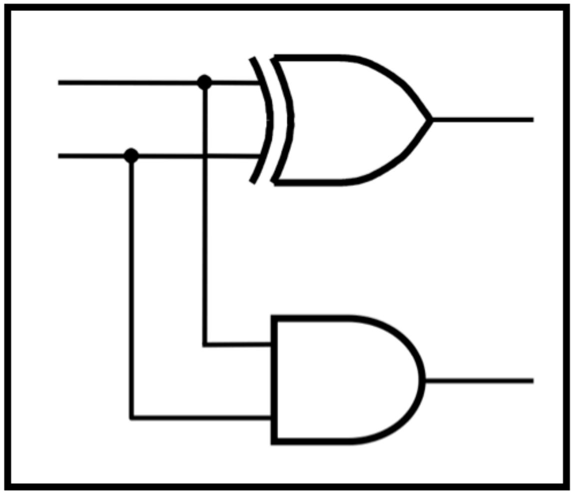


# CprE 281: Digital Logic

**Instructor: Alexander Stoytchev**

**http://www.ece.iastate.edu/~alexs/classes/**

# Logic Gates

*CprE 281: Digital Logic*
*Iowa State University, Ames, IA*

# Administrative Stuff

- HW1 is out
- It is due on Monday  Aug 31 @ 4pm.
- Submit it on paper before the start of the lecture

# Labs Next Week

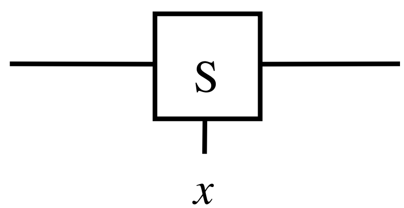
- **Please download and read the lab assignment for next week before you go to your lab section.**

- **You must print the answer sheet and do the prelab before you go to the lab.**

- **The TAs will check your prelab answers at the beginning of the recitation. If you don't have it done you'll lose 20% of the lab grade for that lab.**

# A Binary Switch

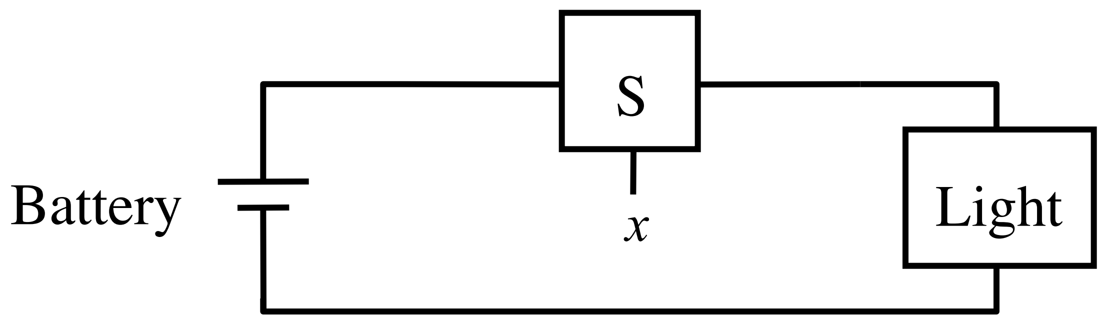

(a) Two states of a switch




(b) Symbol for a switch

[ Figure 2.1 from the textbook ]

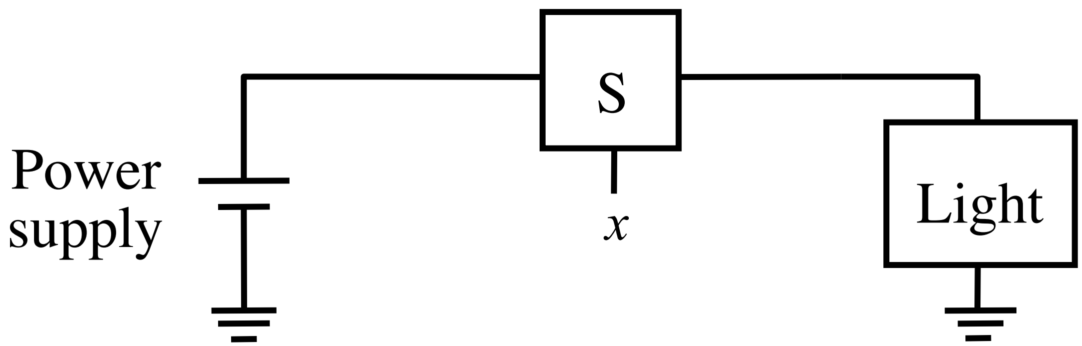
# A Light Controlled by a Switch




(a) Simple connection to a battery

[ Figure 2.2a from the textbook ]

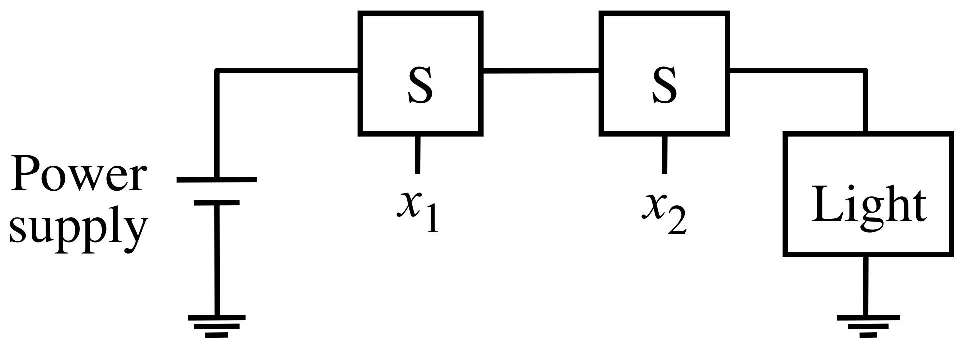
# A Light Controlled by a Switch




(b) Using a ground connection as the return path

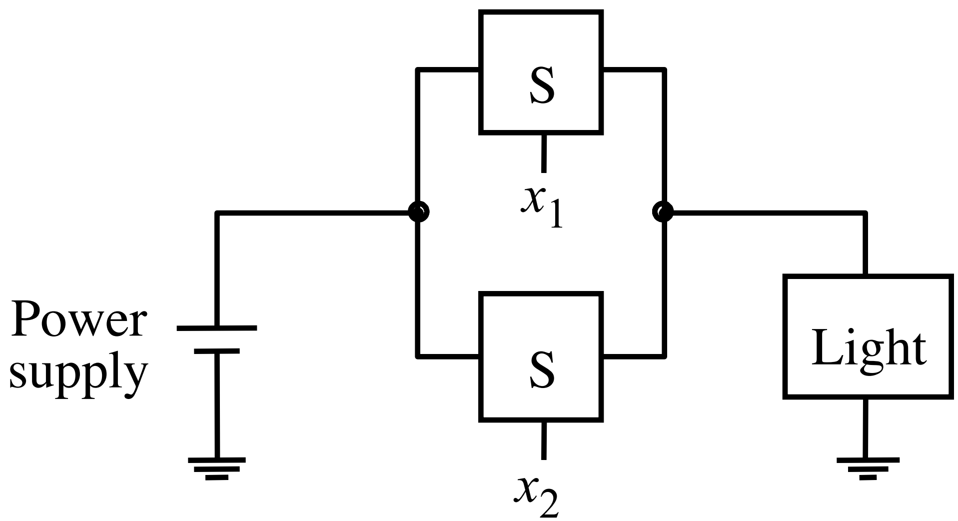
[ Figure 2.2b from the textbook ]

