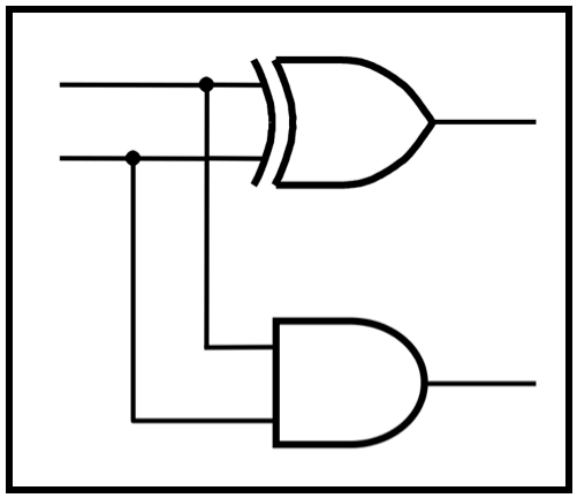


CprE 281: Digital Logic

Instructor: Alexander Stoytchev

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

Intro to Verilog

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

Administrative Stuff

- **HW3 is due on Monday Sep 14 @ 4p**

Administrative Stuff

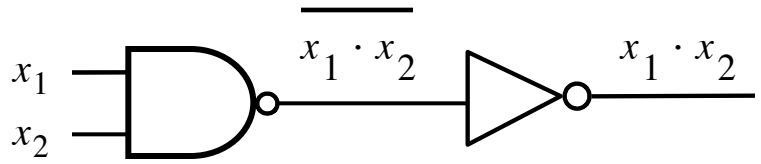
- **HW4 is out**
- **It is due on Monday Sep 21 @ 4pm.**
- **Please write clearly on the first page (in BLOCK CAPITAL letters) the following three things:**
  - **Your First and Last Name**
  - **Your Student ID Number**
  - **Your Lab Section Letter**
- **Also, please**
  - **Staple your pages**
  - **Use Letter-sized sheets**

Administrative Stuff

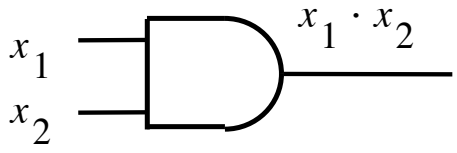
- **Midterm Exam #1**
- **When: Friday Sep 25.**
- **Where: This classroom**
- **What: Chapter 1 and Chapter 2 plus number systems**
- **The exam will be open book and open notes (you can bring up to 3 pages of handwritten notes).**
- **More details to follow.**

Quick Review

NAND followed by NOT = AND



x_1	x_2	f
0	0	1
0	1	1
1	0	1
1	1	0



f
0
0
0
1

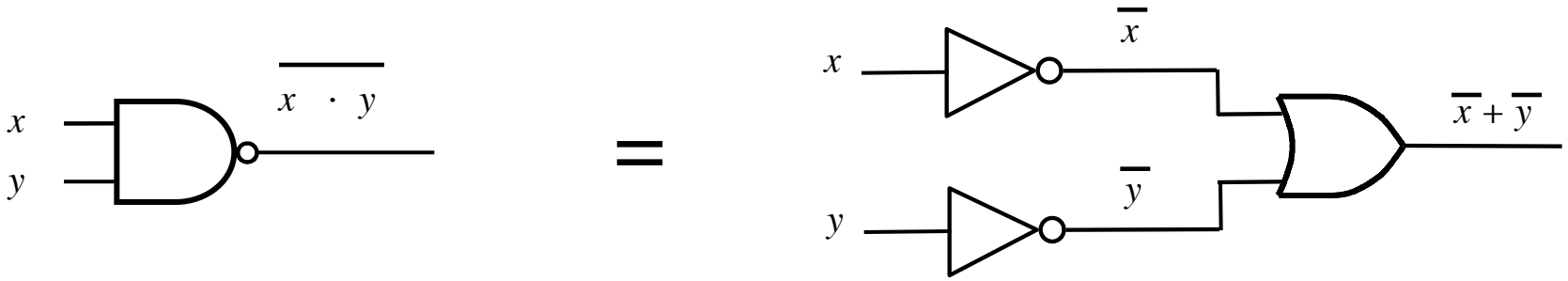
x_1	x_2	f
0	0	0
0	1	0
1	0	0
1	1	1

DeMorgan's Theorem

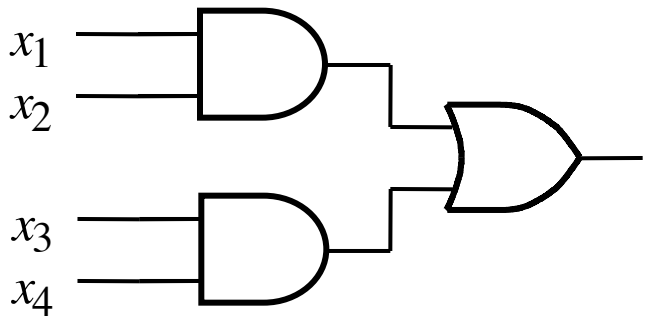
15a. $\overline{x \cdot y} = \overline{x} + \overline{y}$

DeMorgan's Theorem

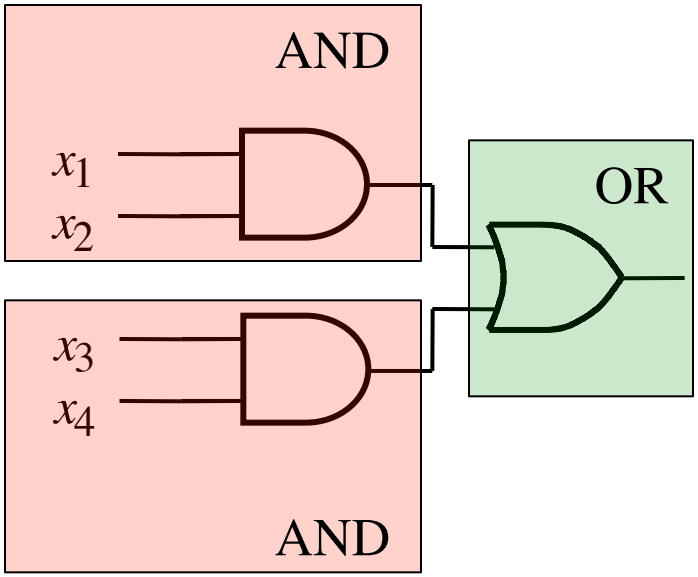
15a. $\overline{x \cdot y} = \overline{x} + \overline{y}$



