building blocks of all digital components!



Transition from logic 1 to logic 0 does not take place instantaneously in real digital systems

Intermediate values may be visible for an instant

Boolean algebra useful for describing the steady state behavior of digital systems

Be aware of the dynamic, time varying behavior too!

Digital Circuit Technologies

Integrated circuit technology

choice of conducting, non-conducting, sometimes conducting ("semiconductor") materials

whether or not their interaction allows electrons to flow forms the basis for electrically controlled switches

Main technologies

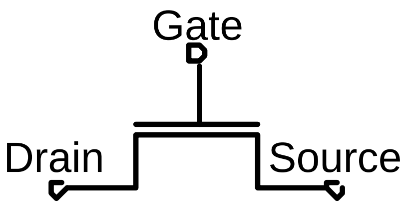
MOS: Metal-Oxide-Silicon

Bipolar
- **Transistor-Transistor Logic**
- **Emitter Coupled Logic**

MOS Technology

Transistor

basic electrical switch

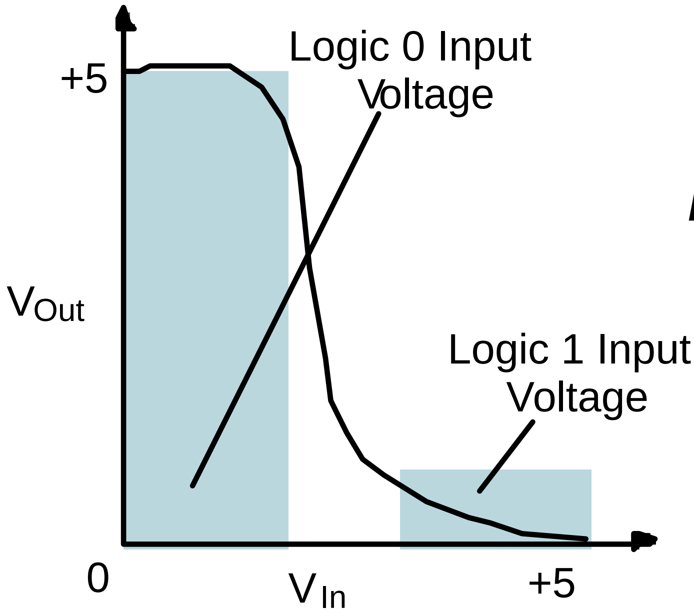


three terminal switch: **gate, source, drain**

voltage between gate and source exceeds threshold
switch is conducting or "closed"
electrons flow between source and drain

when voltage is removed,
the switch is "open" or non-conducting
connection between source and drain is broken

Circuit that implements logical negation (NOT)



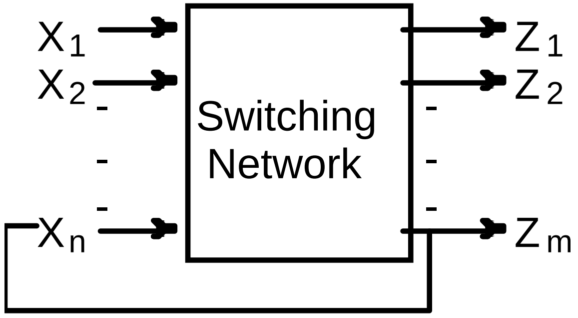
1 at input yields 0 at output
0 at input yields 1 at output

Inverter behavior as a function of input voltage

- **input ramps from 0V to 5V**
- **output holds at 5V for some range of small input voltages**
- **then changes rapidly, but not instantaneously!**

remember distinction between steady state and dynamic behavior

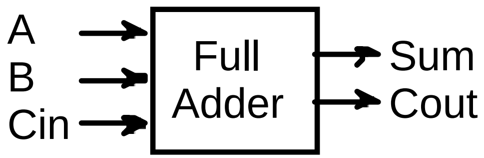
Combinational vs. Sequential Logic



Network implemented from switching elements or logic gates. The presence of feedback distinguishes between *sequential* and *combinational* networks.

Combinational logic

no feedback among inputs and outputs
outputs are a pure function of the inputs
e.g., full adder circuit:
(A, B, Carry In) mapped into (Sum, Carry Out)



Digital Hardware Systems

Sequential logic

inputs and outputs overlap
outputs depend on inputs *and* the entire history of execution!

network typically has only a limited number of unique configurations
these are called *states*
e.g., traffic light controller sequences infinitely through four states

new component in sequential logic networks:
storage elements to remember the current state

output and new state is a function of the inputs and the old state
i.e., the fed back inputs are the state!