# The Logical AND function
## (series connection of the switches)



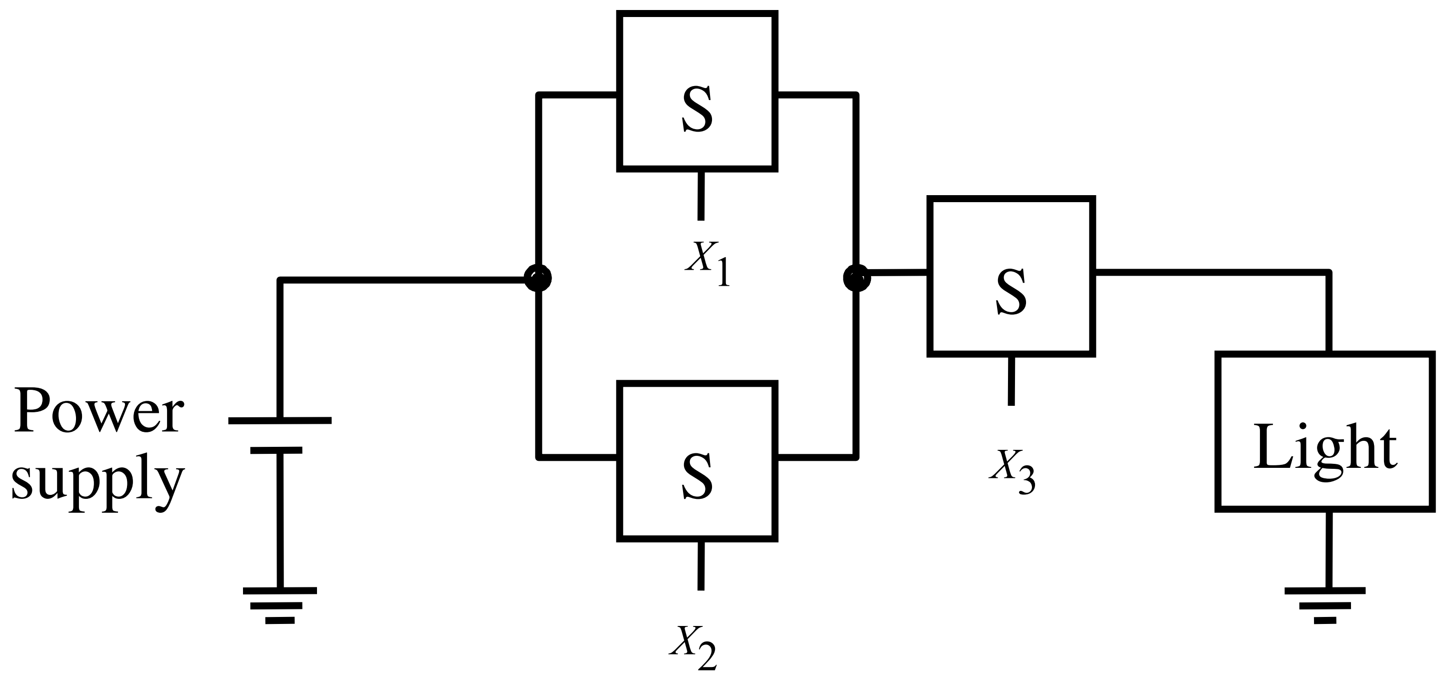

[ Figure 2.3a from the textbook ]

# The Logical OR function
## (parallel connection of the switches)



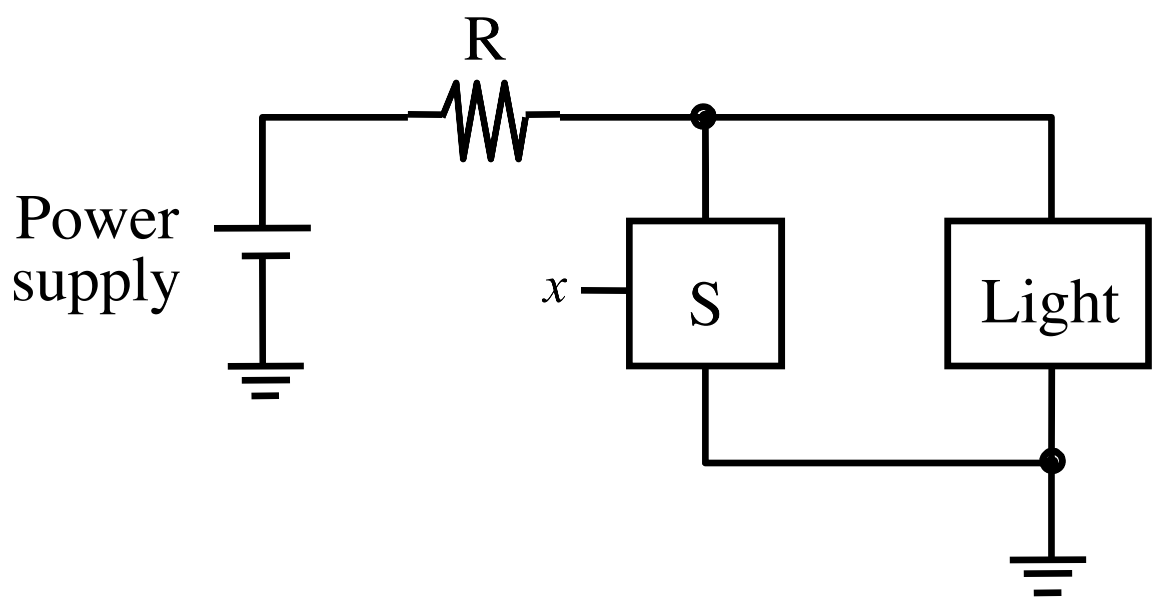

[ Figure 2.3b from the textbook ]

# A series-parallel connection of the switches



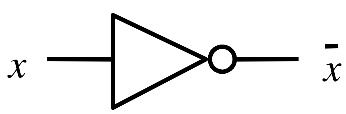

[ Figure 2.4 from the textbook ]

# An Inverting Circuit

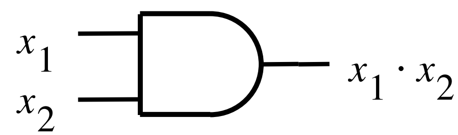



[ Figure 2.5 from the textbook ]

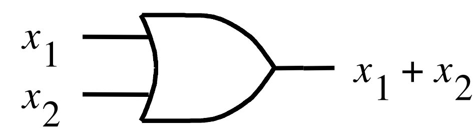
# The Three Basic Logic Gates




NOT gate



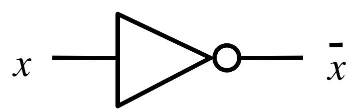

AND gate




OR gate

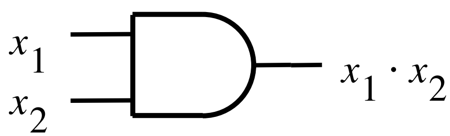
[ Figure 2.8 from the textbook ]

# Truth Table for NOT



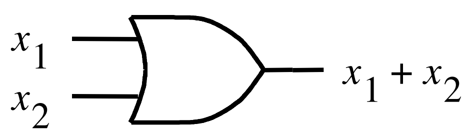

| $x$ | $\overline{x}$ |
|---|---|
| 0 | 1 |
| 1 | 0 |

# Truth Table for AND




| $x_1$ | $x_2$ | $x_1 \cdot x_2$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

# Truth Table for OR



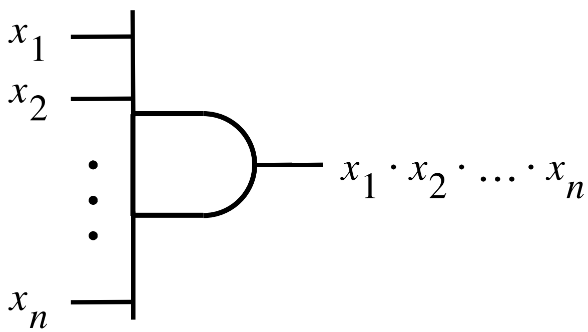

| $x_1$ | $x_2$ | $x_1 + x_2$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

