

2384-3

**ICTP Latin-American Advanced Course on FPGA Design for Scientific
Instrumentation**

19 November - 7 December, 2012

**Digital Design
(Part 3)**

BAZARGAN SABET Pirouz
*Universite Pierre Et Marie Curie (Vi)
Lip6, Departement Asim
4, Place Jussieu
75252 Paris Cedex 05
FRANCE*

Outline

□ Digital CMOS design

- Boolean algebra
- Basic digital CMOS gates
- **Combinational and sequential circuits**
- Coding - Representation of numbers

CMOS Circuits

How can I design a digital circuit ?

- A set of gates (cell library)

combinational gates

memory elements



CMOS Circuits

How can I design a digital circuit ?

- Method to design combinational circuits

Karnaugh table (local optimization)

no method for global optimization

→ synthesis tools



CMOS Circuits

How can I design a digital circuit ?

- Specify the circuit

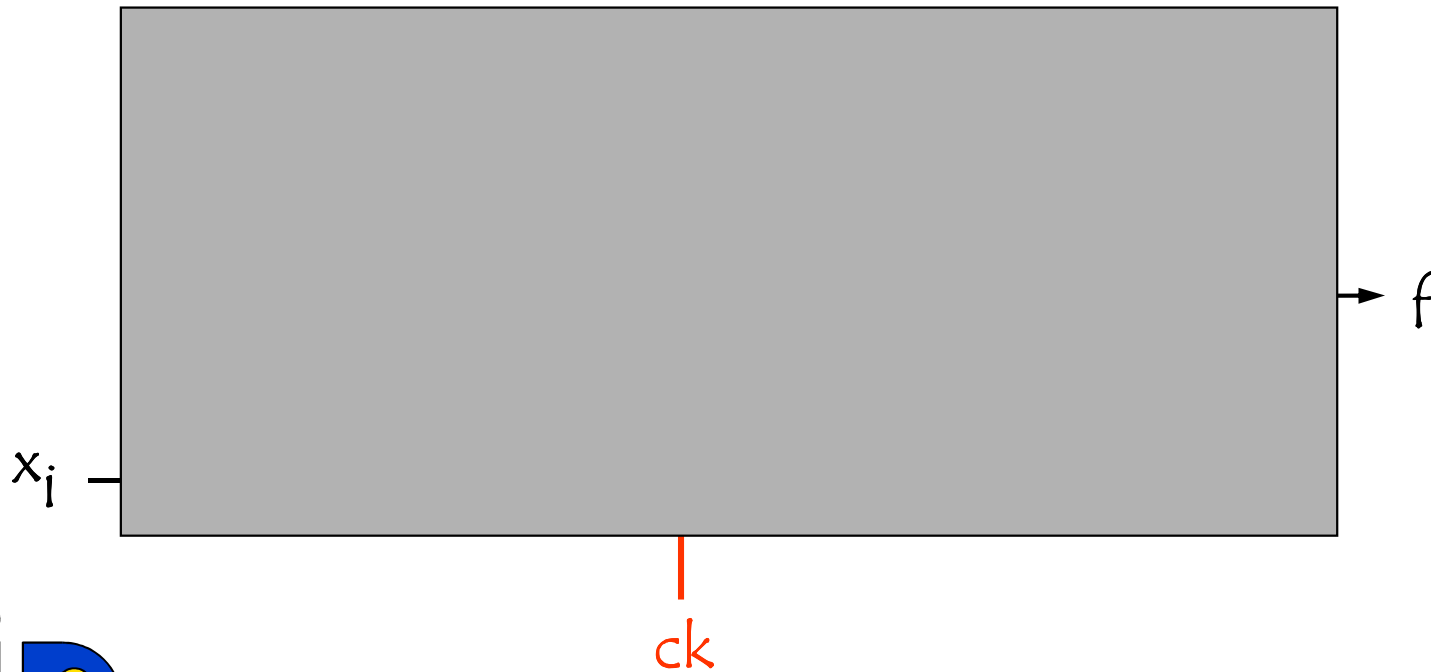
Combinational circuit : Boolean functions

Sequential circuit ?