Synchronous systems

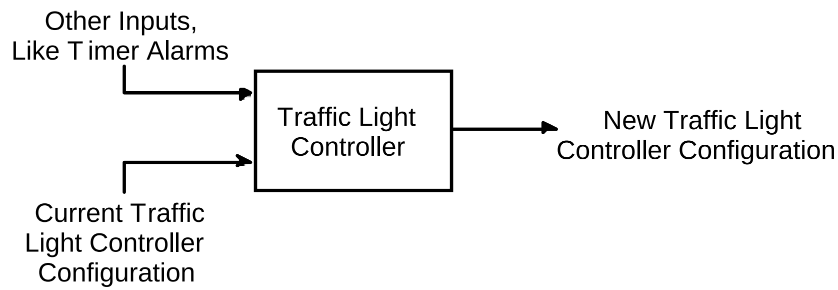
period reference signal, the clock, causes the storage elements to accept new values and to change state

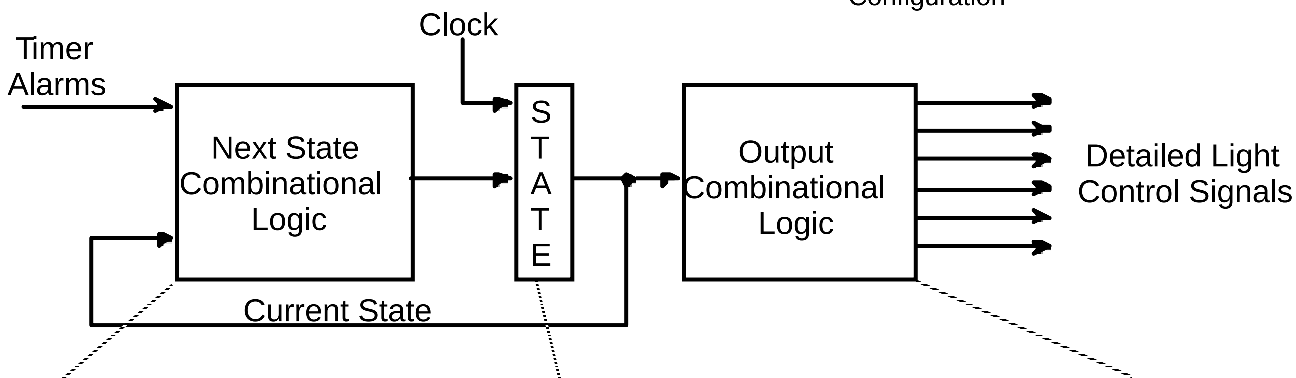
Asynchronous systems

no single indication of when to change state

Combinational vs Sequential Logic

Traffic Light Example





Next State Logic

Maps current state and alarm events into the next state

Current State

Storage elements replaced by next state when the clock signal arrives

Output Logic

Current state mapped into control signals to change the lights and to start the event timers

IF controller in state N-S green, E-W red
AND the 45 second timer alarm is asserted
THEN the next state becomes N-S yellow,
E-W red when the clk signal is next asserted