# Truth Tables for AND and OR

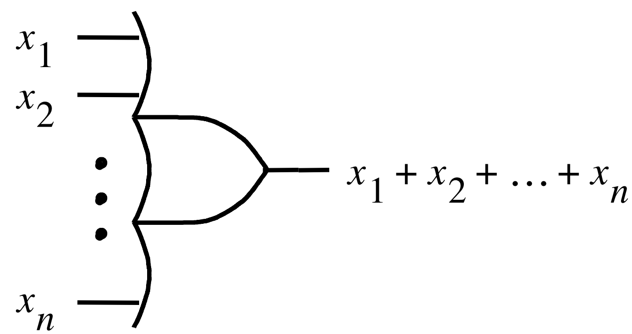
| $x_1$ | $x_2$ | $x_1 \cdot x_2$ | $x_1 + x_2$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 |
| | | AND | OR |

[ Figure 2.6b from the textbook ]

# Logic Gates with n Inputs




AND gate




OR gate

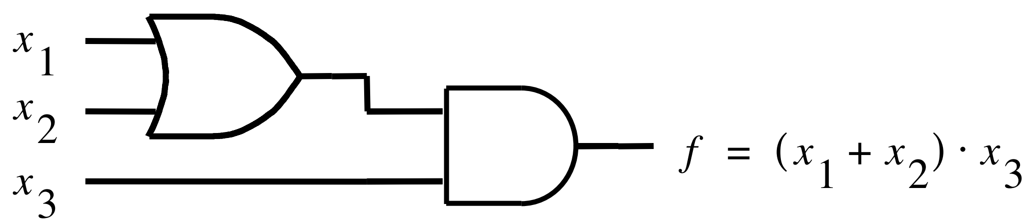
[ Figure 2.8 from the textbook ]

# Truth Table for 3-input AND and OR

| $x_1$ | $x_2$ | $x_3$ | $x_1 \cdot x_2 \cdot x_3$ | $x_1 + x_2 + x_3$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 |
| 0 | 1 | 1 | 0 | 1 |
| 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 |

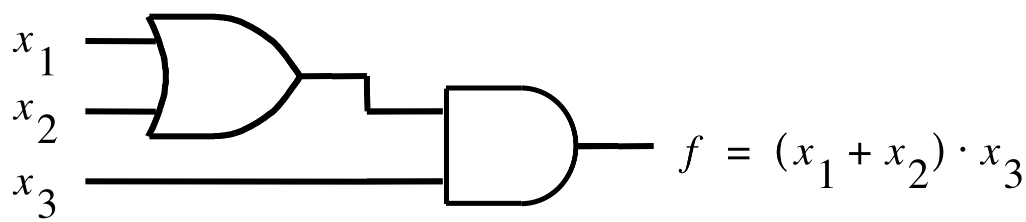
[ Figure 2.7 from the textbook ]

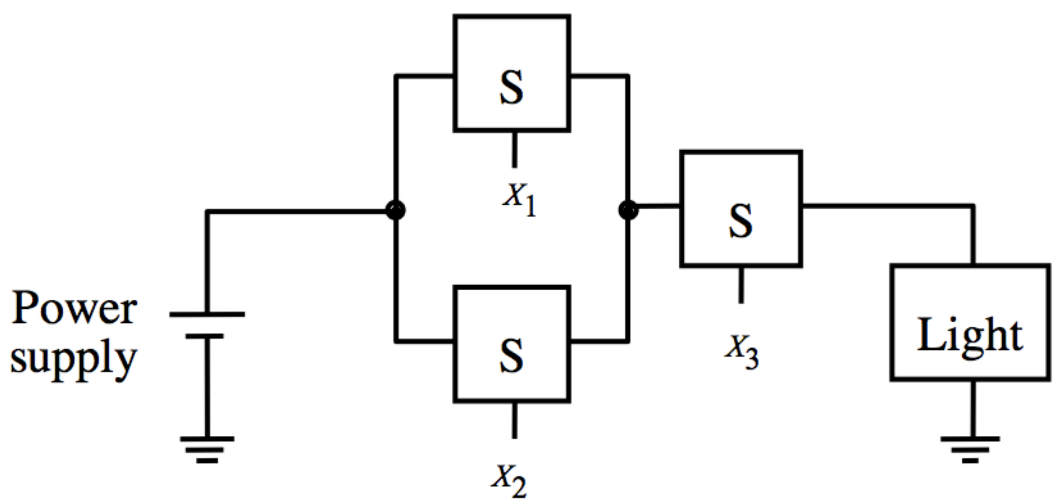
# Example of a Logic Circuit Implemented with Logic Gates




[ Figure 2.8 from the textbook ]

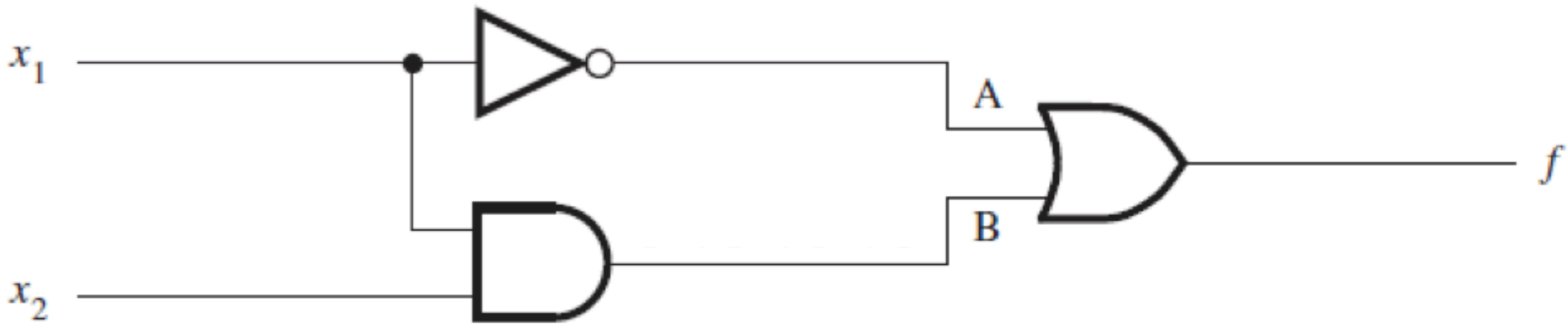
# Example of a Logic Circuit Implemented with Logic Gates




[ Figure 2.8 from the textbook ]

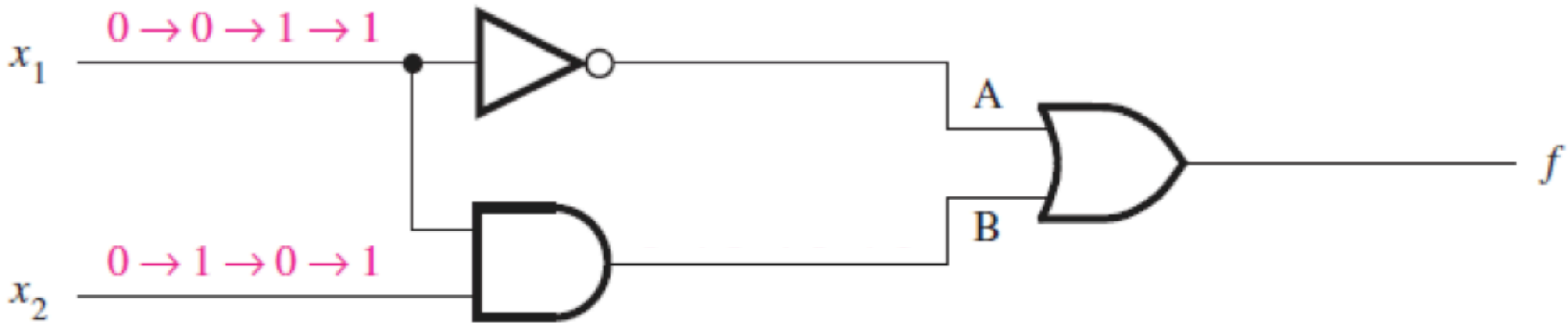
# Network Analysis




(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$

[ Figure 2.10 from the textbook ]