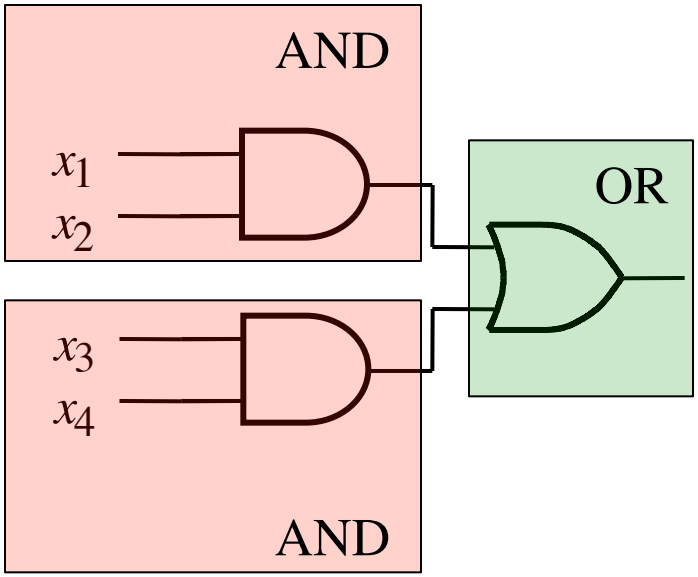
Sum-Of-Products

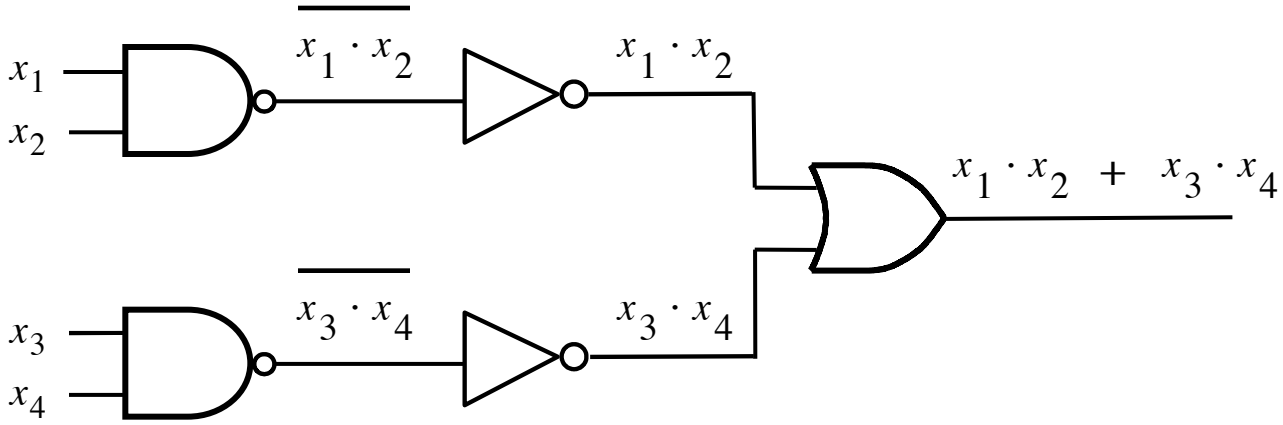


Sum-Of-Products

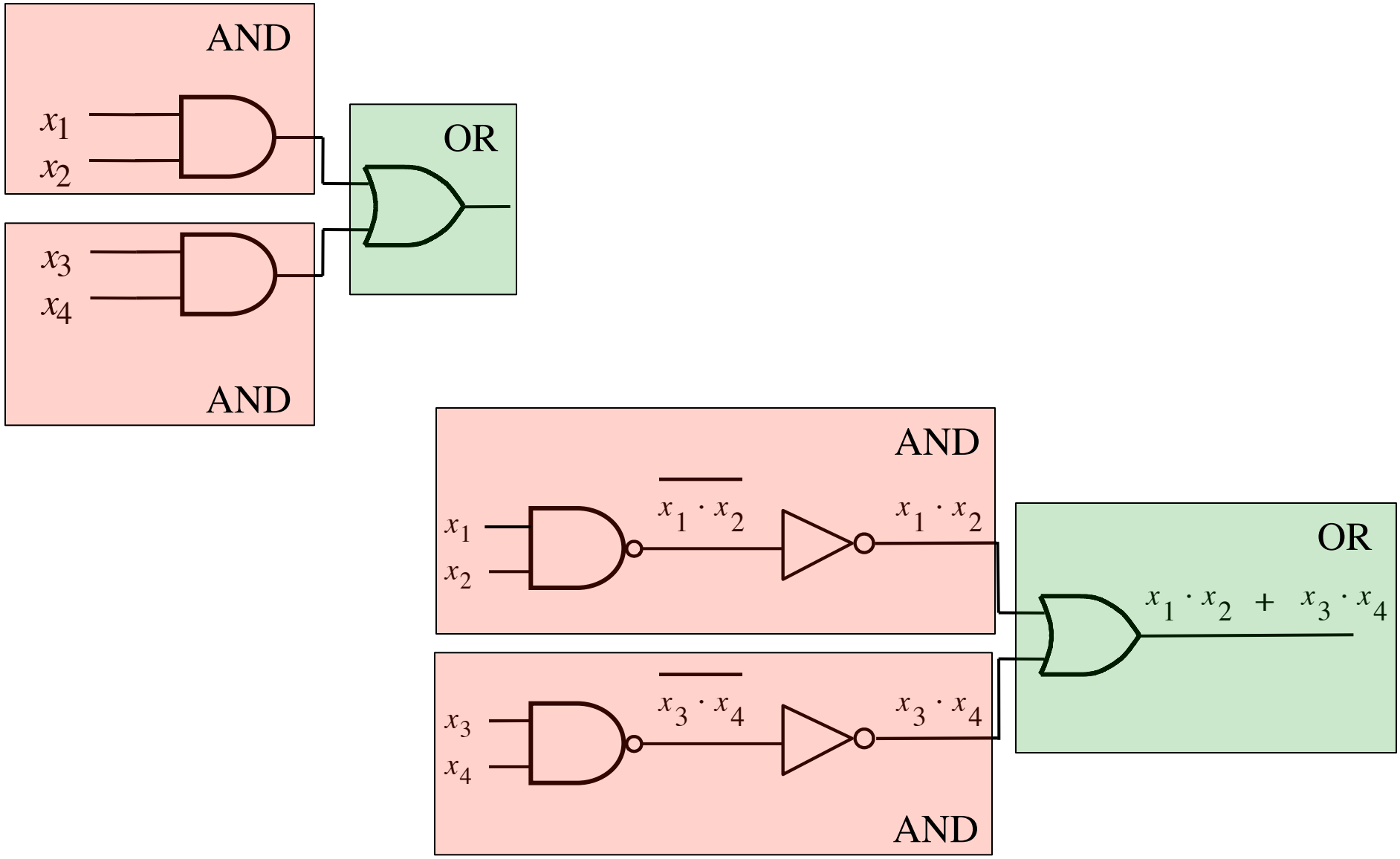


Sum-Of-Products

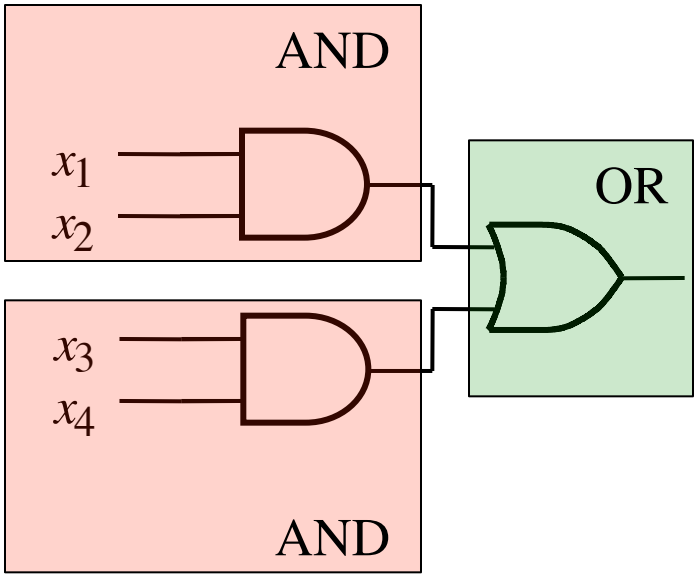


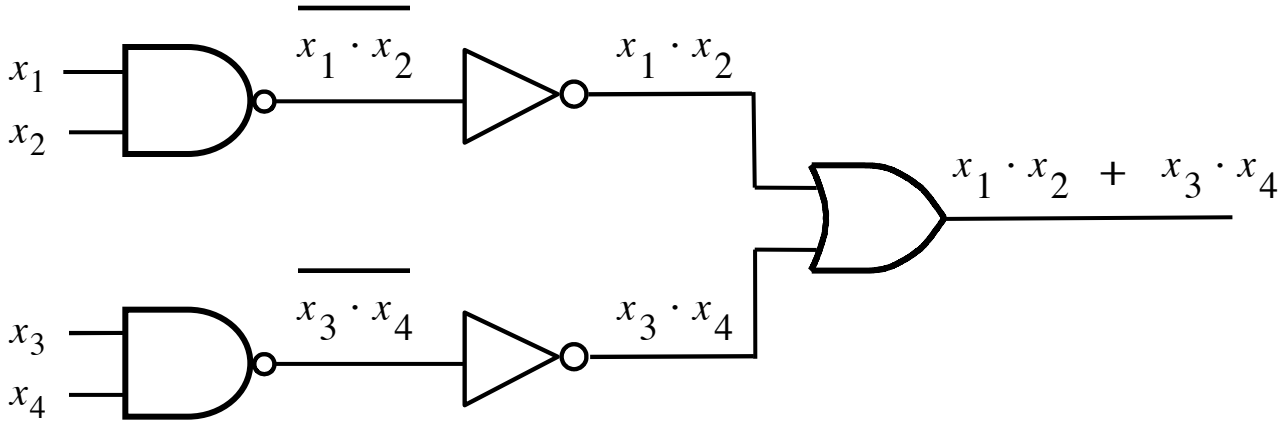


Sum-Of-Products

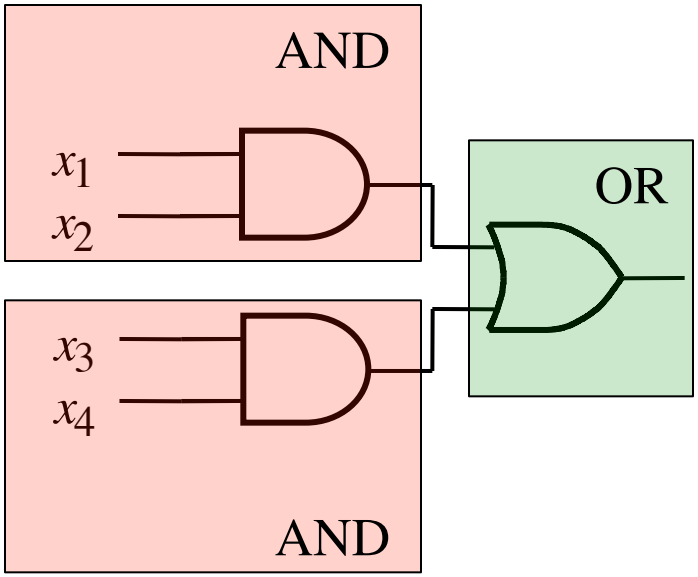


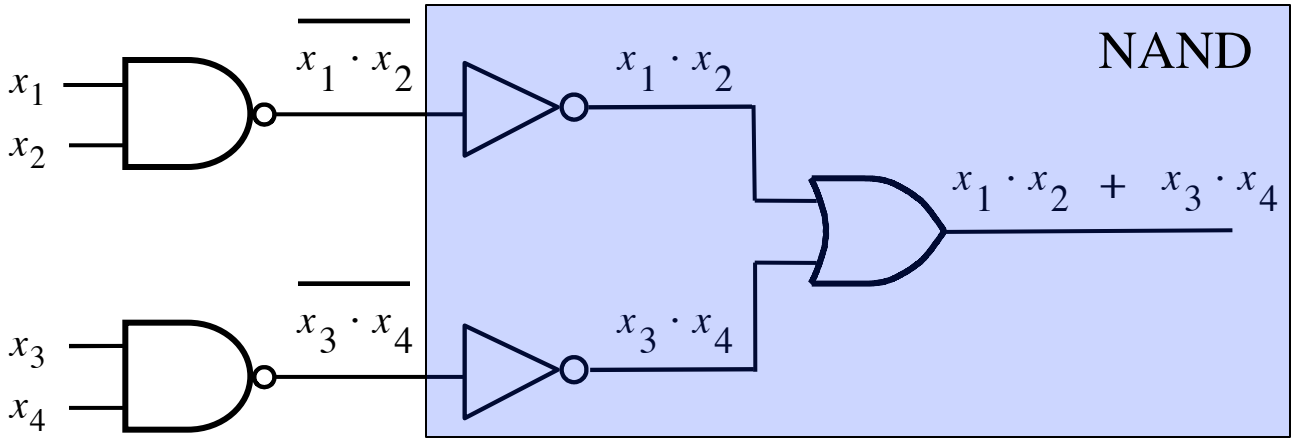
Sum-Of-Products



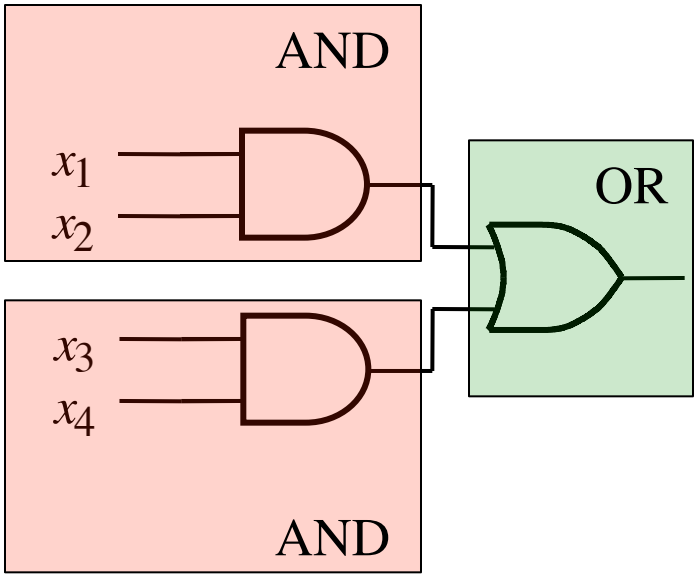


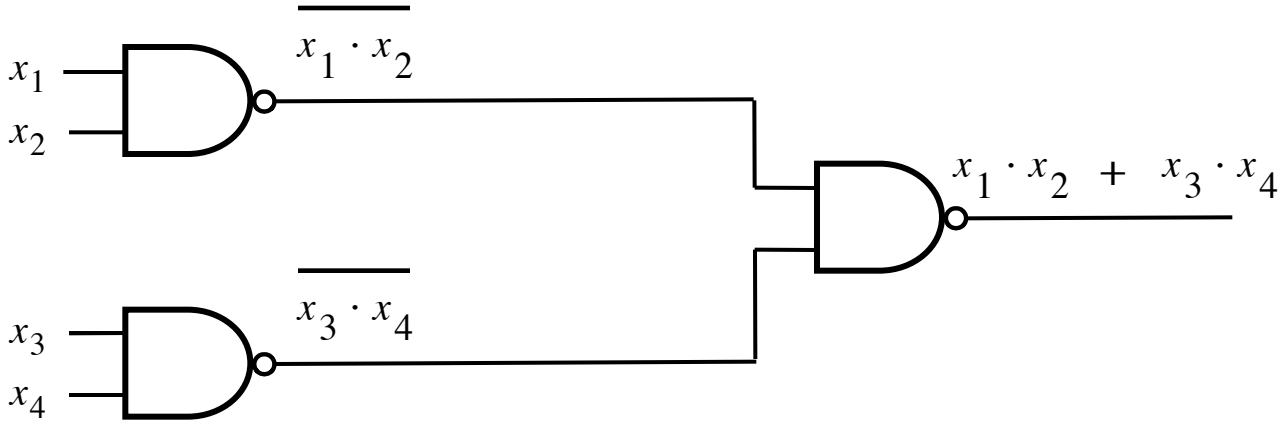
Sum-Of-Products



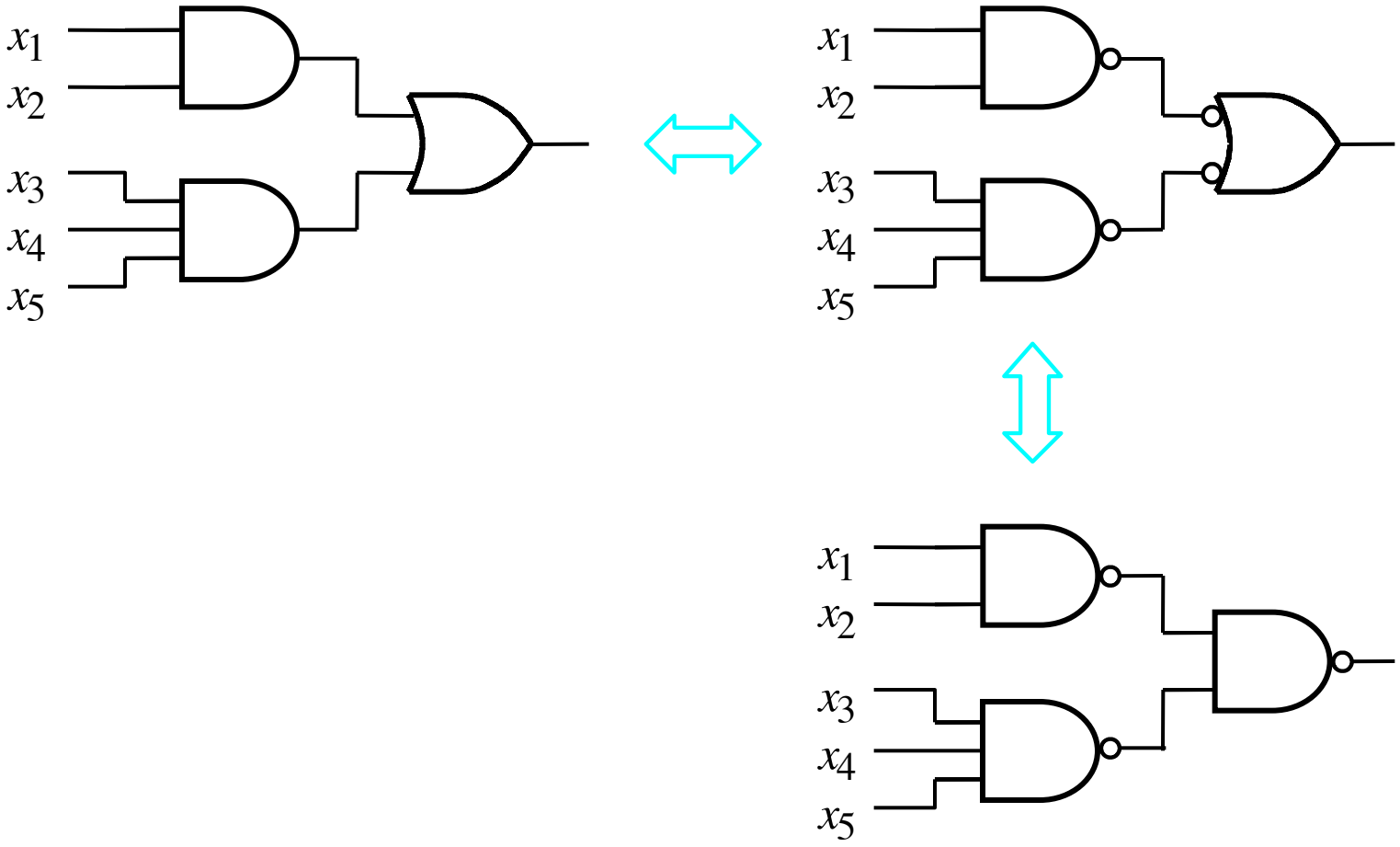


Sum-Of-Products





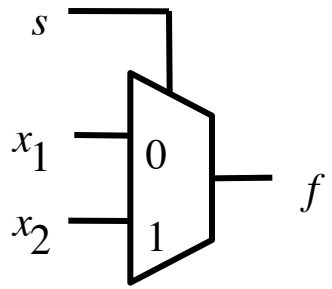
Sum-Of-Products



2-1 Multiplexer (Definition)

- Has two inputs: x_1 and x_2
- Also has another input line s
- If s=0, then the output is equal to x_1
- If s=1, then the output is equal to x_2

Graphical Symbol for a 2-1 Multiplexer



[Figure 2.33c from the textbook]

Let's Derive the SOP form

$s\ x_1\ x_2$	$f(s, x_1, x_2)$	
0 0 0	0	
0 0 1	0	
0 1 0	1	$\overline{s}\ x_1\ \overline{x}_2$
0 1 1	1	$\overline{s}\ x_1\ x_2$
1 0 0	0	
1 0 1	1	$s\ \overline{x}_1\ x_2$
1 1 0	0	
1 1 1	1	$s\ x_1\ x_2$

$$f(s, x_1, x_2) = \overline{s}\ x_1\ \overline{x}_2 + \overline{s}\ x_1\ x_2 + s\ \overline{x}_1\ x_2 + s\ x_1\ x_2$$

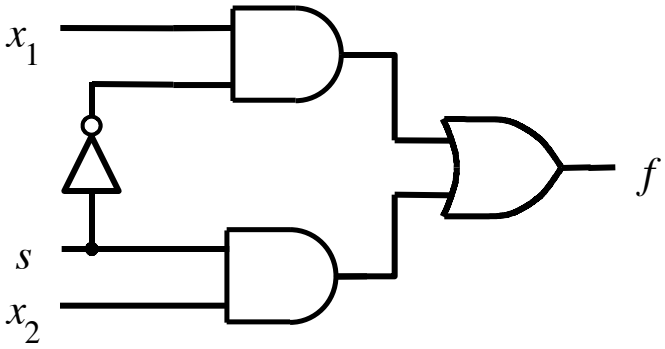
Let's simplify this expression

$$f(s, x_1, x_2) = \overline{s}\, x_1\, \overline{x}_2 + \overline{s}\, x_1\, x_2 + s\, \overline{x}_1\, x_2 + s\, x_1\, x_2$$