Representations of a Digital Design

Switches

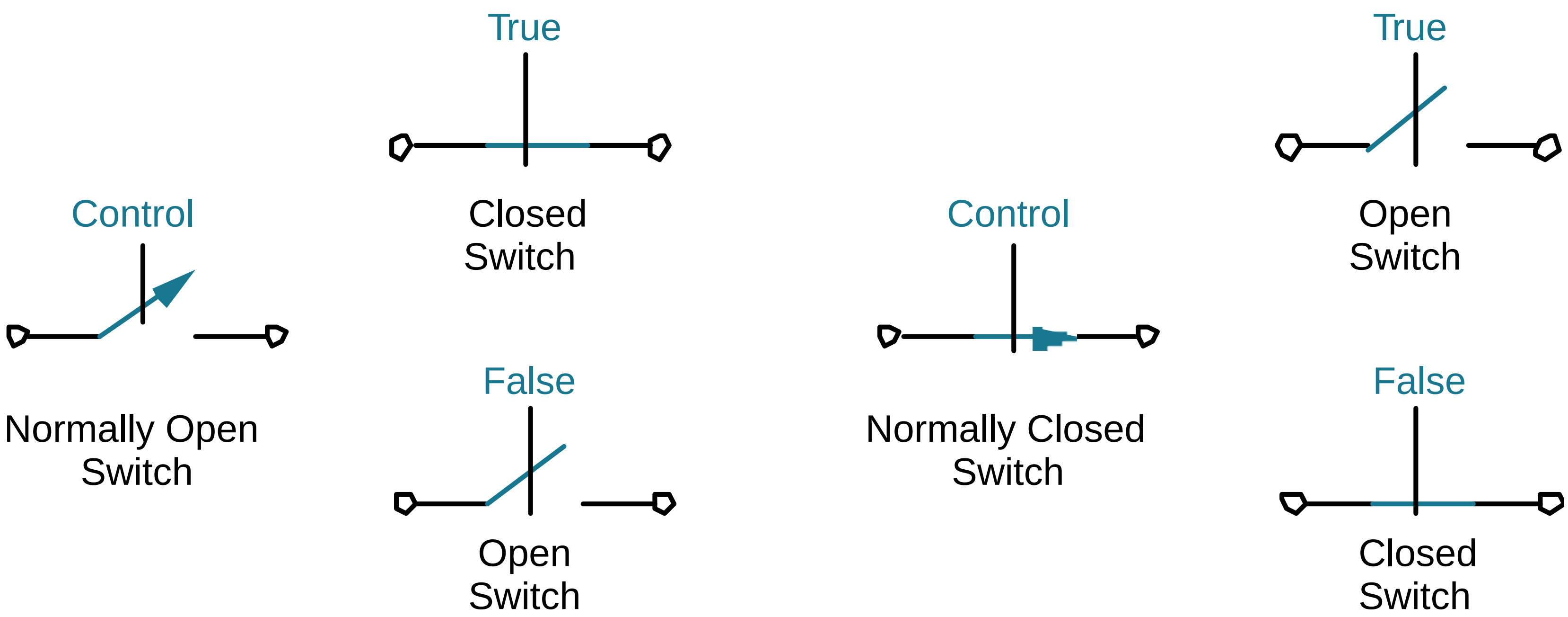
A switch connects two points under control signal.

Normally Open — **when the control signal is 0 (false), the switch is open**

when it is 1 (true), the switch is closed

Normally Closed — **when control is 1 (true), switch is open**

when control is 0 (false), switch is closed

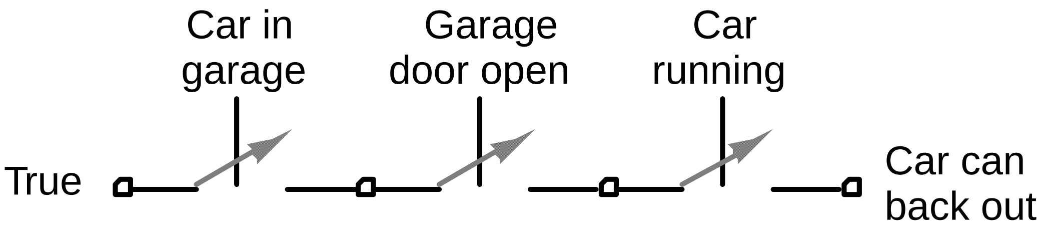


Representations of a Digital Design: Switches

Examples: routing inputs to outputs through a maze

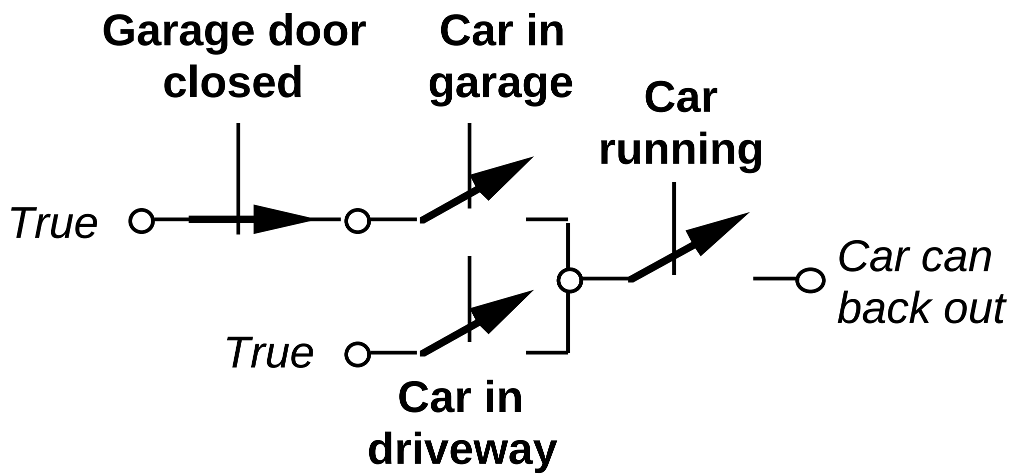
EXAMPLE:

IF car in garage
AND garage door open
AND car running
THEN back out car



EXAMPLE:

IF car in driveway
OR (car in garage
AND NOT garage door closed)
AND car running
THEN can back out car

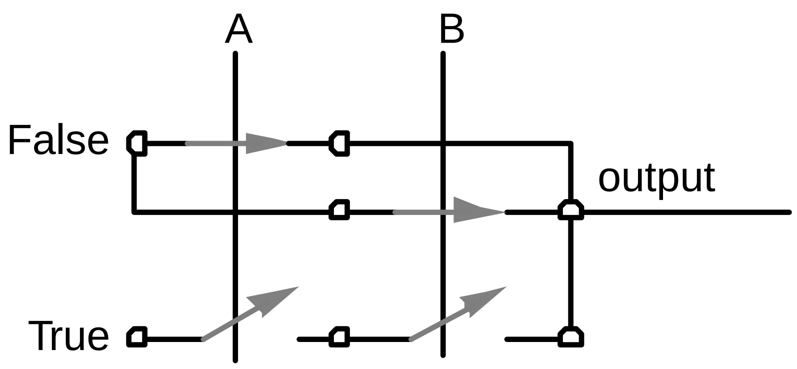


Floating nodes:
- **what happens if the car is not running?**
- **outputs are floating rather than forced to be false**

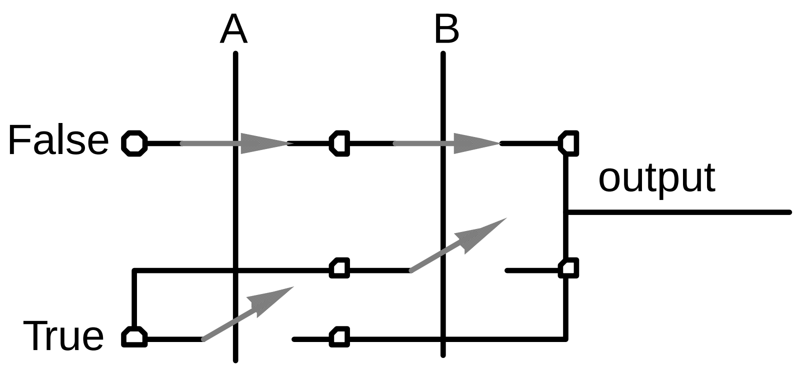
Under all possible control signal settings
- **(1) all outputs must be connected to some input through a path**
- **(2) no output is connected to more than one input through any path**

Representations of a Digital Design: Switches

Implementation of AND and OR Functions with Switches



AND function
Series connection to TRUE



OR function
Parallel connection to TRUE

Representations of a Digital Design

Truth Tables

tabulate all possible input combinations and their associated output values

Example: **half adder**
adds two binary digits to form Sum and Carry

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

NOTE: 1 plus 1 is 0 with a carry of 1 in binary

Example: **full adder**
adds two binary digits and Carry in to form Sum and Carry Out

A	B	Cin	Sum	Cout
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Representations of a Digital Design

Boolean Algebra

values: 0, 1
variables: A, B, C, . . ., X, Y, Z
operations: NOT, AND, OR, . . .

NOT X is written as $\overline{X}$
X AND Y is written as X & Y, or sometimes X Y
X OR Y is written as X + Y

Deriving Boolean equations from truth tables:

A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Sum = $\overline{A}\,B + A\,\overline{B}$

OR'd together *product* terms for each truth table row where the function is 1

if input variable is 0, it appears in complemented form; if 1, it appears uncomplemented

Carry = A B

Representations of a Digital Design: Boolean Algebra

Another example:

A	B	Cin	Sum	Cout
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

$$\text{Sum} = \overline{A}\ \overline{B}\ \text{Cin} + \overline{A}\ B\ \overline{\text{Cin}} + A\ \overline{B}\ \overline{\text{Cin}} + A\ B\ \text{Cin}$$

$$\text{Cout} = \overline{A}\ B\ \text{Cin} + A\ \overline{B}\ \text{Cin} + A\ B\ \overline{\text{Cin}} + A\ B\ \text{Cin}$$

Representations of a Digital Design: Boolean Algebra

Reducing the complexity of Boolean equations

Laws of Boolean algebra can be applied to full adder's carry out function to derive the following simplified expression:

Cout = A Cin + B Cin + A B

B Cin

A Cin

A B

A	B	Cin	Cout
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

Verify equivalence with the original Carry Out truth table:

place a 1 in each truth table row where the product term is true

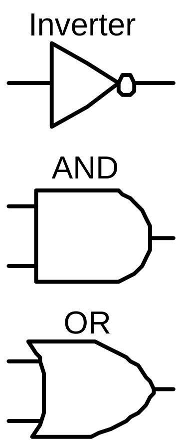
each product term in the above equation covers exactly two rows in the truth table; several rows are "covered" by more than one term

Representations of a Digital Design