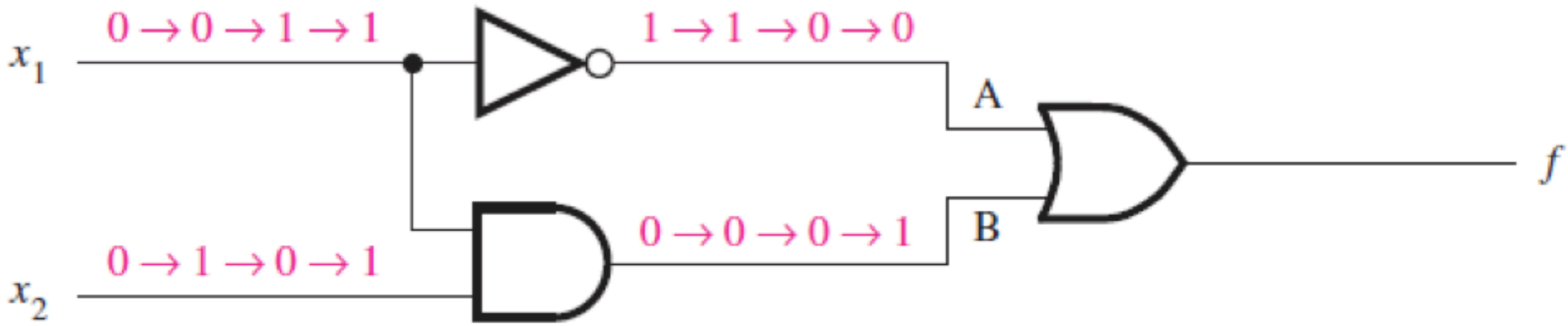
# Network Analysis




(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$

[ Figure 2.10 from the textbook ]

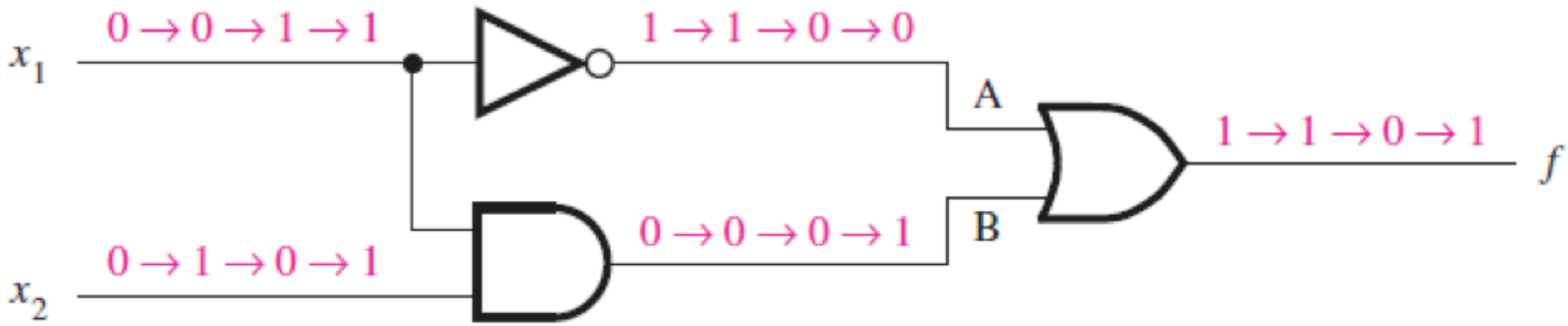
# Network Analysis




(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$

[ Figure 2.10 from the textbook ]

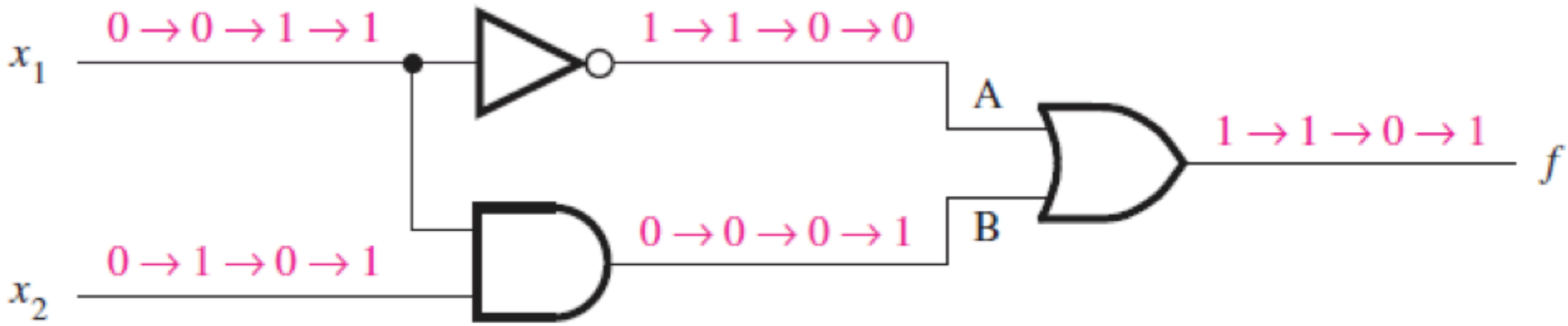
# Network Analysis



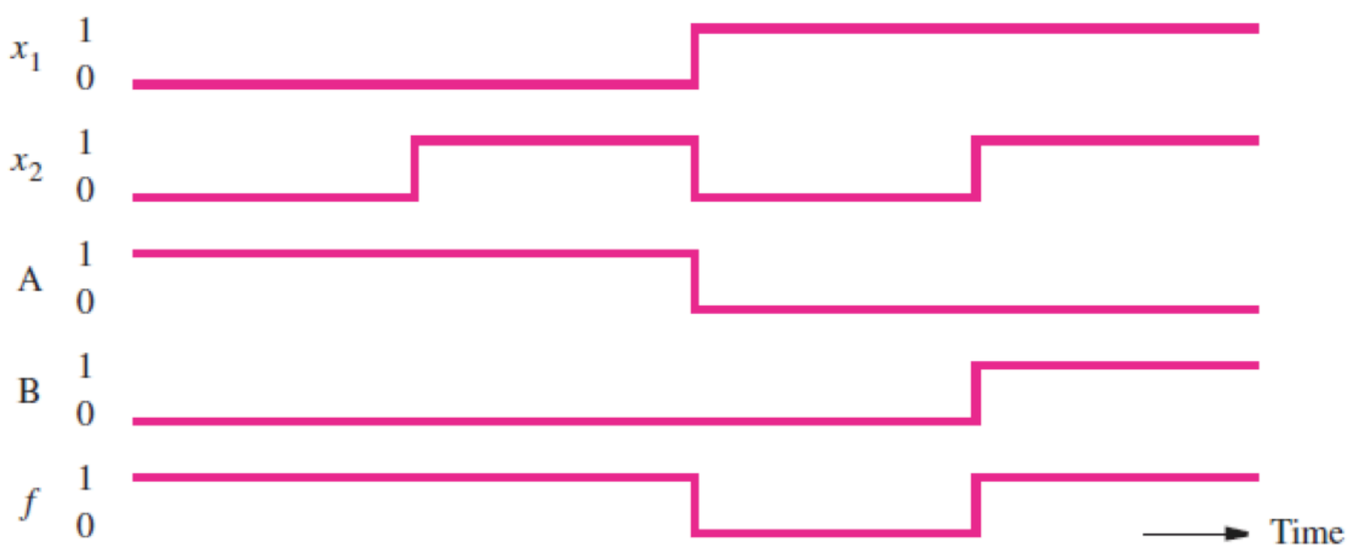

(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$

[ Figure 2.10 from the textbook ]