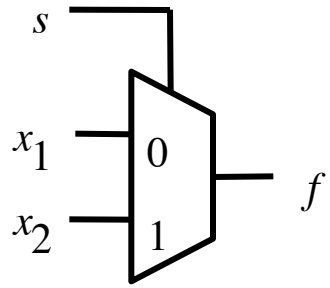
$$f(s, x_1, x_2) = \overline{s}\, x_1\, (\overline{x}_2 + x_2) + s\, (\overline{x}_1 + x_1)\, x_2$$

$$f(s, x_1, x_2) = \overline{s}\, x_1 + s\, x_2$$

Circuit for 2-1 Multiplexer



(b) Circuit



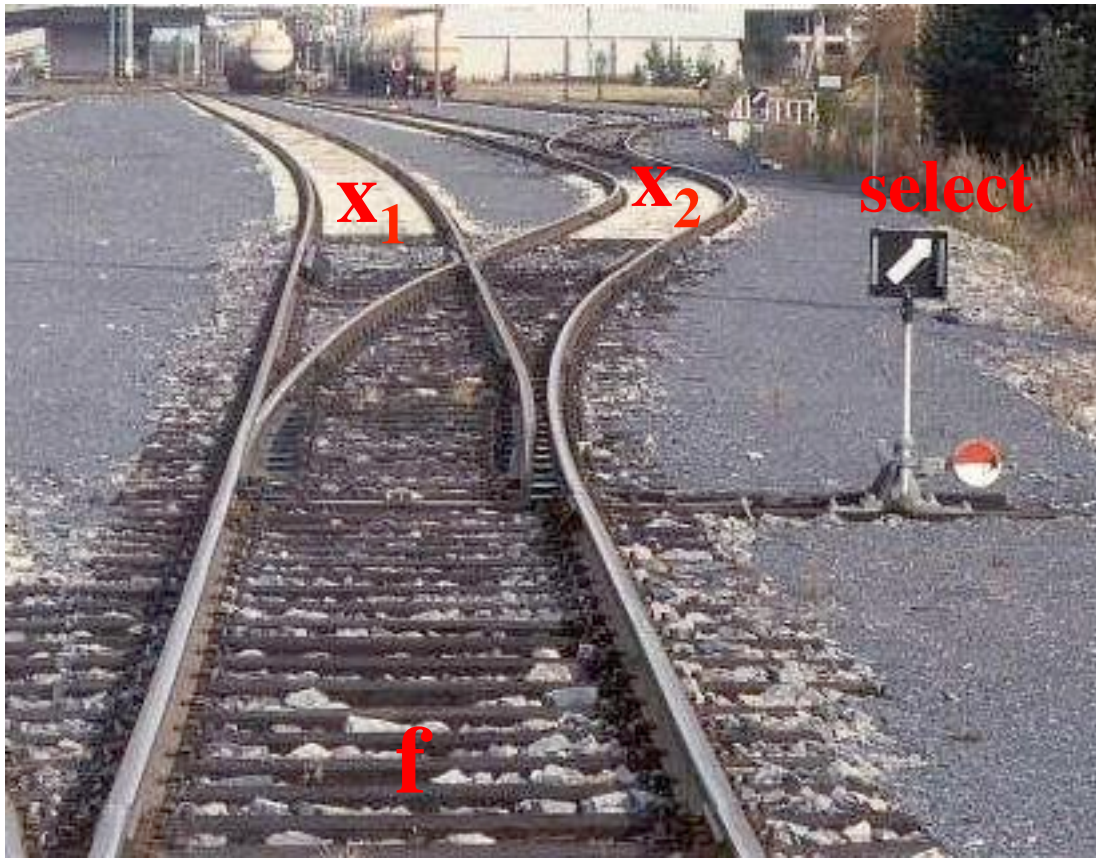
(c) Graphical symbol

[Figure 2.33b-c from the textbook]

Analogy: Railroad Switch

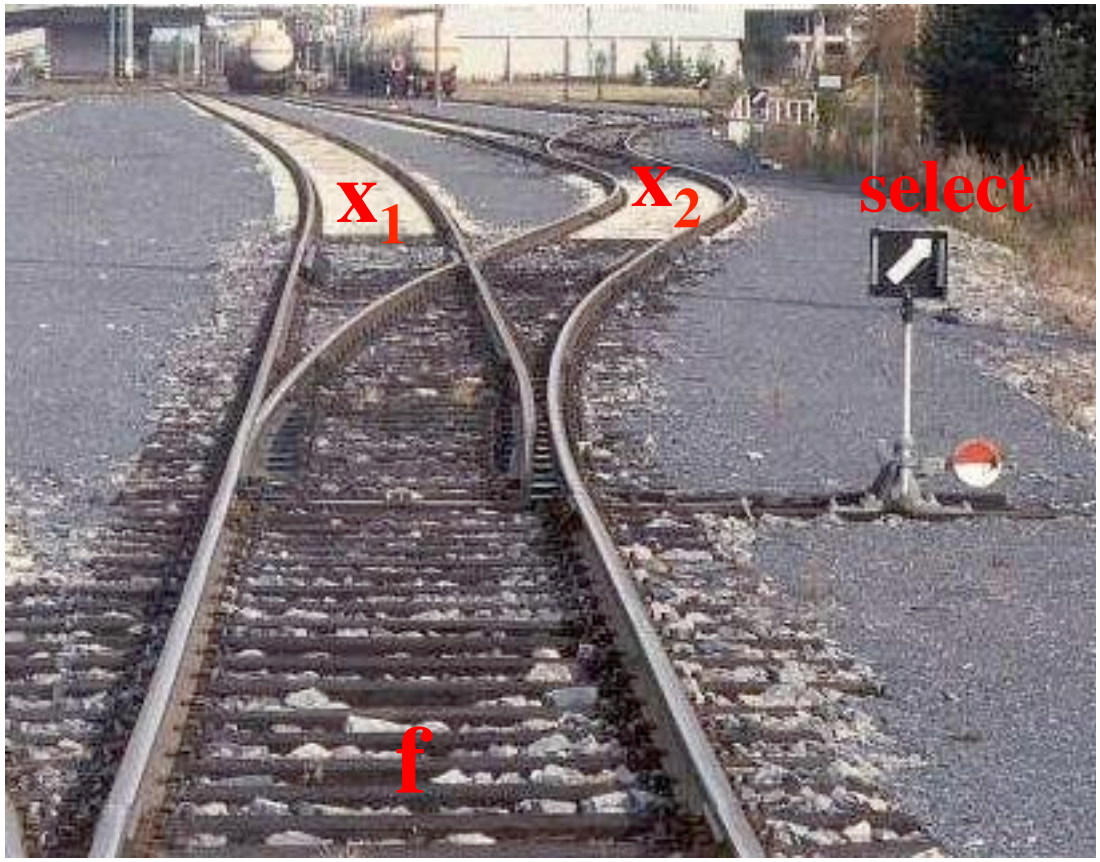
http://en.wikipedia.org/wiki/Railroad_switch]

Analogy: Railroad Switch



http://en.wikipedia.org/wiki/Railroad_switch]

Analogy: Railroad Switch



This is not a perfect analogy because the trains can go in either direction, while the multiplexer would only allow them to go from top to bottom.

http://en.wikipedia.org/wiki/Railroad_switch]

More Compact Truth-Table Representation

$s\ x_1\ x_2$	$f(s, x_1, x_2)$
0 0 0	0
0 0 1	0
0 1 0	1
0 1 1	1
1 0 0	0
1 0 1	1
1 1 0	0
1 1 1	1

(a)Truth table

s	$f(s, x_1, x_2)$
0	x_1
1	x_2

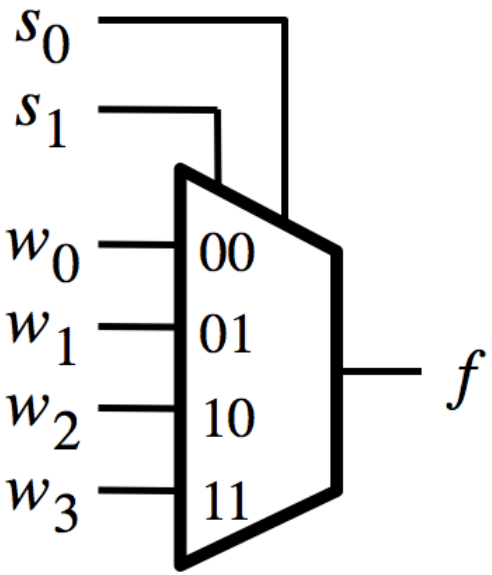
[Figure 2.33 from the textbook]

4-1 Multiplexer (Definition)

- Has four inputs: w_0 , w_1, w_2, w_3
- Also has two select lines: s_1 and s_0
- If s_1=0 and s_0=0, then the output f is equal to w_0
- If s_1=0 and s_0=1, then the output f is equal to w_1
- If s_1=1 and s_0=0, then the output f is equal to w_2
- If s_1=1 and s_0=1, then the output f is equal to w_3

We'll talk more about this when we get to chapter 4, but here is a quick preview.