CMOS Circuits

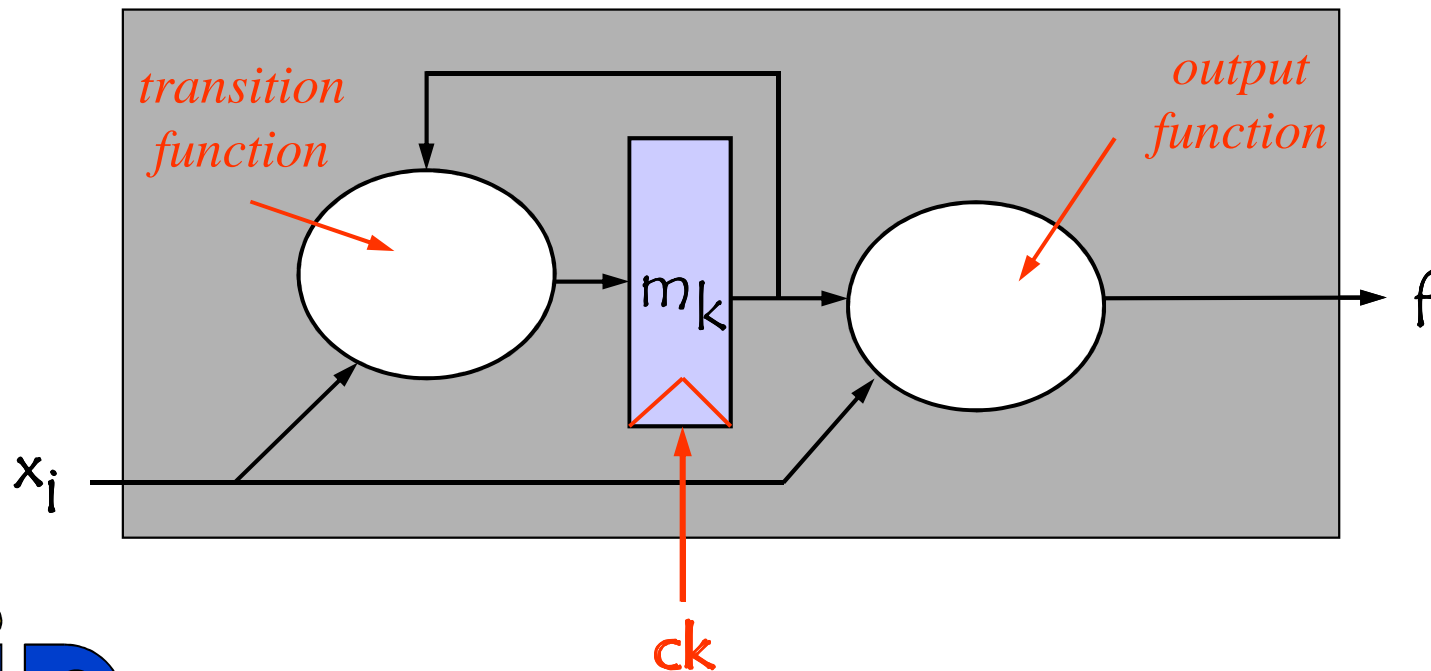
Sequential Circuit



CMOS Circuits

How can I design a sequential circuit ?

I need a method to go from a black box to a white box



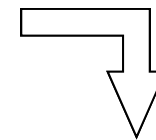
CMOS Circuits

How can I design a sequential circuit ?

The starting point (what I know)

What the circuit is supposed to do

Capture this knowledge into a
representation that can be
transposed into Boolean functions



The aim

How it will do it

number of required
memory elements



CMOS Circuits

Representation of a sequential circuit ?