# Network Analysis

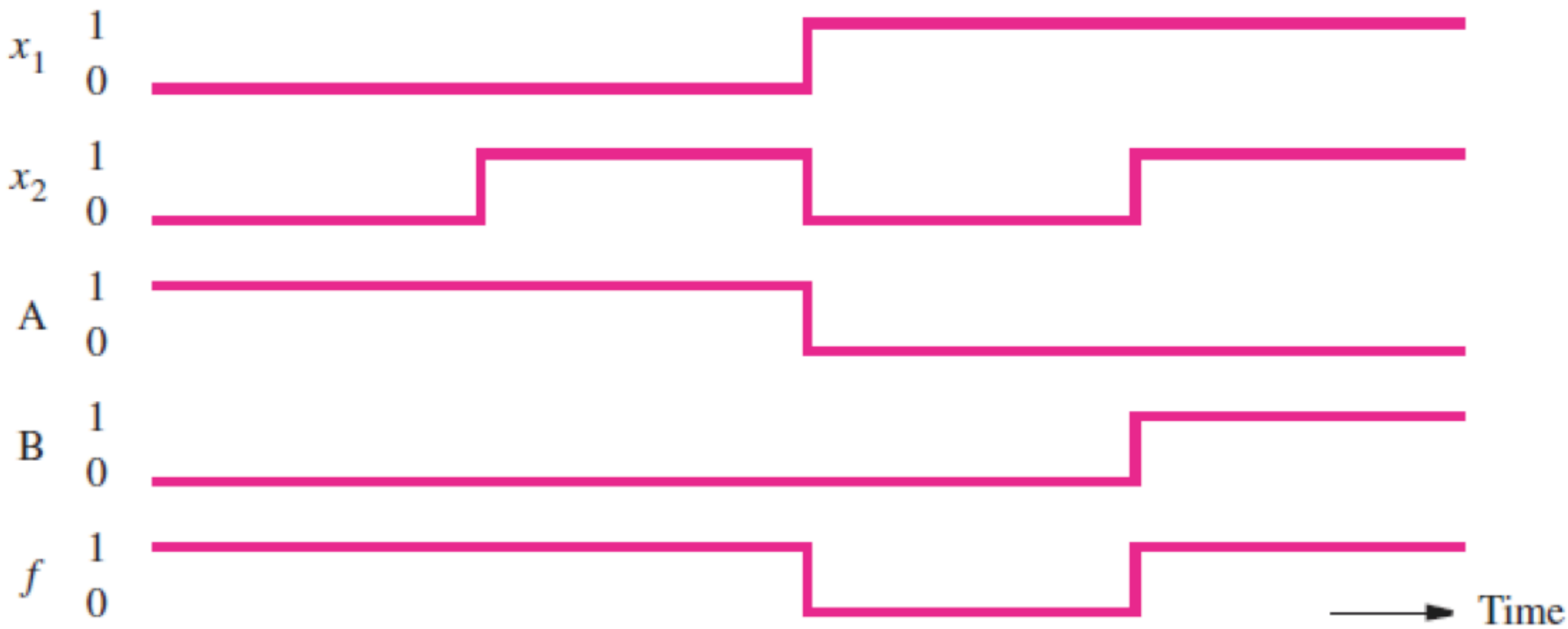



(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$




[ Figure 2.10 from the textbook ]

# Timing Diagram



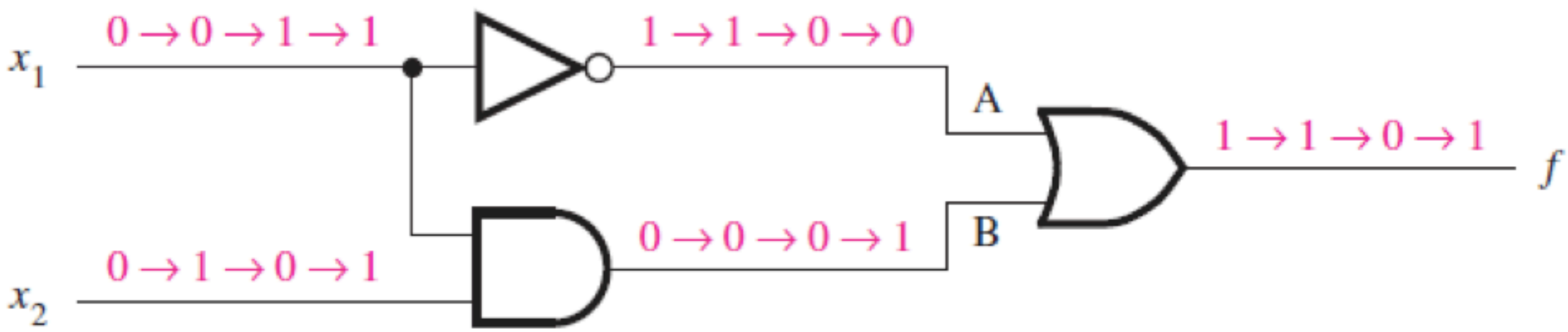

[ Figure 2.10 from the textbook ]

# Truth Table for this Network

| $x_1$ | $x_2$ | $f(x_1, x_2)$ | A | B |
|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 1 |

[ Figure 2.10 from the textbook ]

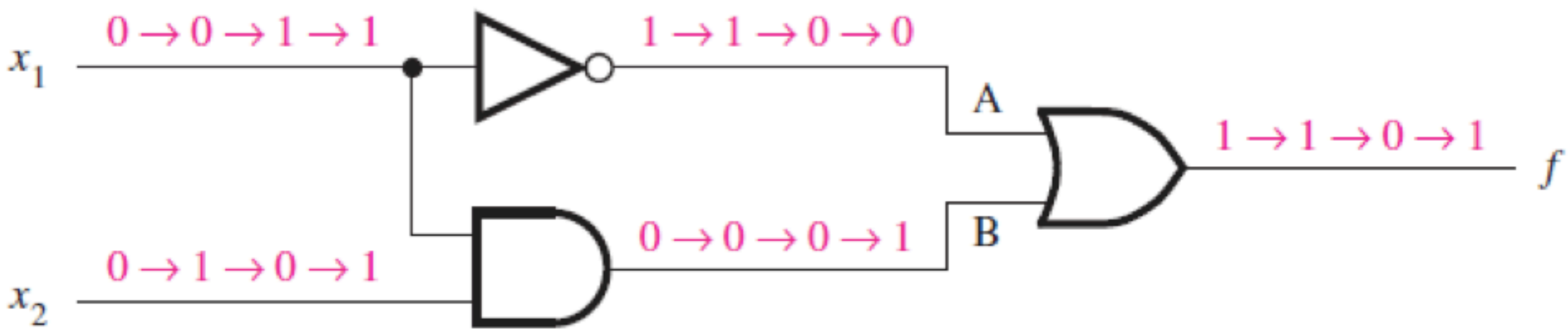
# Functionally Equivalent Networks



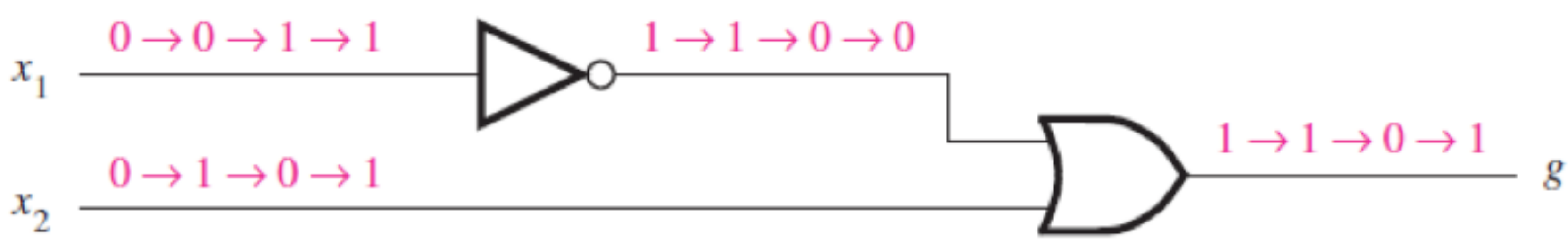

(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$

[ Figure 2.10 from the textbook ]