Graphical Symbol and Truth Table



(a) Graphic symbol

s_1	s_0	f
0	0	w_0
0	1	w_1
1	0	w_2
1	1	w_3

(b) Truth table

[Figure 4.2a-b from the textbook]

The long-form truth table

S_1	S_0	I_3	I_2	I_1	I_0	F
0	0	0	0	0	0	0
		0	0	0	1	1
		0	0	1	0	0
		0	0	1	1	1
		0	1	0	0	0
		0	1	0	1	1
		0	1	1	0	0
		0	1	1	1	1
		1	0	0	0	0
		1	0	0	1	1
		1	0	1	0	0
		1	0	1	1	1
		1	1	0	0	0
		1	1	0	1	1
		1	1	1	0	0
		1	1	1	1	1

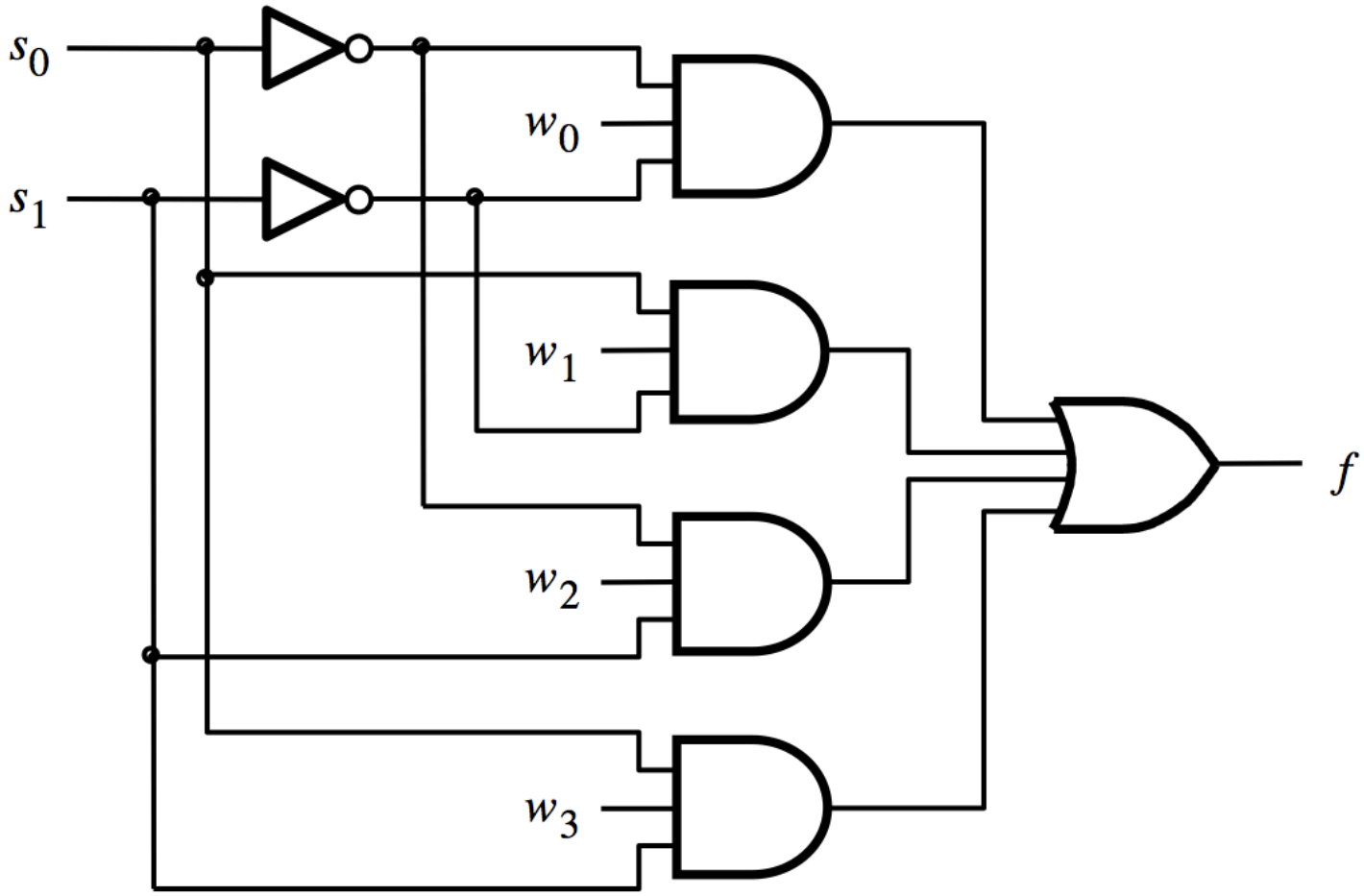
S_1	S_0	I_3	I_2	I_1	I_0	F
0	1	0	0	0	0	0
		0	0	0	1	0
		0	0	1	0	1
		0	0	1	1	1
		0	1	0	0	0
		0	1	0	1	0
		0	1	1	0	1
		0	1	1	1	1
		1	0	0	0	0
		1	0	0	1	0
		1	0	1	0	1
		1	0	1	1	1
		1	1	0	0	0
		1	1	0	1	0
		1	1	1	0	1
		1	1	1	1	1

S_1	S_0	I_3	I_2	I_1	I_0	F
1	0	0	0	0	0	0
		0	0	0	1	0
		0	0	1	0	0
		0	0	1	1	0
		0	1	0	0	1
		0	1	0	1	1
		0	1	1	0	1
		0	1	1	1	1
		1	0	0	0	0
		1	0	0	1	0
		1	0	1	0	0
		1	0	1	1	0
		1	1	0	0	1
		1	1	0	1	1
		1	1	1	0	1
		1	1	1	1	1

S_1	S_0	I_3	I_2	I_1	I_0	F
1	1	0	0	0	0	0
		0	0	0	1	0
		0	0	1	0	0
		0	0	1	1	0
		0	1	0	0	0
		0	1	0	1	0
		0	1	1	0	0
		0	1	1	1	0
		1	0	0	0	1
		1	0	0	1	1
		1	0	1	0	1
		1	0	1	1	1
		1	1	0	0	1
		1	1	0	1	1
		1	1	1	0	1
		1	1	1	1	1

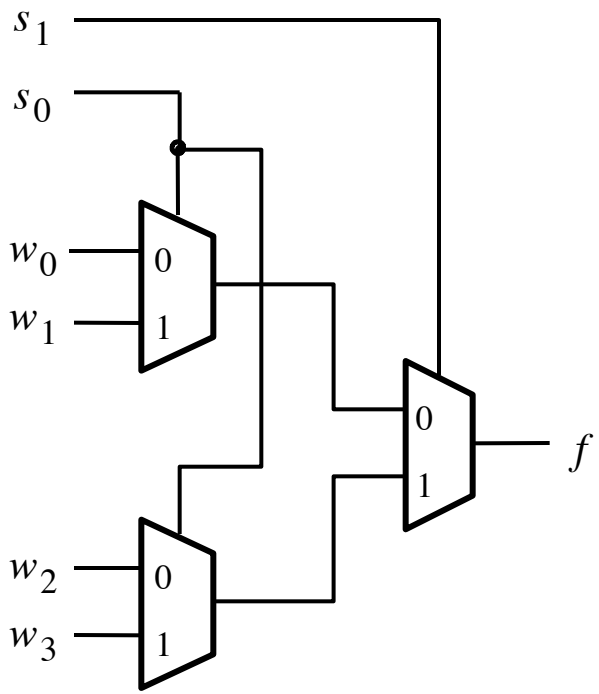
[http://www.absoluteastronomy.com/topics/Multiplexer]

4-1 Multiplexer (SOP circuit)



[Figure 4.2c from the textbook]

Using three 2-to-1 multiplexers to build one 4-to-1 multiplexer

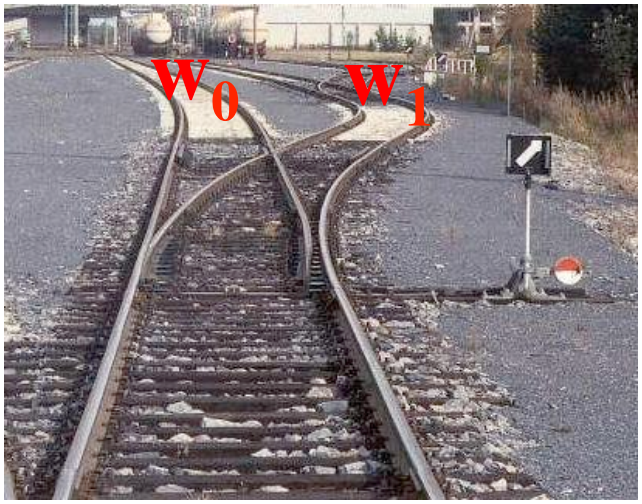


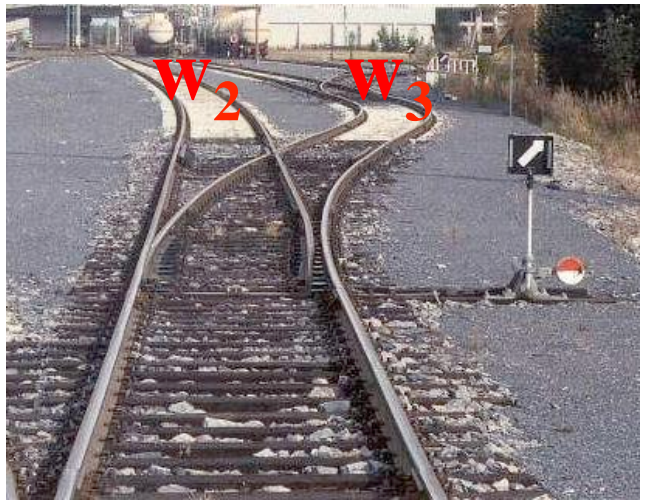
[Figure 4.3 from the textbook]

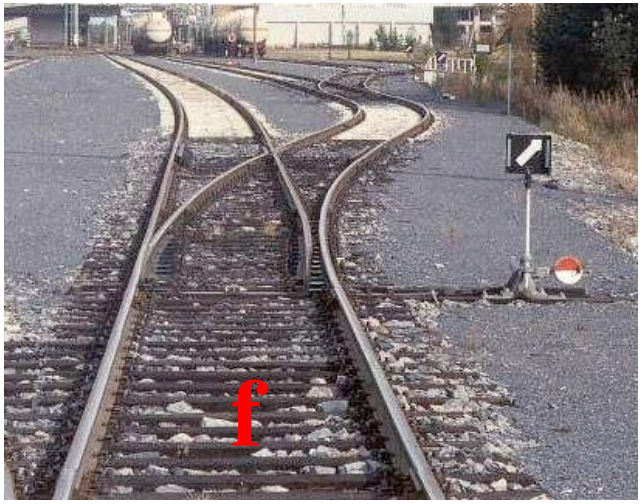
Analogy: Railroad Switches

http://en.wikipedia.org/wiki/Railroad_switch]

Analogy: Railroad Switches



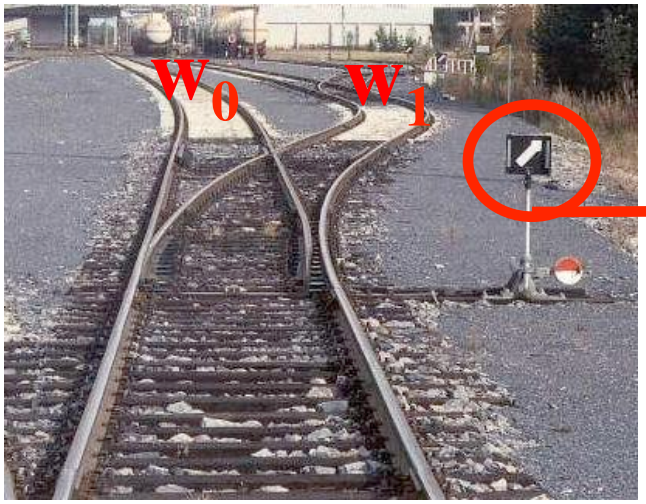


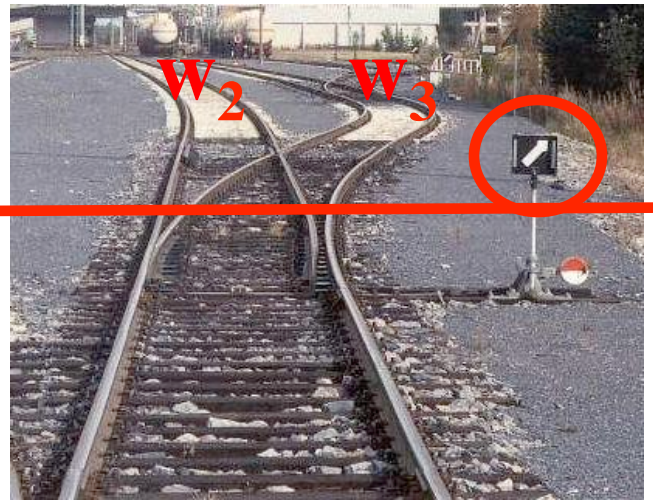


s_1

http://en.wikipedia.org/wiki/Railroad_switch]