● State graph

$$G = (X, Y, S, T, O)$$

X : input variables

Y : output variables

S : states

T : transitions

O : output set conditions



CMOS Circuits

○ $G = (X, Y, S, T, O)$

T : set of transitions

$$t \in T, \quad t = (s, s', f)$$

$s \in S$: source state

$s' \in S$: target state

$f \in B_n$: transition condition



CMOS Circuits

$$\bigcirc G = (X, Y, S, T, O)$$

O : output set conditions

$$o \in O, \quad o = (y, s, c)$$

$y \in Y$: output variable

$s \in S$: state

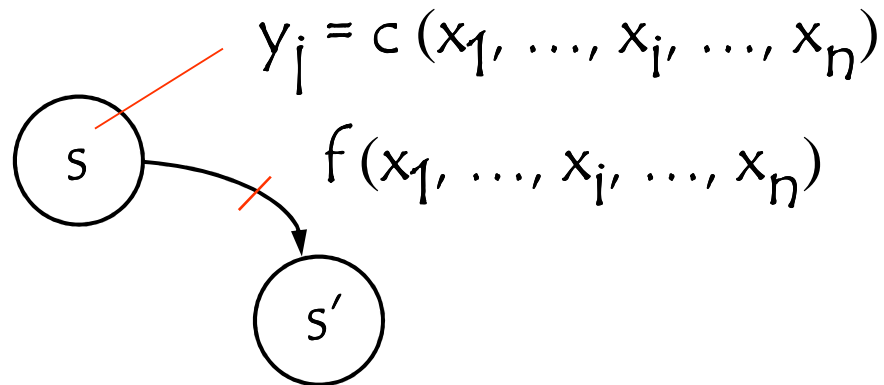
$c \in B_n$: output set condition



CMOS Circuits

- Let consider a graph $G = (X, Y, S, T, O)$

Graphic representation of G



CMOS Circuits

Representation of a sequential circuit ?

- State graph

Transpose into a graphic representation the expected behavior of a sequential system

$$G = (X, Y, S, T, O)$$



CMOS Circuits

Example

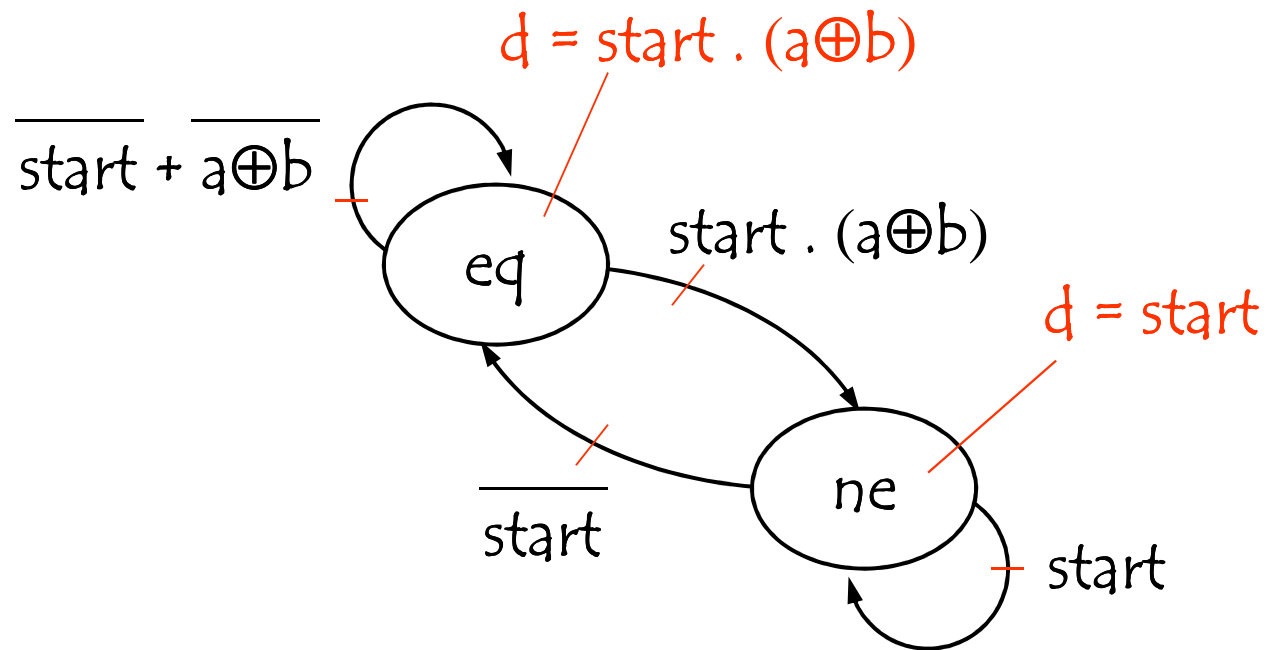
Two signals a , b each transmitting a series of bits (1 bit at a cycle)

