Circuits

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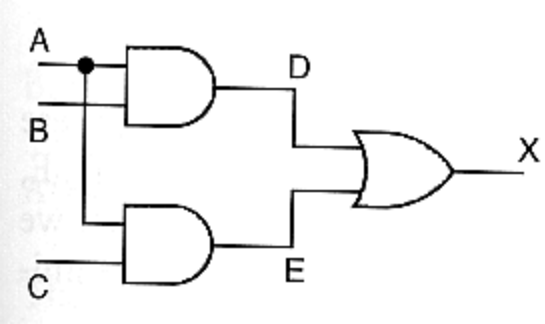
Combinatorial and Sequential Circuits: Definitions

A *combinatorial circuit* is a circuit whose output is solely determined by its input values.

A *sequential circuit* is a circuit whose output is a function of input values **and** the current state of the circuit.

Combinatorial Circuits

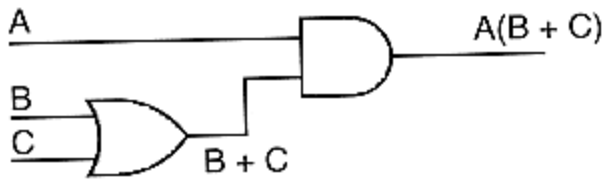


A	B	C	D	E	X
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

Java expression:

```
boolean A,B,C,X;
X = ((A && B) || (A && C));
```

Combinatorial Circuits (cont'd)



A	B	C	B + C	A(B+C)
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	0
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

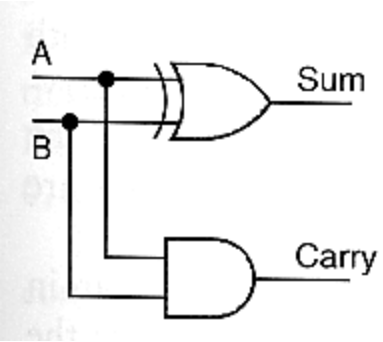
Java expression:

```
boolean A,B,C,X;
X = A && (B || C);
```

Properties of Boolean Algebra

Property	AND	OR
Commutative	$A \cdot B = B \cdot A$	$A+B = B+A$
Associative	$(A \cdot B) \cdot C = A \cdot (B \cdot C)$	$(A+B)+C=A+(B+C)$
Distributive	$A \cdot (B+C) = (A \cdot B)+(A \cdot C)$	$A+(B \cdot C)=(A+B) \cdot (A+C)$
Identity	$A \cdot 1 = A$	$A+0=A$
Complement	$A \cdot (A')=0$	$A+(A')=1$
DeMorgan's law	$(A \cdot B)' = (A')+(B')$	$(A+B)'=(A') \cdot (B')$