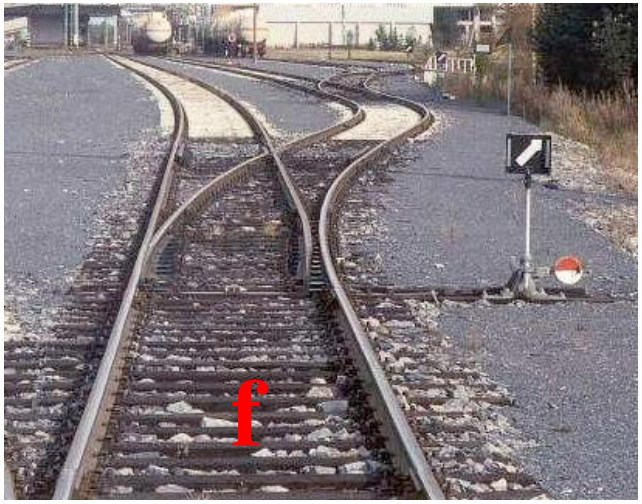
Analogy: Railroad Switches





s_0

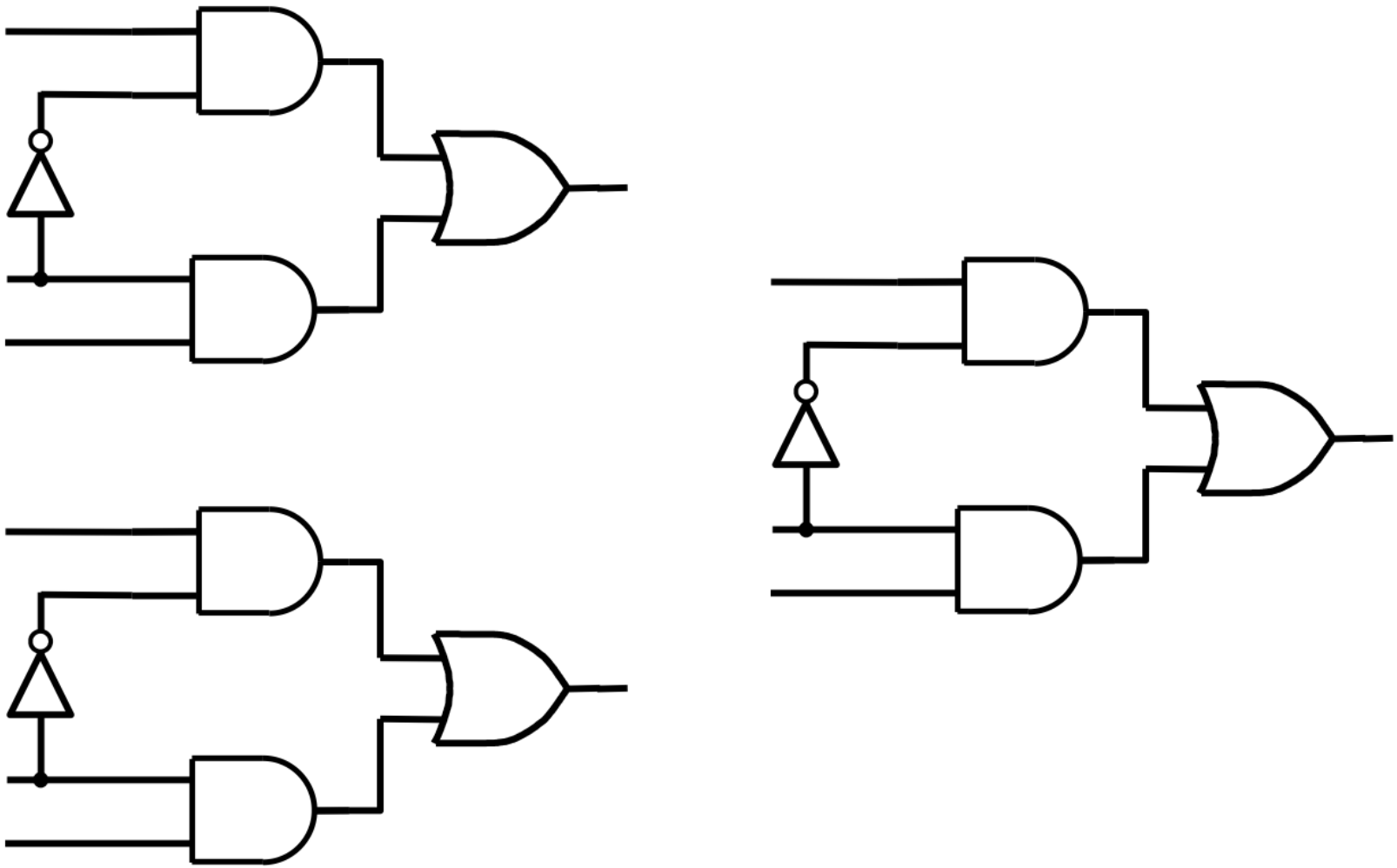
these two switches are controlled together



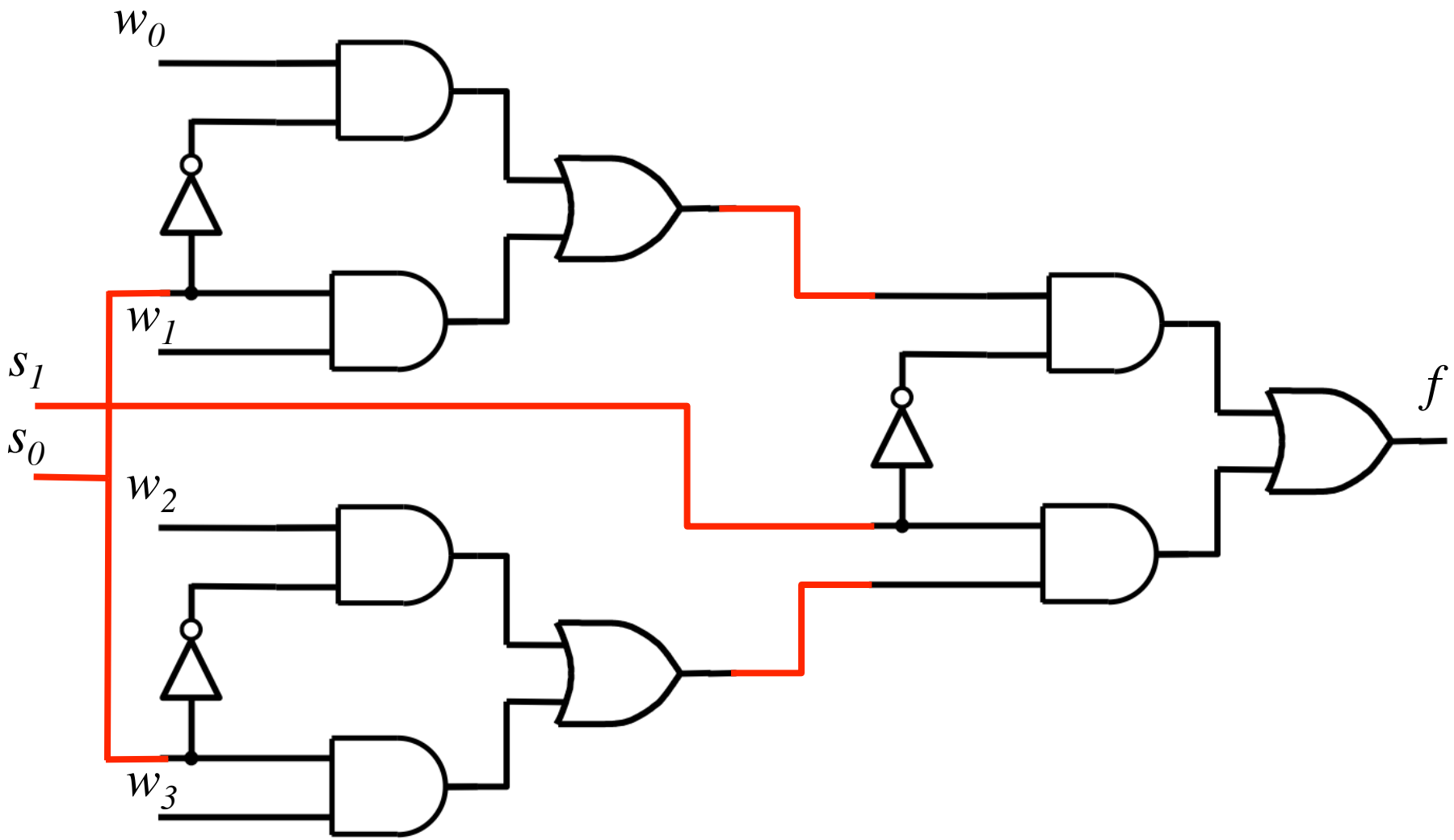
s_1

http://en.wikipedia.org/wiki/Railroad_switch]

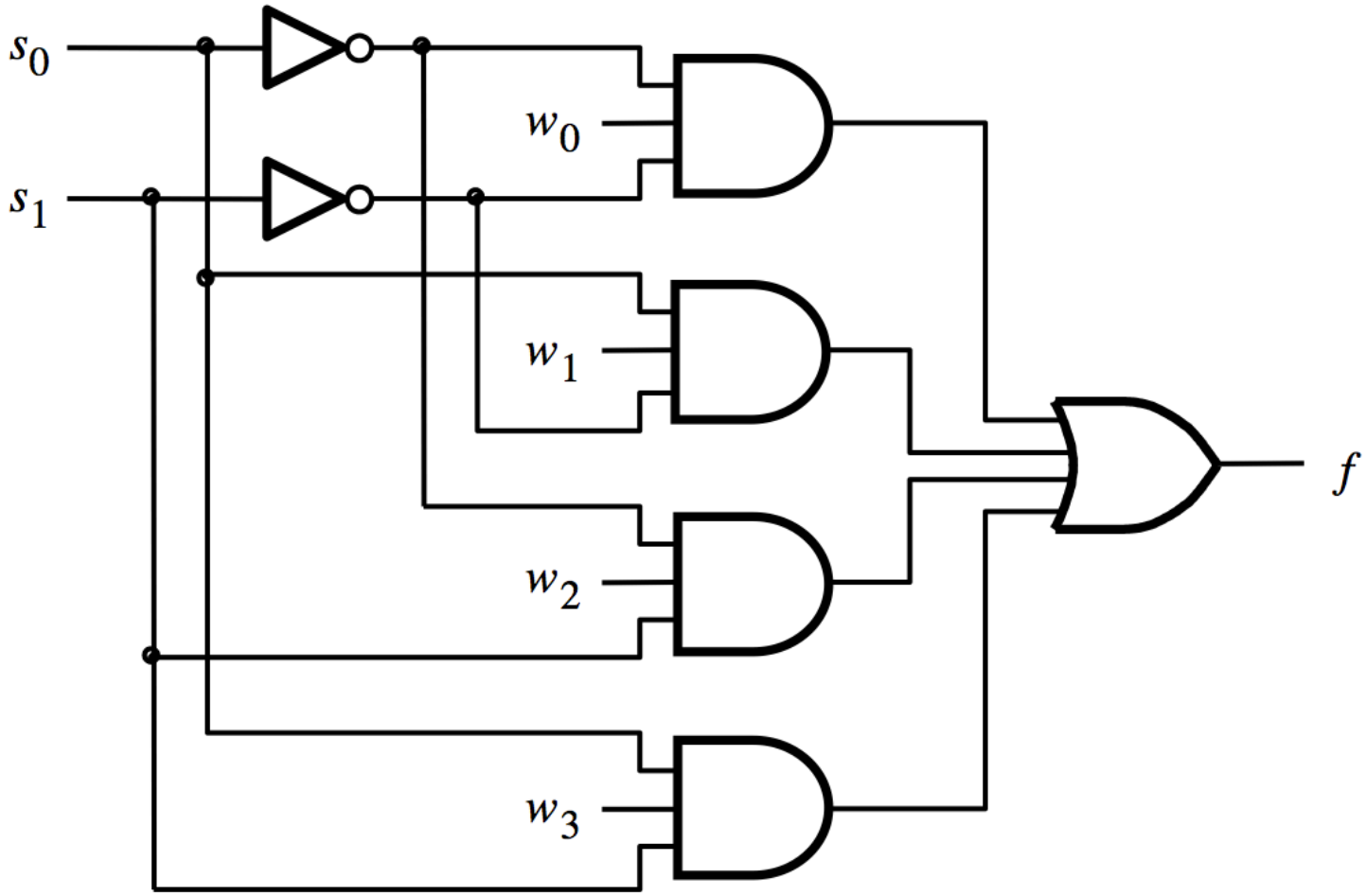
Using three 2-to-1 multiplexers to build one 4-to-1 multiplexer