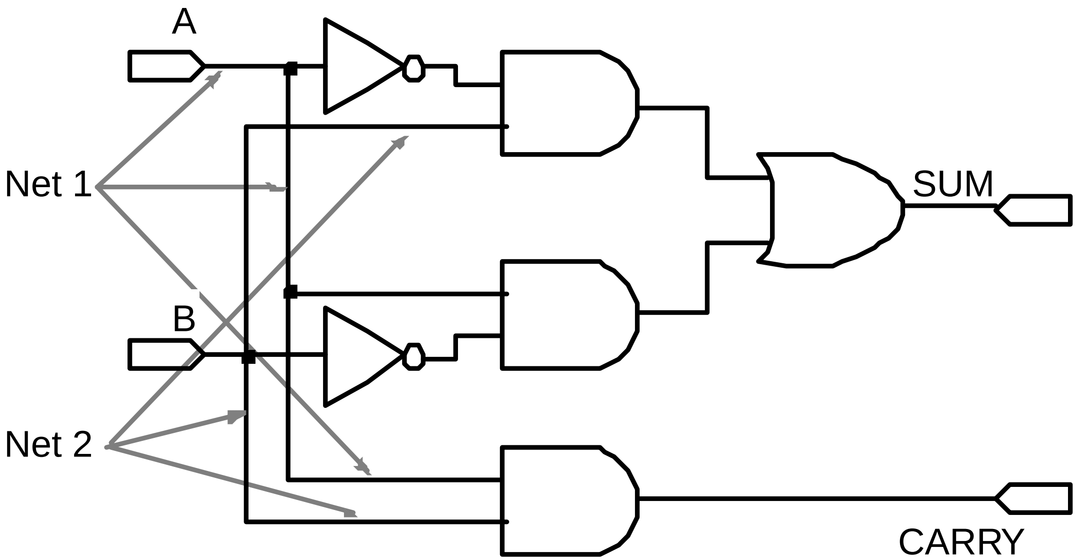
Gates

most widely used primitive building block in digital system design

Standard Logic Gate Representation



Half Adder Schematic

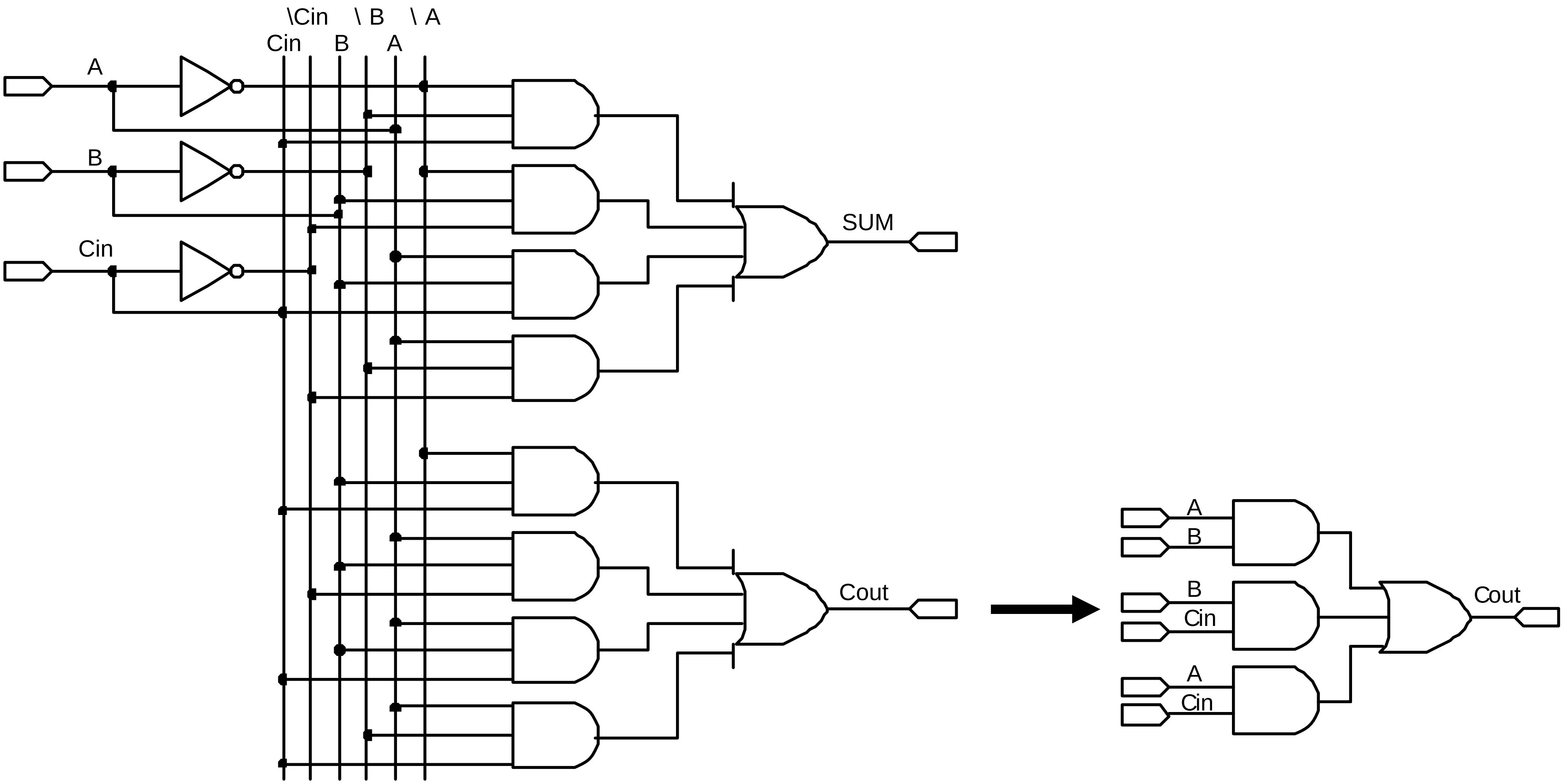


Net: **electrically connected collection of wires**

Netlist: **tabulation of gate inputs & outputs and the nets they are connected to**

Representations of a Digital Design: Gates

Full Adder Schematic



Fan-in: **number of inputs to a gate**
Fan-out: **number of gate inputs an output is connected to**

Technology "Rules of Composition" place limits on fan-in/fan-out

Representations of a Digital Design

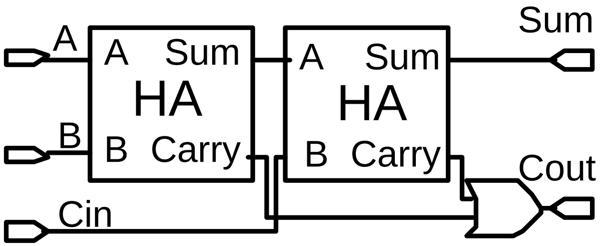
Blocks

structural organization of the design

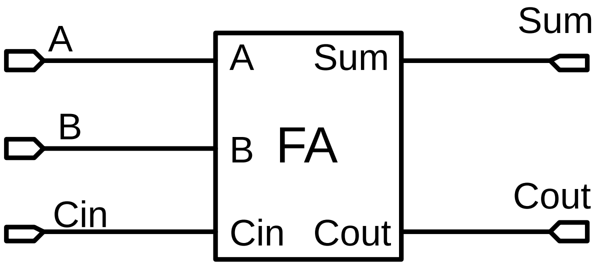
black boxes with input and output connections

corresponds to well defined functions

concentrates on how the components are composed by wiring



Full Adder realized in terms of composition of half adder blocks



Block diagram representation of the Full Adder