Design a system that sets a flag d if the value transmitted by a is different than b



CMOS Circuits

Example



CMOS Circuits

Representation of a sequential circuit ?

- State graph

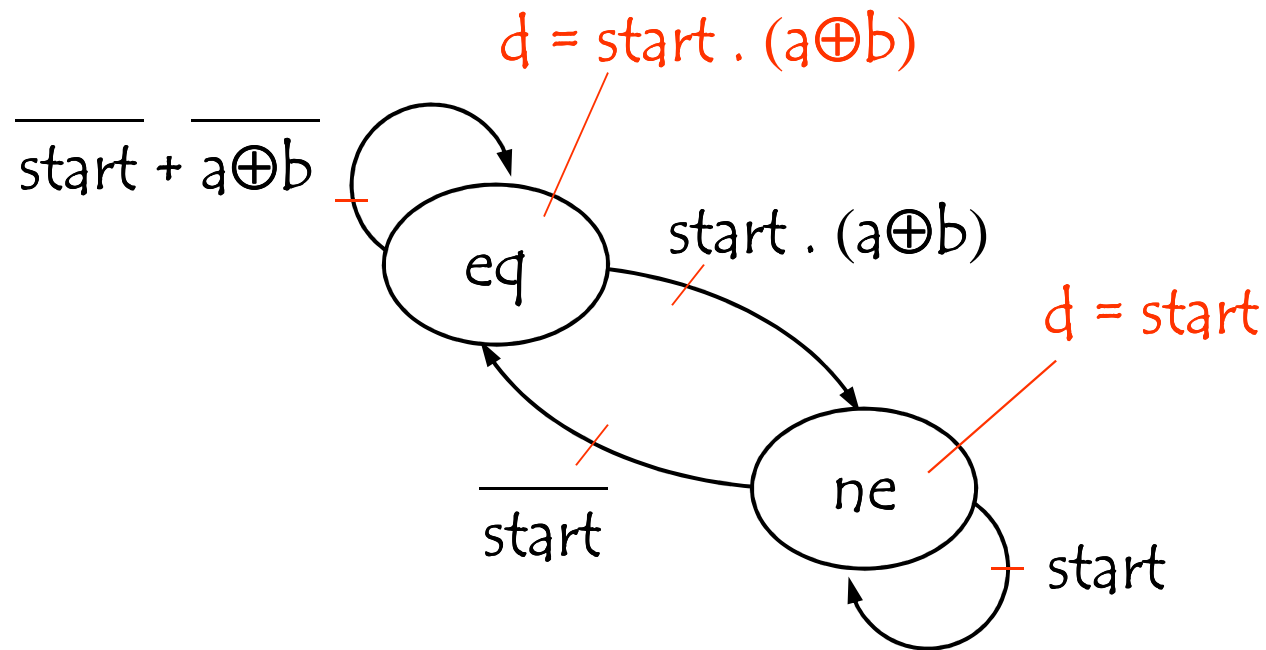
$$G = (X, Y, S, T, O)$$

define the number of memory elements
required to represent $S : M$



CMOS Circuits

Example



2 states \longrightarrow 1 memory element

CMOS Circuits

Representation of a sequential circuit ?