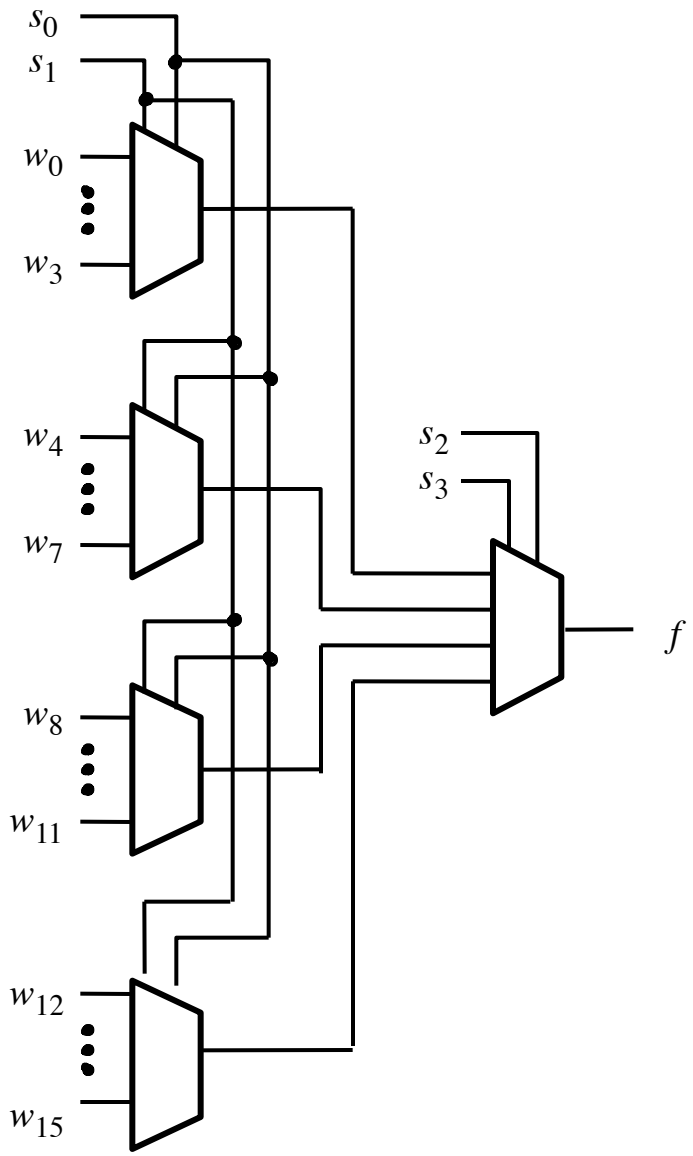
Using three 2-to-1 multiplexers to build one 4-to-1 multiplexer



That is different from the SOP form of the 4-1 multiplexer shown below, which uses less gates



16-1 Multiplexer

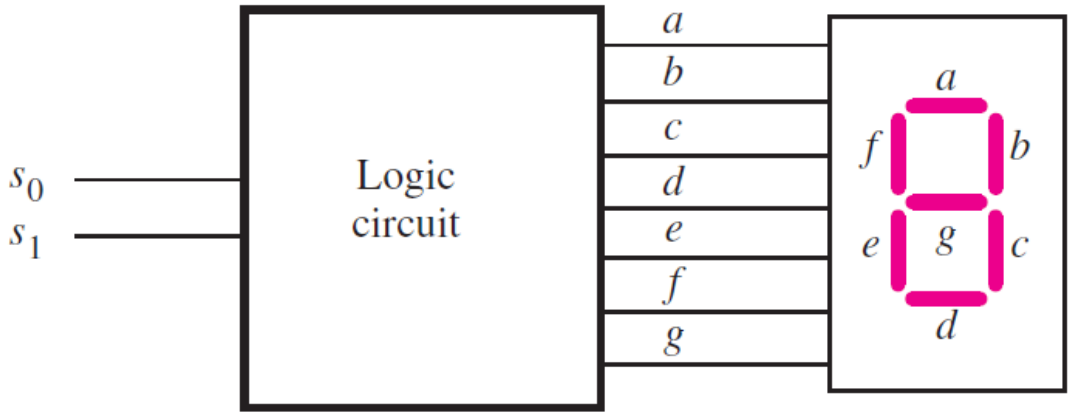


[Figure 4.4 from the textbook]

[http://upload.wikimedia.org/wikipedia/commons/2/26/SunsetTracksCrop.JPG]

7-Segment Display Example

Display of numbers



(a) Logic circuit and 7-segment display

	s_1	s_0	a	b	c	d	e	f	g
0	0	0	1	1	1	1	1	1	0
1	0	1	0	1	1	0	0	0	0
2	1	0	1	1	0	1	1	0	1

(b) Truth table

[Figure 2.34 from the textbook]

Display of numbers

s_1	s_0	a	b	c	d	e	f	g
0	0	1	1	1	1	1	1	0
0	1	0	1	1	0	0	0	0
1	0	1	1	0	1	1	0	1

Display of numbers

s_1	s_0	a	b	c	d	e	f	g
0	0	1	1	1	1	1	1	0
0	1	0	1	1	0	0	0	0
1	0	1	1	0	1	1	0	1

$a = \overline{s_0}$ $c = \overline{s_1}$ $e = \overline{s_0}$ $g = s_1 \overline{s_0}$

$b = 1$ $d = \overline{s_0}$ $f = \overline{s_1}\,\overline{s_0}$

Intro to Verilog

History

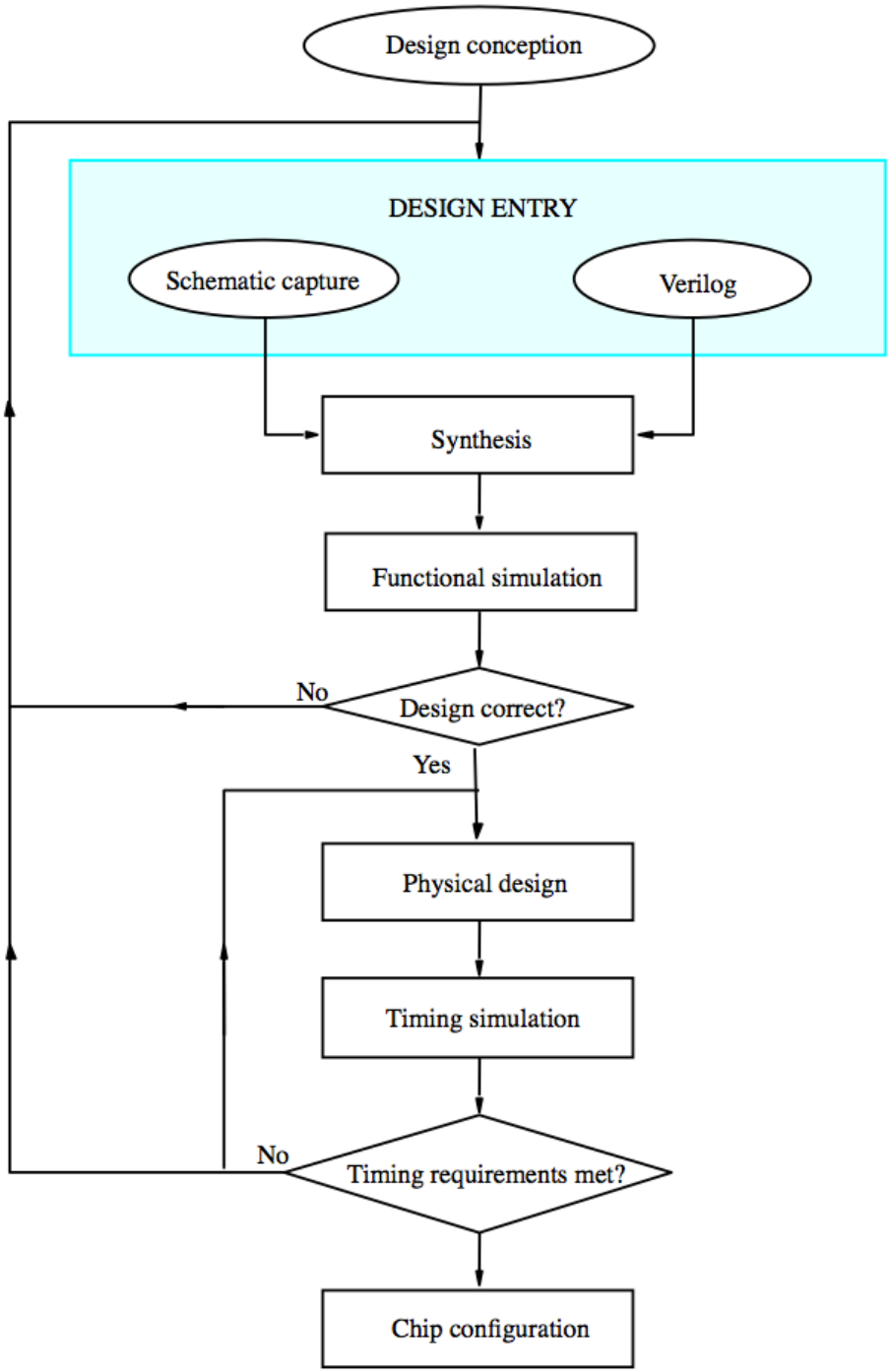
- Created in 1983/1984
- Verilog-95 (IEEE standard 1364-1995)
- Verilog 2001 (IEEE Standard 1364-2001)
- Verilog 2005 (IEEE Standard 1364-2005)
- SystemVerilog
- SystemVerilog 2009 (IEEE Standard 1800-2009).

HDL

- **Hardware Description Language**
- **Verilog HDL**
- **VHDL**

Verilog HDL != VHDL

- **These are two different Languages!**
- **Verilog is closer to C**
- **VHDL is closer to Ada**



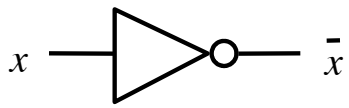
[Figure 2.35 from the textbook]

“Hello World” in Verilog

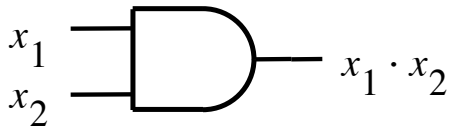
```
module main;
  initial
    begin
      $display("Hello world!");
      $finish;
    end
endmodule
```

[http://en.wikipedia.org/wiki/Verilog]

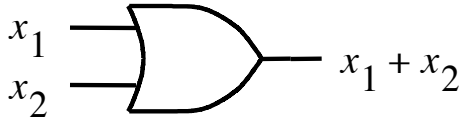
The Three Basic Logic Gates



NOT gate



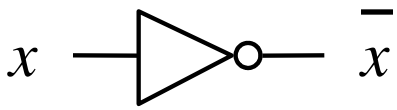
AND gate



OR gate

[Figure 2.8 from the textbook]