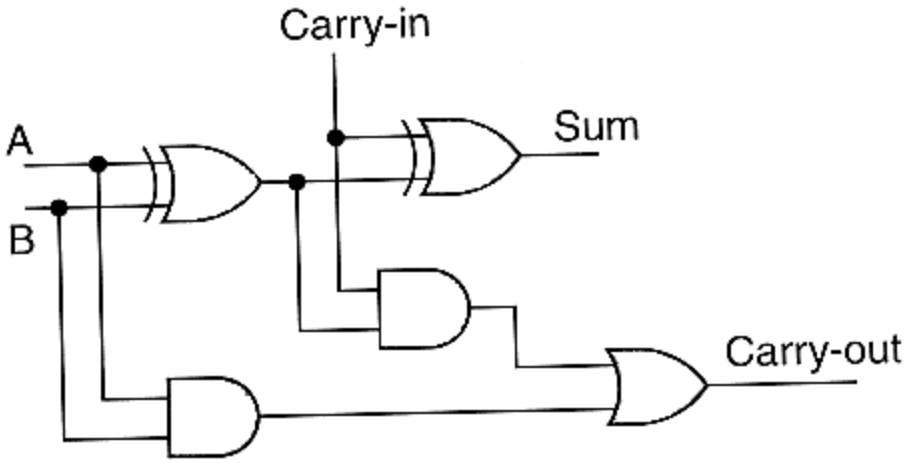
Half Adder



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

Problem with the Half Adder: No Carry-In

Full Adder

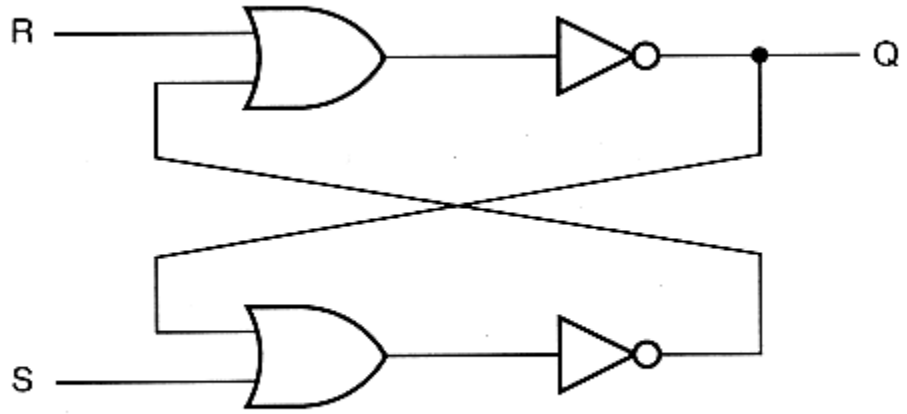


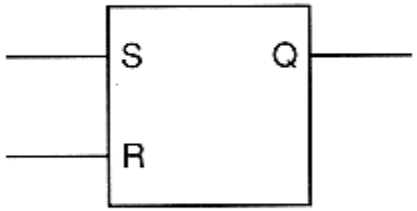
A	B	Carry-in	Sum	Carry-out
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Multiplexer

A *multiplexer*, or a *mux*, is a circuit that takes several input signals and produces one output signal so that its output is equal to one of the inputs chosen based on the values of a few more special input signals called *select signals*, or *select control lines*.

Circuits as Memory

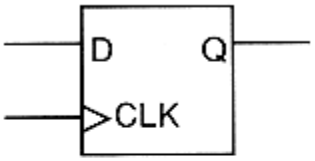




S	R	Q
0	0	last Q
0	1	0
1	0	1
1	1	illegal

A simple S-R flip-flop: (a) circuit; (b) symbol; (c) function table.

Circuits as Memory (cont'd)



(a)

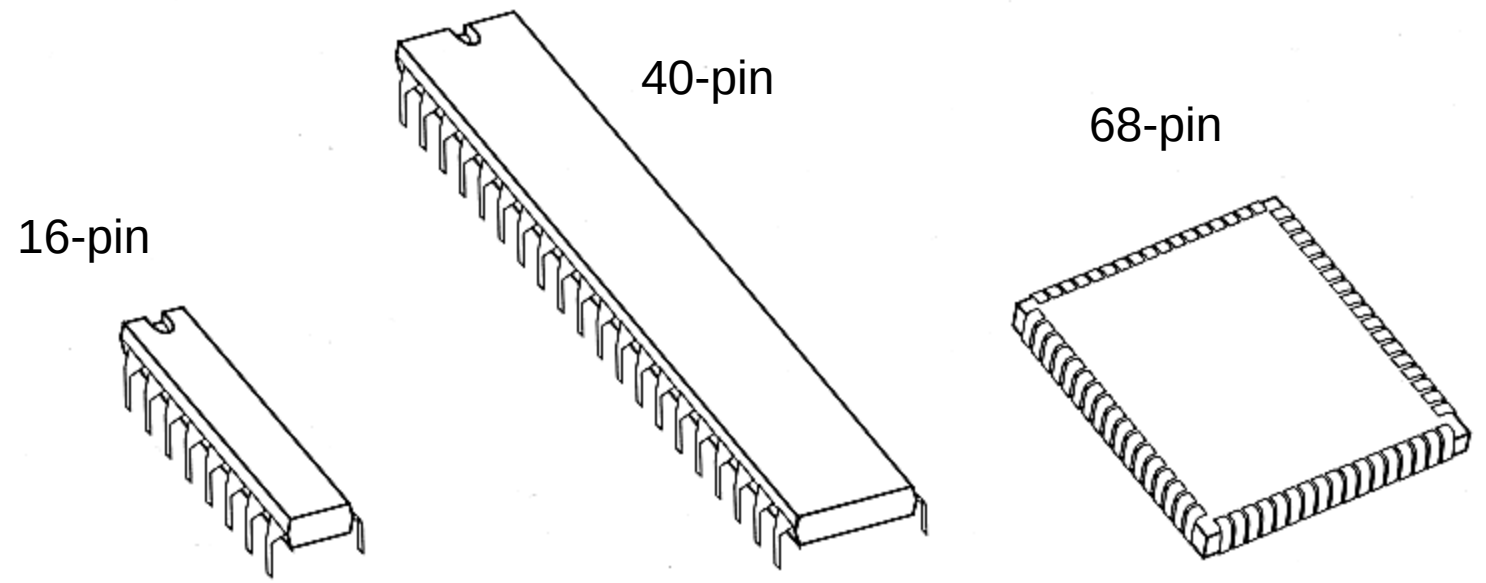
CLK	D	Q
↑	0	0
↑	1	1
0	x	last Q
1	x	last Q

(b)

Positive edge-triggered D flip-flop: (a) symbol; (b) function table.

D flip-flops are grouped together into *registers* to store multi-bit quantities in a computer.

Integrated Circuits (Chips)



SSI: 1 to 10 gates LSI: 100 to 100,000 gates VLSI: more than 100,000 gates
MSI: 10 to 100 gates

SSI: Small-Scale Integration
MSI: Medium-Scale Integration
LSI: Large-Scale Integration
VLSI: Very-Large-Scale Integration