# Functionally Equivalent Networks



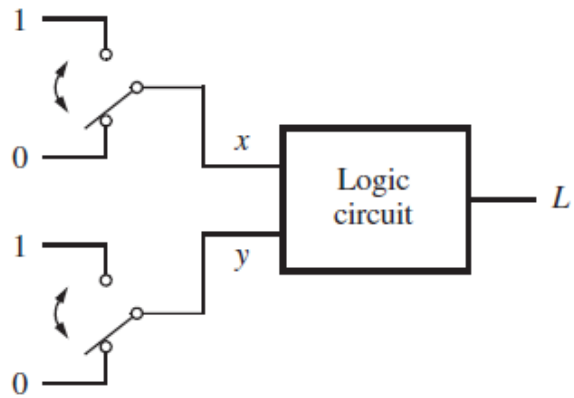

(a) Network that implements $f = \bar{x}_1 + x_1 \cdot x_2$




(d) Network that implements $g = \bar{x}_1 + x_2$

[ Figure 2.10 from the textbook ]

# The XOR Logic Gate



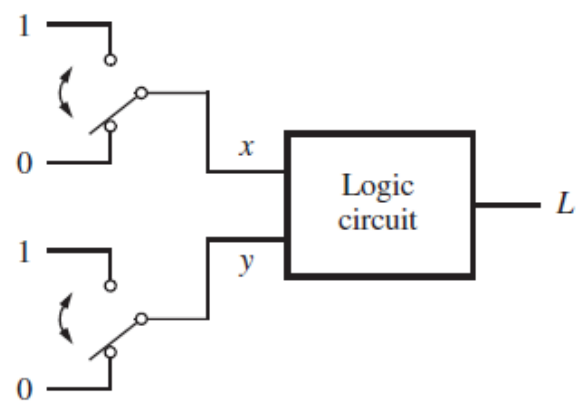

(a) Two switches that control a light

| x | y | L |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

(b) Truth table

[ Figure 2.11 from the textbook ]

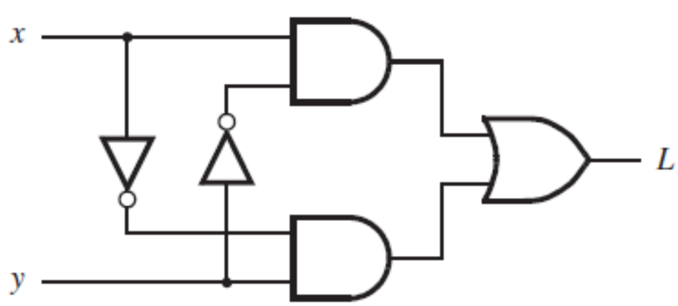
# The XOR Logic Gate




(a) Two switches that control a light

| x | y | L |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

(b) Truth table




(c) Logic network


(d) XOR gate symbol

[ Figure 2.11 from the textbook ]

# Addition of Binary Numbers

$$
\begin{array}{r}
a \\
+\,b \\
\hline
s_1\,s_0
\end{array}
\qquad
\begin{array}{r}
0 \\
+\,0 \\
\hline
0\,0
\end{array}
\qquad
\begin{array}{r}
0 \\
+\,1 \\
\hline
0\,1
\end{array}
\qquad
\begin{array}{r}
1 \\
+\,0 \\
\hline
0\,1
\end{array}
\qquad
\begin{array}{r}
1 \\
+\,1 \\
\hline
1\,0
\end{array}
$$

[ Figure 2.12 from the textbook ]

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\;0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\;0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

[ Figure 2.12 from the textbook ]

# Addition of Binary Numbers

| $a$ | 0 | 0 | 1 | 1 |
|---|---|---|---|---|
| $+b$ | $+0$ | $+1$ | $+0$ | $+1$ |
| $s_1\,s_0$ | 0 0 | 0 1 | 0 1 | 1 0 |

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| | | | | |
|---|---|---|---|---|
| $a$ | 0 | 0 | 1 | 1 |
| $+b$ | $+0$ | $+1$ | $+0$ | $+1$ |
| $s_1\,s_0$ | 0 0 | 0 1 | 0 1 | 1 0 |

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\;0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\;0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| | | | | |
|---|---|---|---|---|
| $a$ | 0 | 0 | 1 | 1 |
| $+b$ | $+0$ | $+1$ | $+0$ | $+1$ |
| $s_1\ s_0$ | 0 0 | 0 1 | 0 1 | 1 0 |

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| | | | | |
|---|---|---|---|---|
| $a$ | 0 | 0 | 1 | 1 |
| $+\,b$ | $+\,0$ | $+\,1$ | $+\,0$ | $+\,1$ |
| $s_1\,s_0$ | 0 0 | 0 1 | 0 1 | 1 0 |

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\;0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\;0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\,0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\,0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1 s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\,0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\,0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\;0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\;1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\;0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\,0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\,0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array} \qquad \begin{array}{r} 0 \\ +\,0 \\ \hline 0\,0 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 0\,1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 1\,0 \end{array}$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

$$
\begin{array}{r} a \\ +\,b \\ \hline s_1\,s_0 \end{array}
\qquad
\begin{array}{r} 0 \\ +\,0 \\ \hline 0\;0 \end{array}
\quad
\begin{array}{r} 0 \\ +\,1 \\ \hline 0\;1 \end{array}
\quad
\begin{array}{r} 1 \\ +\,0 \\ \hline 0\;1 \end{array}
\quad
\begin{array}{r} 1 \\ +\,1 \\ \hline 1\;0 \end{array}
$$

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| $a$ | $b$ | $s_1$ ? | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

AND

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

?

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

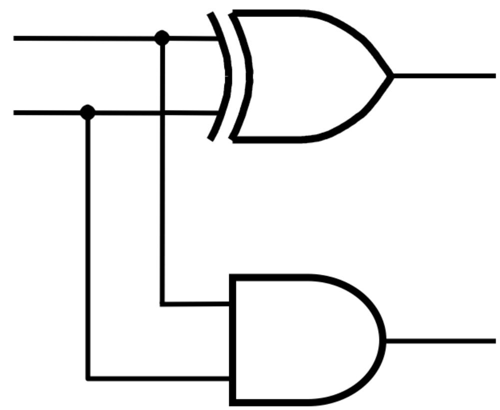
# Addition of Binary Numbers

| $a$ | $b$ | $s_1$ | $s_0$ (XOR) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers

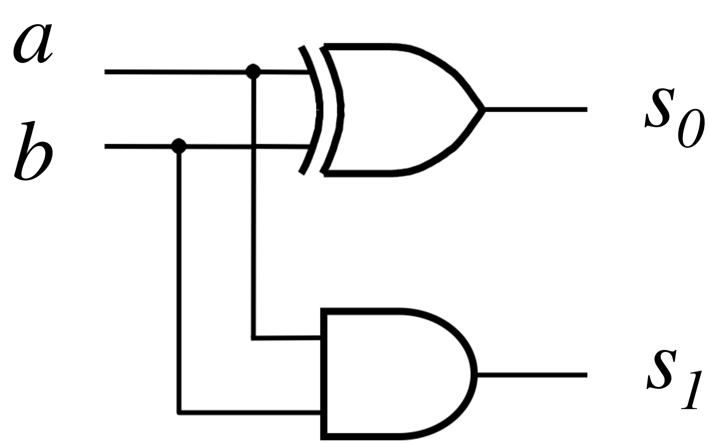
| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# Addition of Binary Numbers