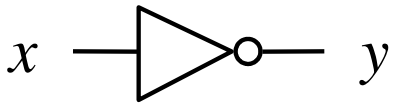
How to specify a NOT gate in Verilog



NOT gate

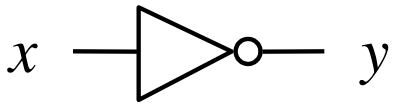
How to specify a NOT gate in Verilog

we'll use the letter y for the output



NOT gate

How to specify a NOT gate in Verilog

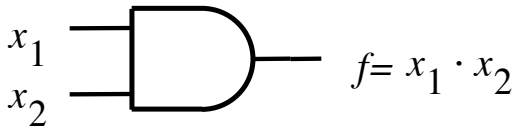


NOT gate

```
not (y, x)
```

Verilog code

How to specify an AND gate in Verilog

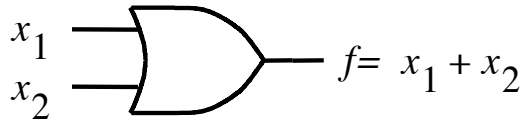


AND gate

```
and (f, x1, x2)
```

Verilog code

How to specify an OR gate in Verilog

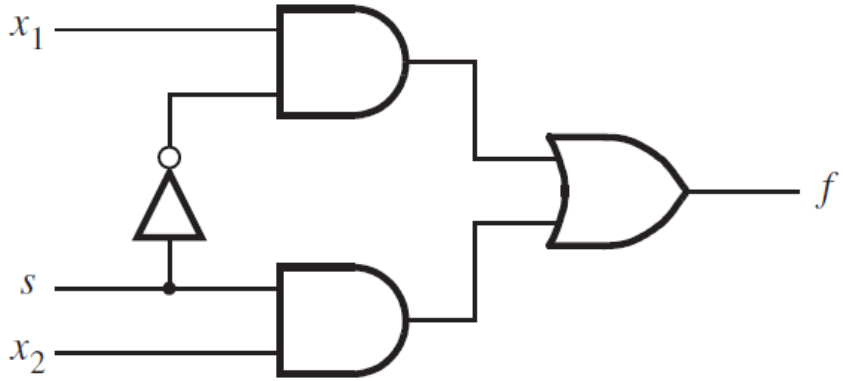


OR gate

```
or (f, x1, x2)
```

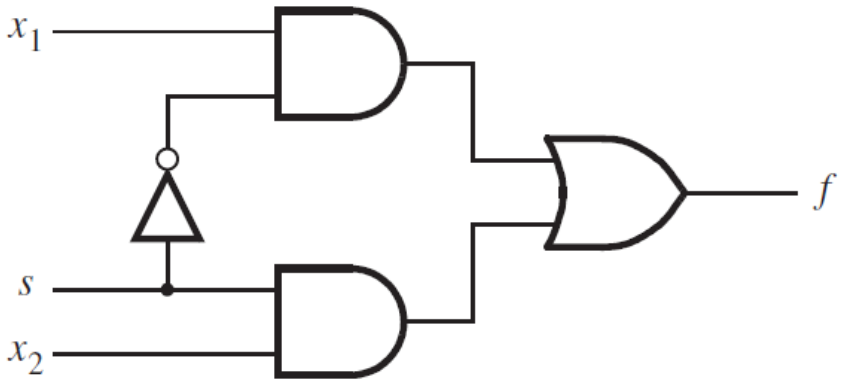
Verilog code

2-1 Multiplexer



[Figure 2.36 from the textbook]

Verilog Code for a 2-1 Multiplexer

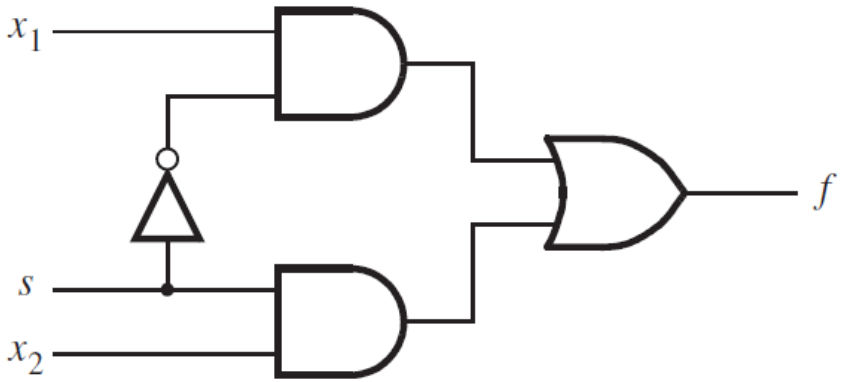


[Figure 2.36 from the textbook]

```
module example1 (x1, x2, s, f);
    input x1, x2, s;
    output f;

    not (k, s);
    and (g, k, x1);
    and (h, s, x2);
    or (f, g, h);

endmodule
```

[Figure 2.37 from the textbook]

Verilog Code for a 2-1 Multiplexer

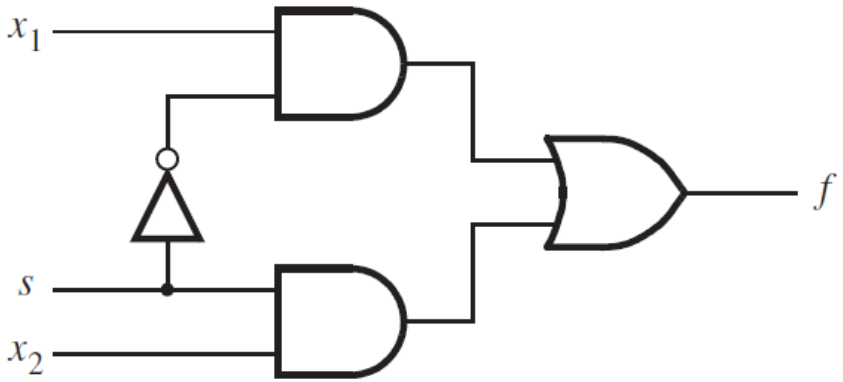



```
module  example3 (x1, x2, s, f);
    input x1, x2, s;
    output f;

    assign  f = (~s & x1) | (s & x2);

endmodule
```

[Figure 2.36 from the textbook]

[Figure 2.40 from the textbook]

Verilog Code for a 2-1 Multiplexer

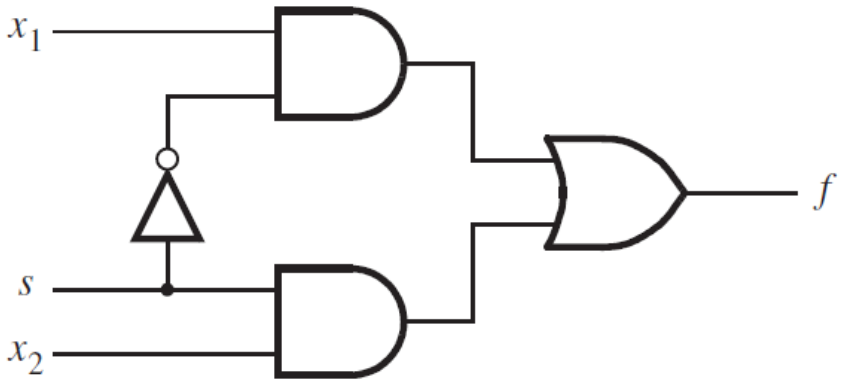


[Figure 2.36 from the textbook]

```
// Behavioral specification
module  example5 (x1, x2, s, f);
    input  x1, x2, s;
    output f;
    reg f;

    always @(x1 or x2 or s)
        if (s == 0)
            f = x1;
        else
            f = x2;

endmodule
```

[Figure 2.42 from the textbook]

Verilog Code for a 2-1 Multiplexer



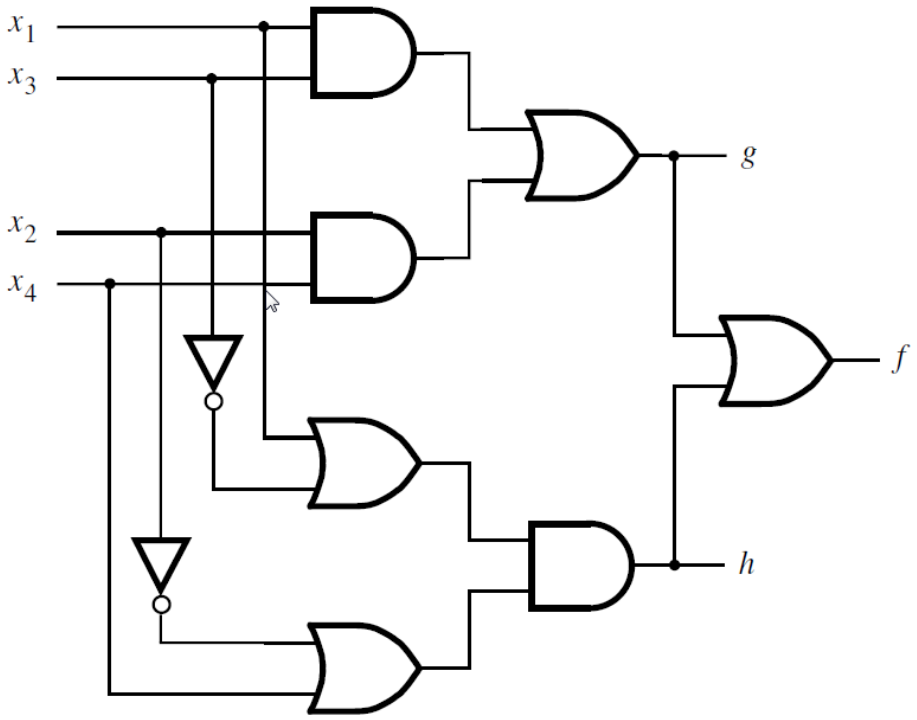

```
// Behavioral specification
module  example5 (input x1, x2, s, output reg f);

    always @(x1, x2, s)
        if (s == 0)
            f = x1;
        else
            f = x2;

endmodule
```

[Figure 2.36 from the textbook]

[Figure 2.43 from the textbook]

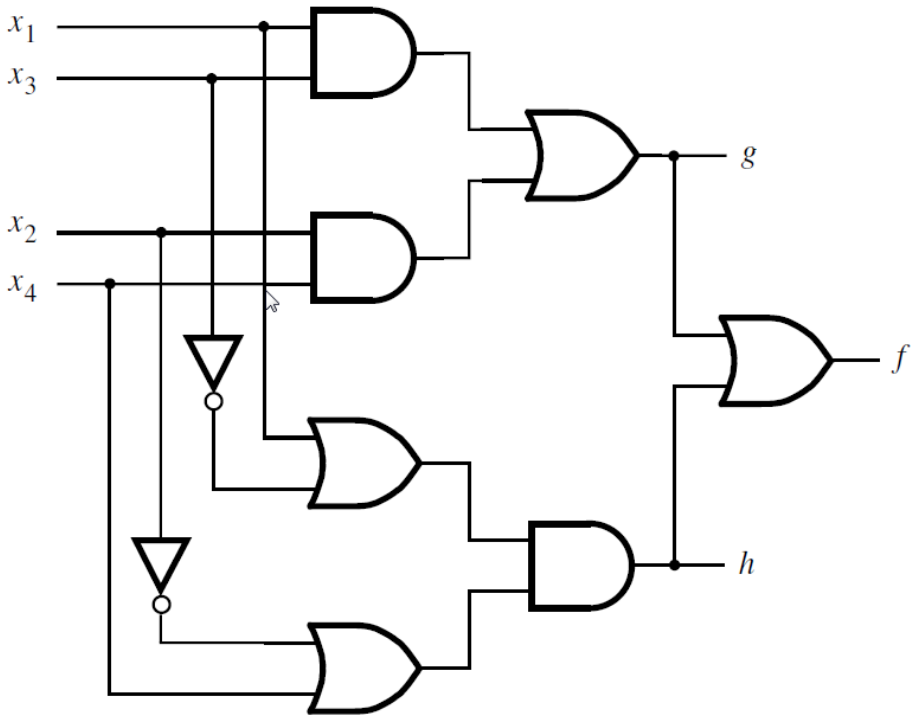
Another Example

Let's Write the Code for This Circuit



[Figure 2.39 from the textbook]