- State graph

$$G = (X, Y, S, T, O)$$

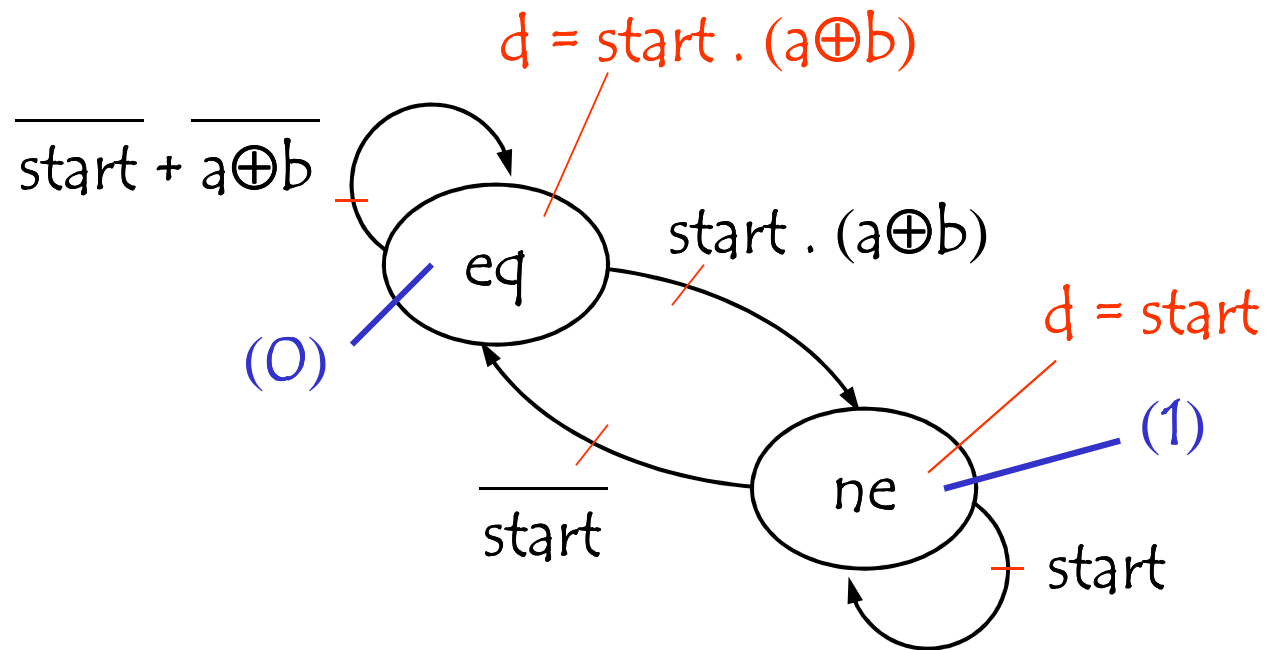
define the number of memory elements
required to represent $S : M$

represent each state s by a vector of M



CMOS Circuits

Example



2 states \longrightarrow 1 memory element

CMOS Circuits

Representation of a sequential circuit ?