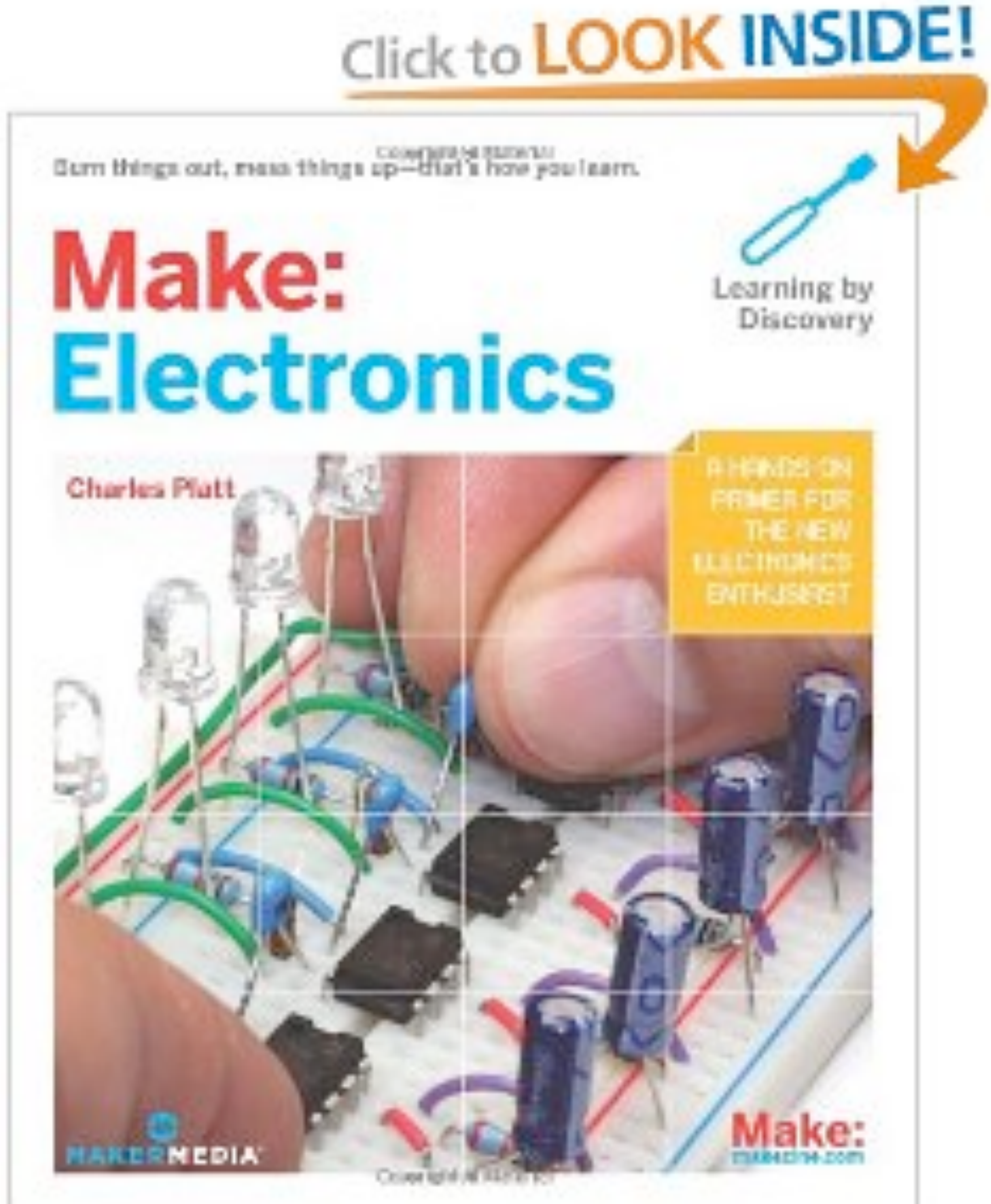
| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