Let's Write the Code for This Circuit

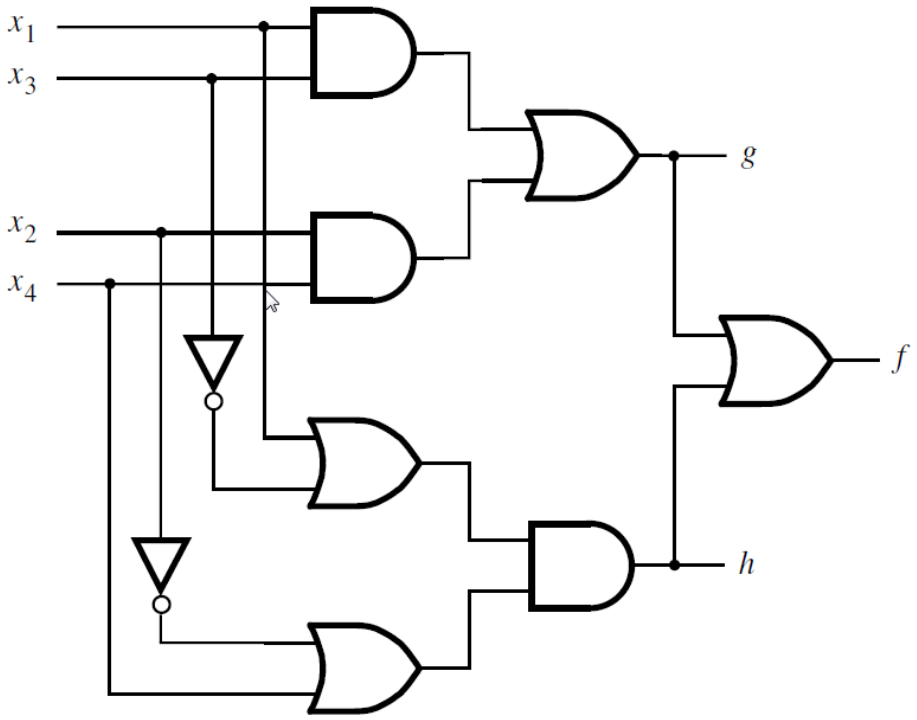


[Figure 2.39 from the textbook]

```
module example2 (x1, x2, x3, x4, f, g, h);
        input x1, x2, x3, x4;
        output f, g, h;

        and (z1, x1, x3);
        and (z2, x2, x4);
        or (g, z1, z2);
        or (z3, x1, ~x3);
        or (z4, ~x2, x4);
        and (h, z3, z4);
        or (f, g, h);

endmodule
```

[Figure 2.38 from the textbook]

Let's Write the Code for This Circuit



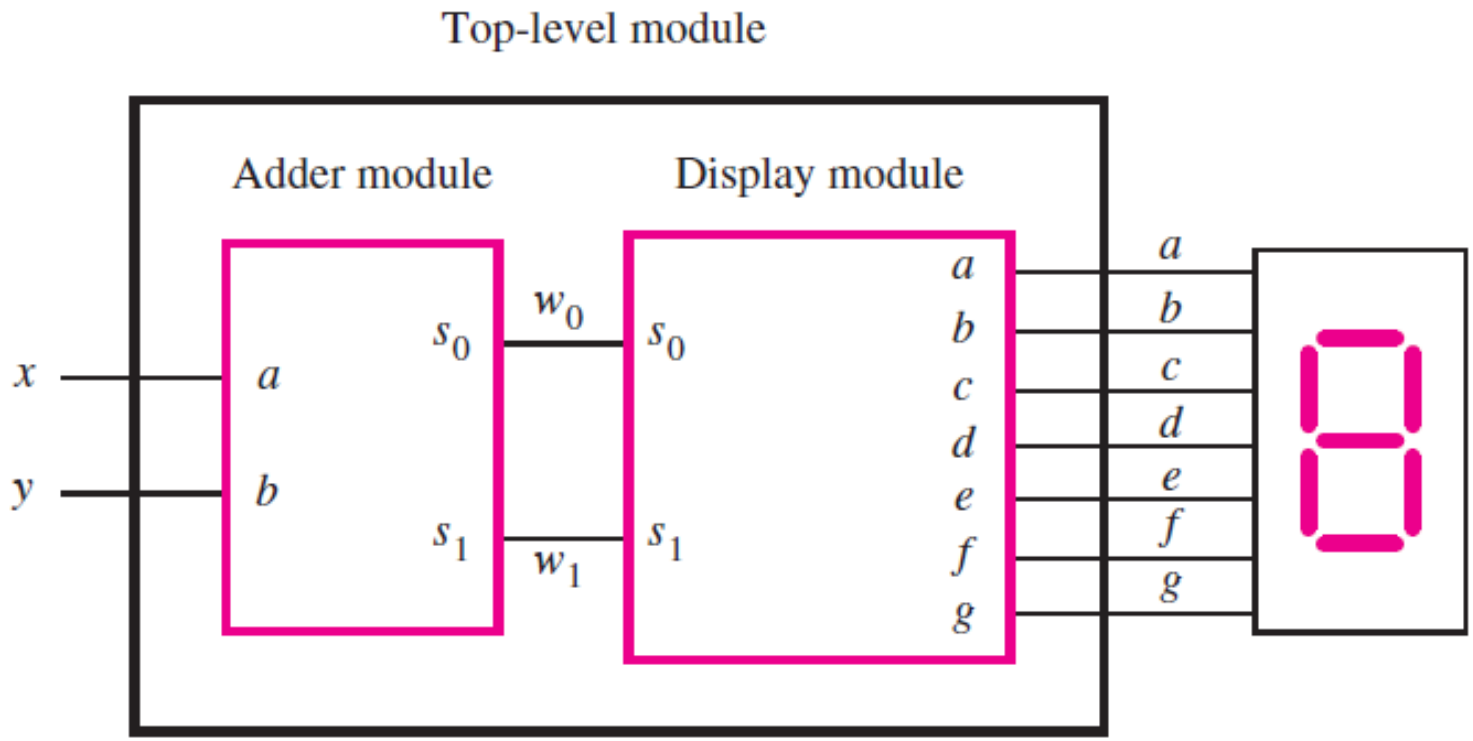
[Figure 2.39 from the textbook]

```
module example4 (x1, x2, x3, x4, f, g, h);
        input x1, x2, x3, x4;
        output f, g, h;

        assign g = (x1 & x3) | (x2 & x4);
        assign h = (x1 | ~x3) & (~x2 | x4);
        assign f = g | h;

endmodule
```

[Figure 2.41 from the textbook]

Yet Another Example

A logic circuit with two modules



[Figure 2.44 from the textbook]

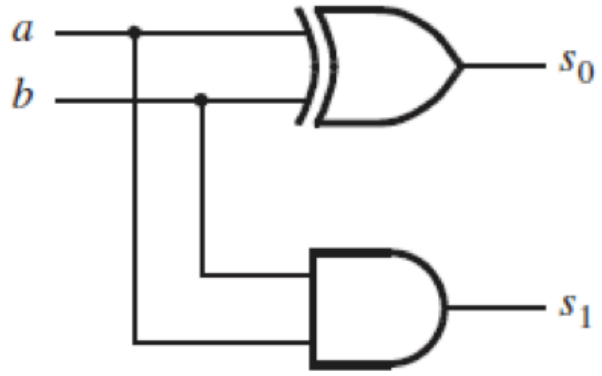
The adder module

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

(a) Evaluation of $S = a + b$

a	b	s_1	s_0
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

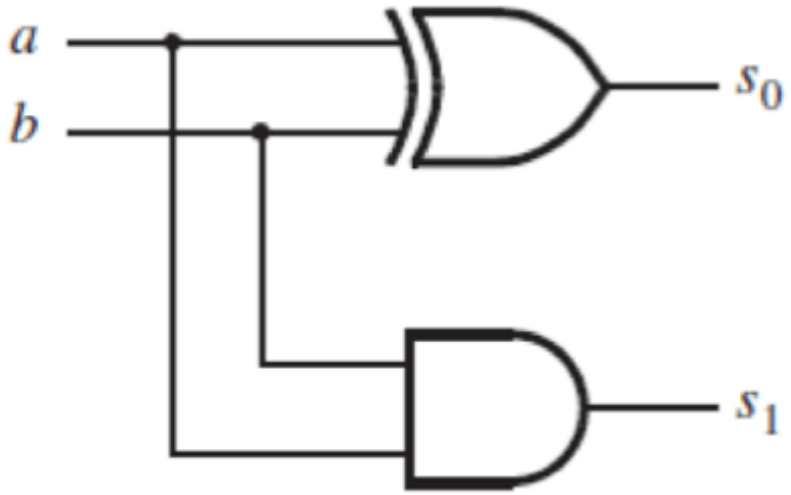
(b) Truth table



(c) Logic network

[Figure 2.12 from the textbook]

The adder module




```
// An adder module
module  adder (a, b, s1, s0);
    input a, b;
    output s1, s0;

    assign s1 = a & b;
    assign s0 = a ^ b;

endmodule
```

[Figure 2.45 from the textbook]

The display module

s_1	s_0	a	b	c	d	e	f	g
0	0	1	1	1	1	1	1	0
0	1	0	1	1	0	0	0	0
1	0	1	1	0	1	1	0	1

$a = \overline{s_0}$ $c = \overline{s_1}$ $e = \overline{s_0}$ $g = s_1 \overline{s_0}$

$b = 1$ $d = \overline{s_0}$ $f = \overline{s_1}\,\overline{s_0}$

The display module

$a = \overline{s_0}$

$b = 1$

$c = \overline{s_1}$

$d = \overline{s_0}$

$e = \overline{s_0}$

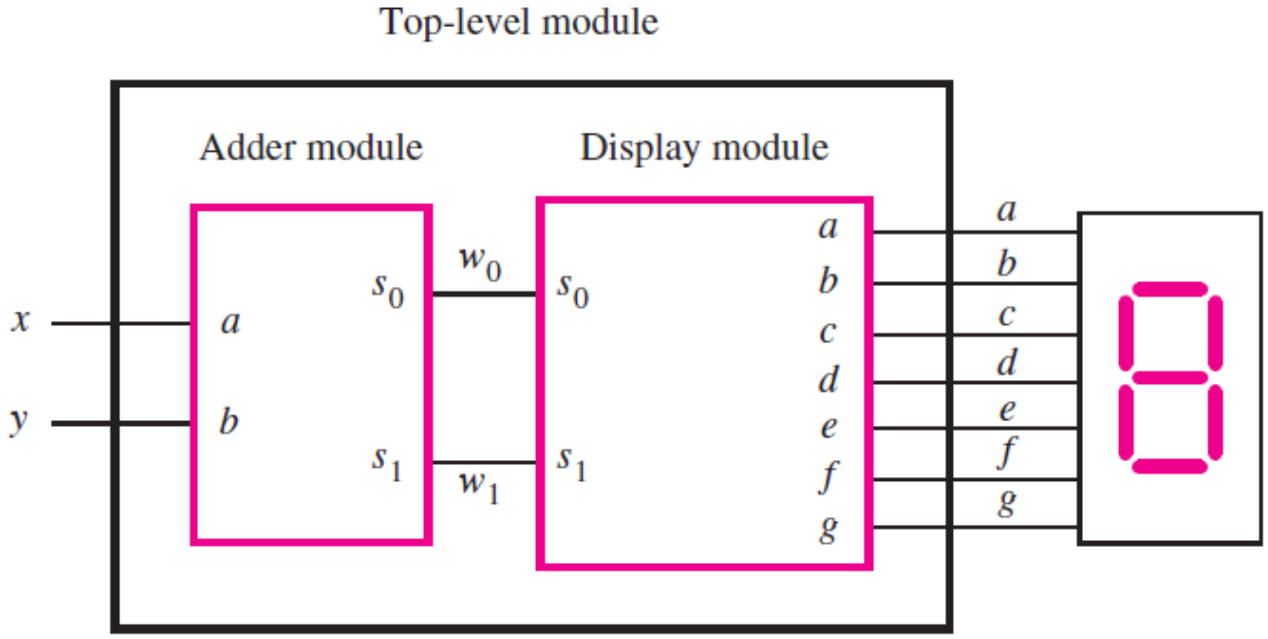
$f = \overline{s_1}\,\overline{s_0}$

$g = s_1\,\overline{s_0}$

```
// A module for driving a 7-segment display
module display (s1, s0, a, b, c, d, e, f, g);
    input s1, s0;
    output a, b, c, d, e, f, g;

    assign a = ~s0;
    assign b = 1;
    assign c = ~s1;
    assign d = ~s0;
    assign e = ~s0;
    assign f = ~s1 & ~s0;
    assign g = s1 & ~s0;

endmodule
```

[Figure 2.46 from the textbook]

Putting it all together




```
// An adder module
module  adder (a, b, s1, s0)
    input a, b;
    output s1, s0;

    assign s1 = a & b;
    assign s0 = a ^ b;

endmodule
```

```
// A module for driving a 7-segment display
module display (s1, s0, a, b, c, d, e, f, g);
    input s1, s0;
    output a, b, c, d, e, f, g;

    assign a = ~s0;
    assign b = 1;
    assign c = ~s1;
    assign d = ~s0;
    assign e = ~s0;
    assign f = ~s1 & ~s0;
    assign g = s1 & ~s0;

endmodule
```

```
module adder_display (x, y, a, b, c, d, e, f, g);
    input x, y;
    output a, b, c, d, e, f, g;
    wire w1, w0;

    adder U1 (x, y, w1, w0);
    display U2 (w1, w0, a, b, c, d, e, f, g);

endmodule
```

Questions?

THE END