- State graph

$$G = (X, Y, S, T, O)$$

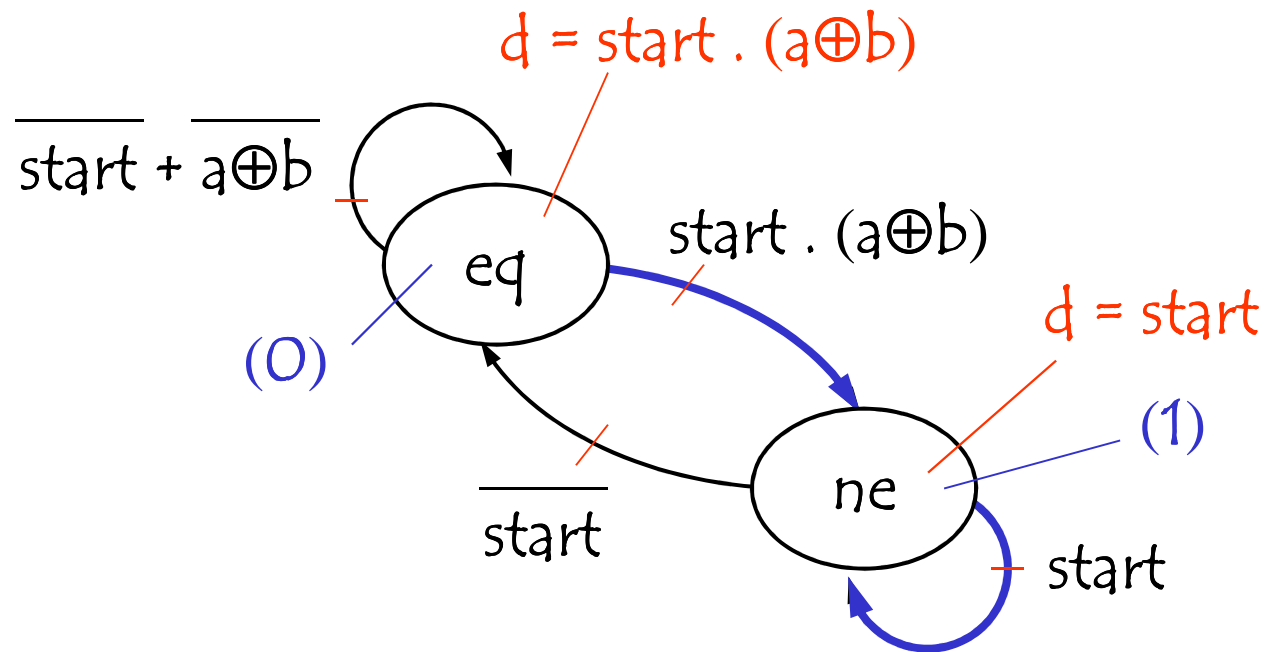
define the *transition function* : m_k

m_k = sum of the Boolean function of the transitions
that have as target a state where $m_k=1$



CMOS Circuits

Example



$$m_1 = \overline{m_1} \cdot \text{start} \cdot (a \oplus b) + m_1 \cdot \text{start}$$

CMOS Circuits

Representation of a sequential circuit ?