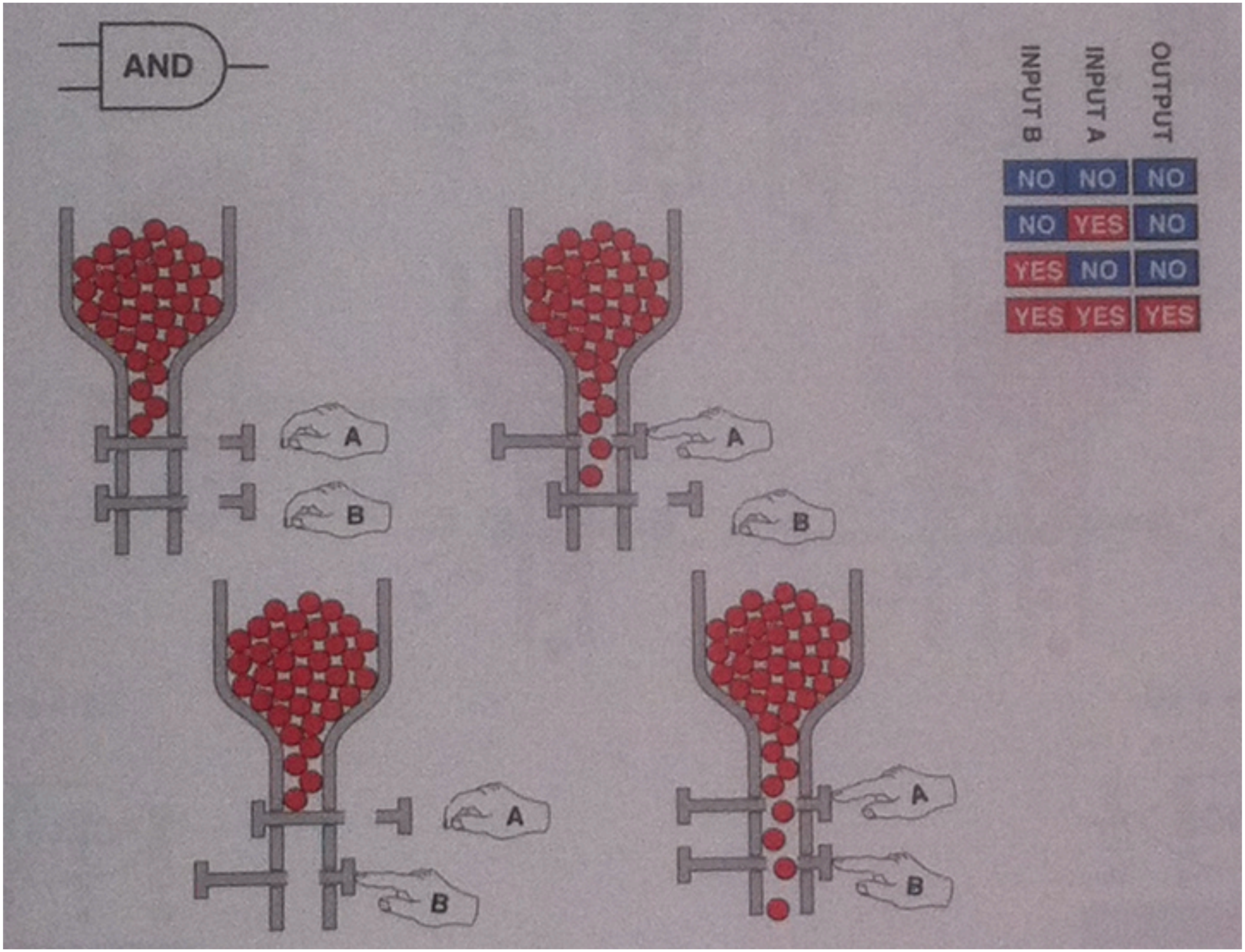
# Addition of Binary Numbers



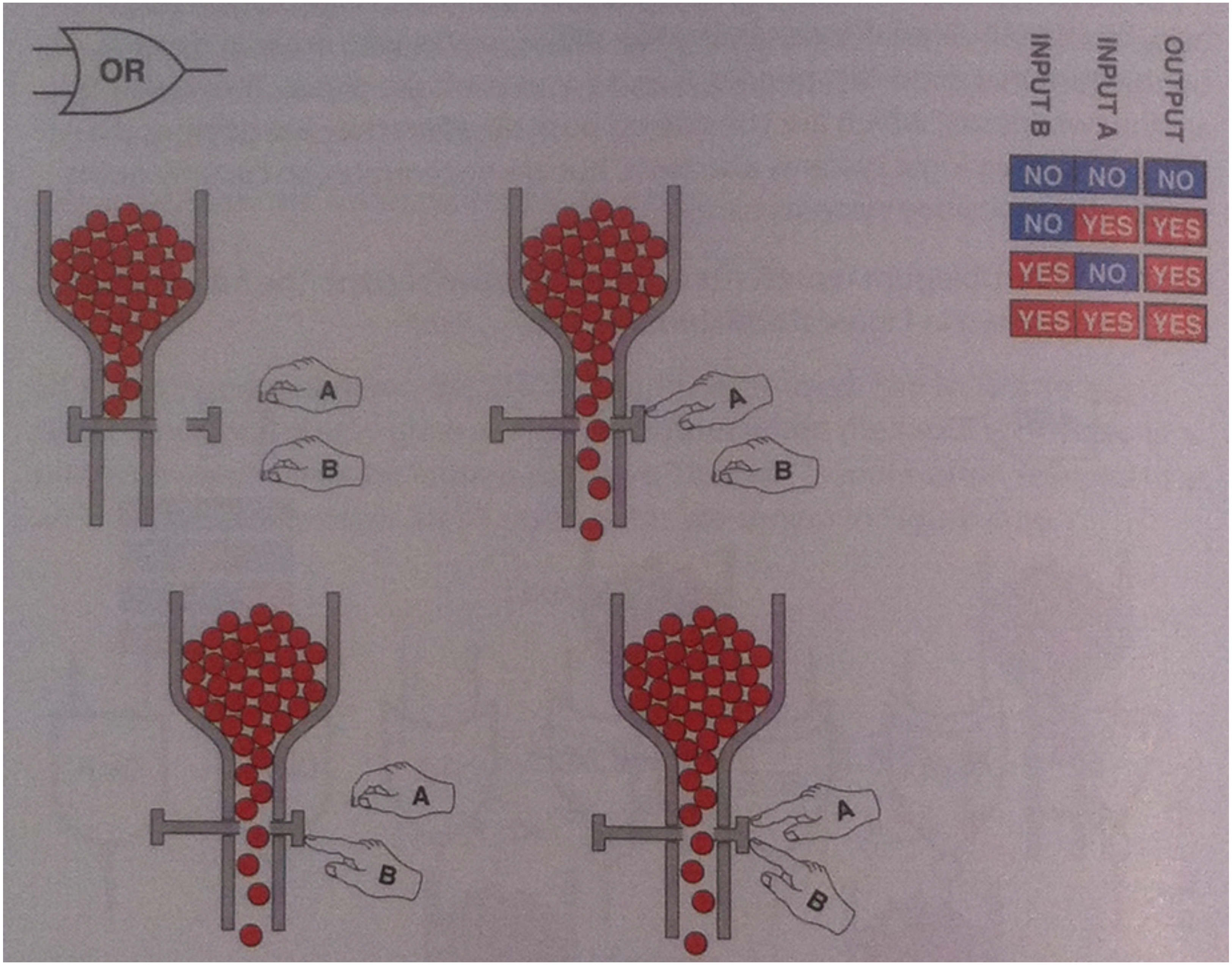

| $a$ | $b$ | $s_1$ | $s_0$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 |

# The following examples came from this book

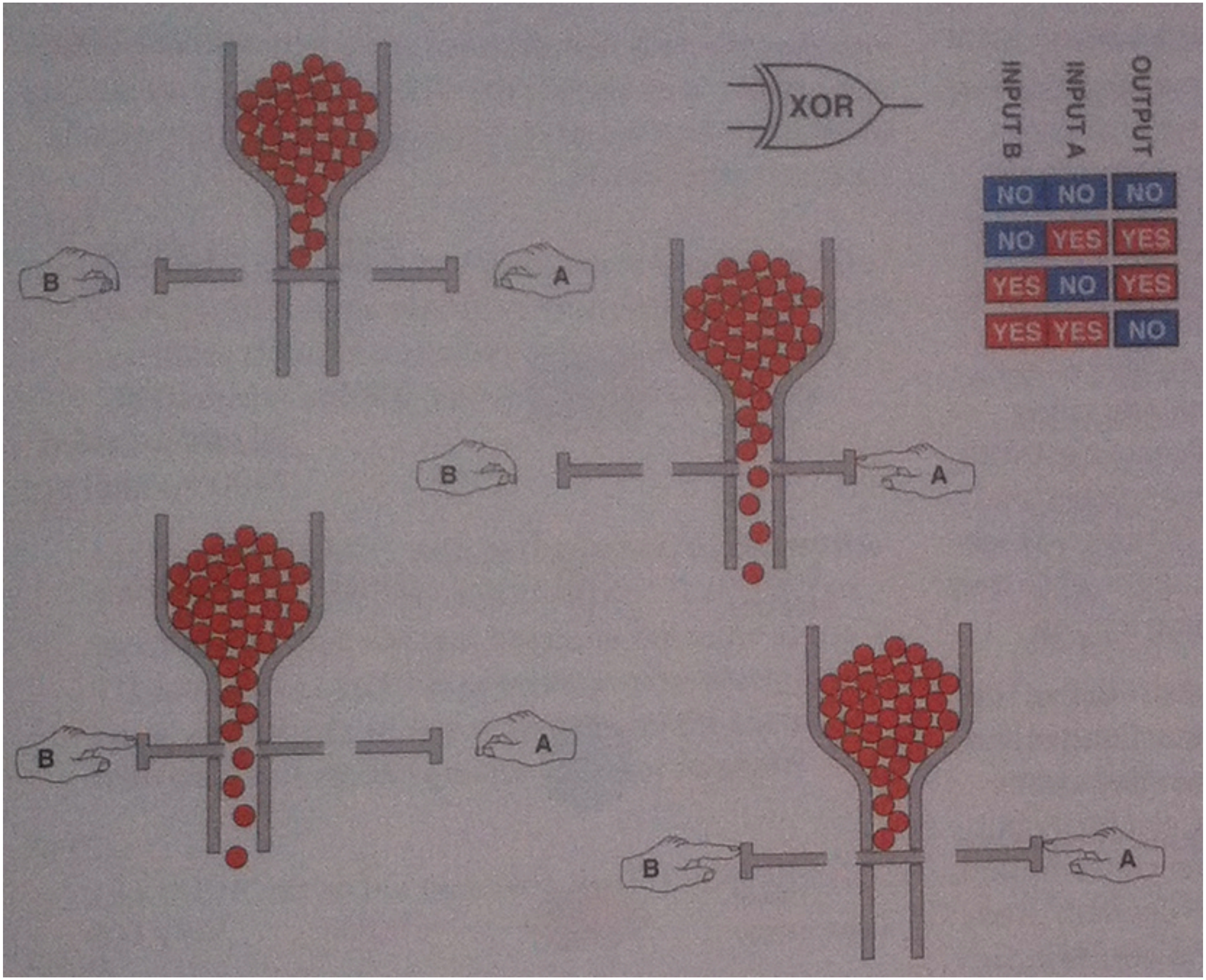



AND
INPUT B
INPUT A
OUTPUT
NO NO NO
NO YES NO
YES NO NO
YES YES YES
A
B

[ Platt 2009 ]


OR
INPUT B
INPUT A
OUTPUT
NO
NO
NO
NO
YES
YES
YES
NO
YES
YES
YES
YES
A
B
A
B
A
B
A
B

[ Platt 2009 ]


XOR
INPUT B
INPUT A
OUTPUT
NO NO NO
NO YES YES
YES NO YES
YES YES NO
B
A

[ Platt 2009 ]

# Questions?

**THE END**