- State graph

$$G = (X, Y, S, T, O)$$

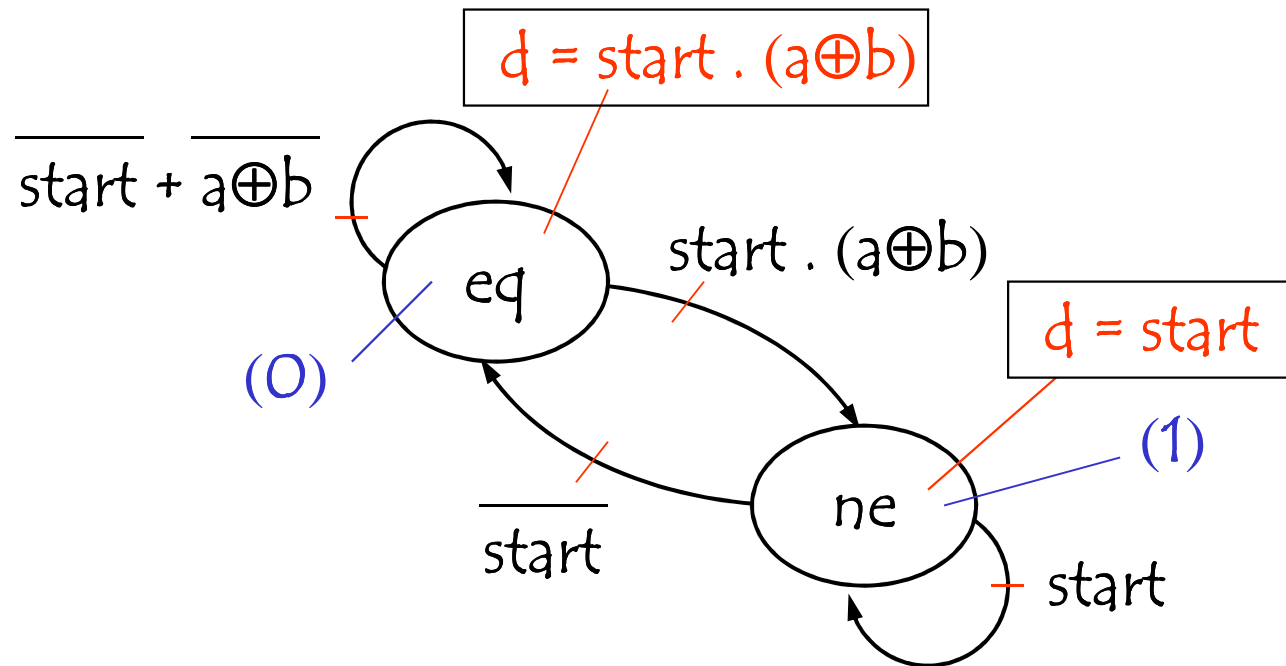
define the *output function* : y_i

$y_i =$ sum of the output conditions concerning y_i



CMOS Circuits

Example



$$d = \overline{m_1} . start . (a \oplus b) + m_1 . start$$

CMOS Circuits

Representation of a sequential circuit ?

- State graph

$$G = (X, Y, S, T, O)$$

implement the Boolean functions : m_k, y_j



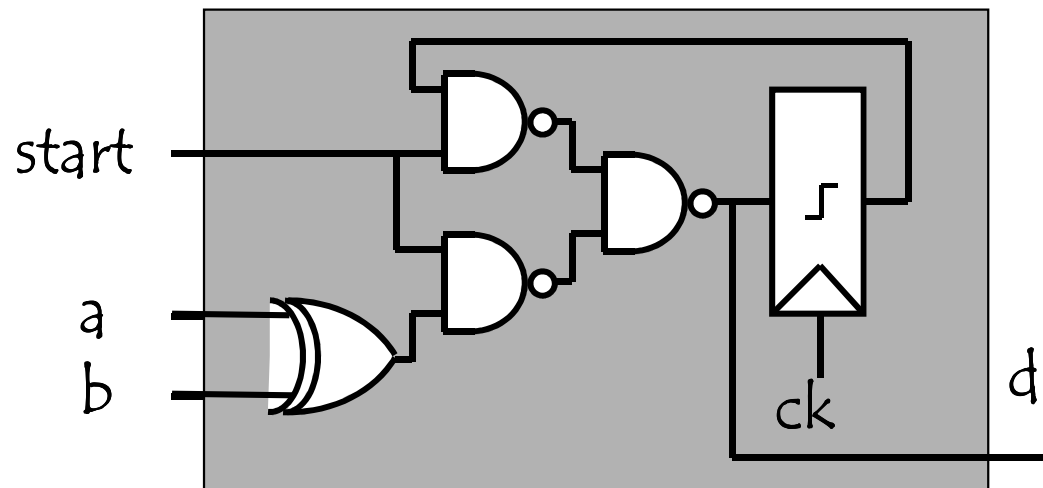
CMOS Circuits

Example

$$m_1 = \overline{m_1} \cdot \text{start} \cdot (a \oplus b) + m_1 \cdot \text{start}$$

$$d = \overline{m_1} \cdot \text{start} \cdot (a \oplus b) + m_1 \cdot \text{start}$$

$$m_1 = \text{start} \cdot (a \oplus b) + \text{start} \cdot m_1$$



CMOS Circuits

How can I design a sequential circuit (summary) ?

○ $G = (X, Y, S, T, O)$



➤ graphic representation of the behavior

➤ define the number of memory elements required to represent $S : M$

➤ represent each state by a vector of M

➤ define the *transition function*

➤ define the *output function*

➤ implement the Boolean functions

FSM synthesis tool

