

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

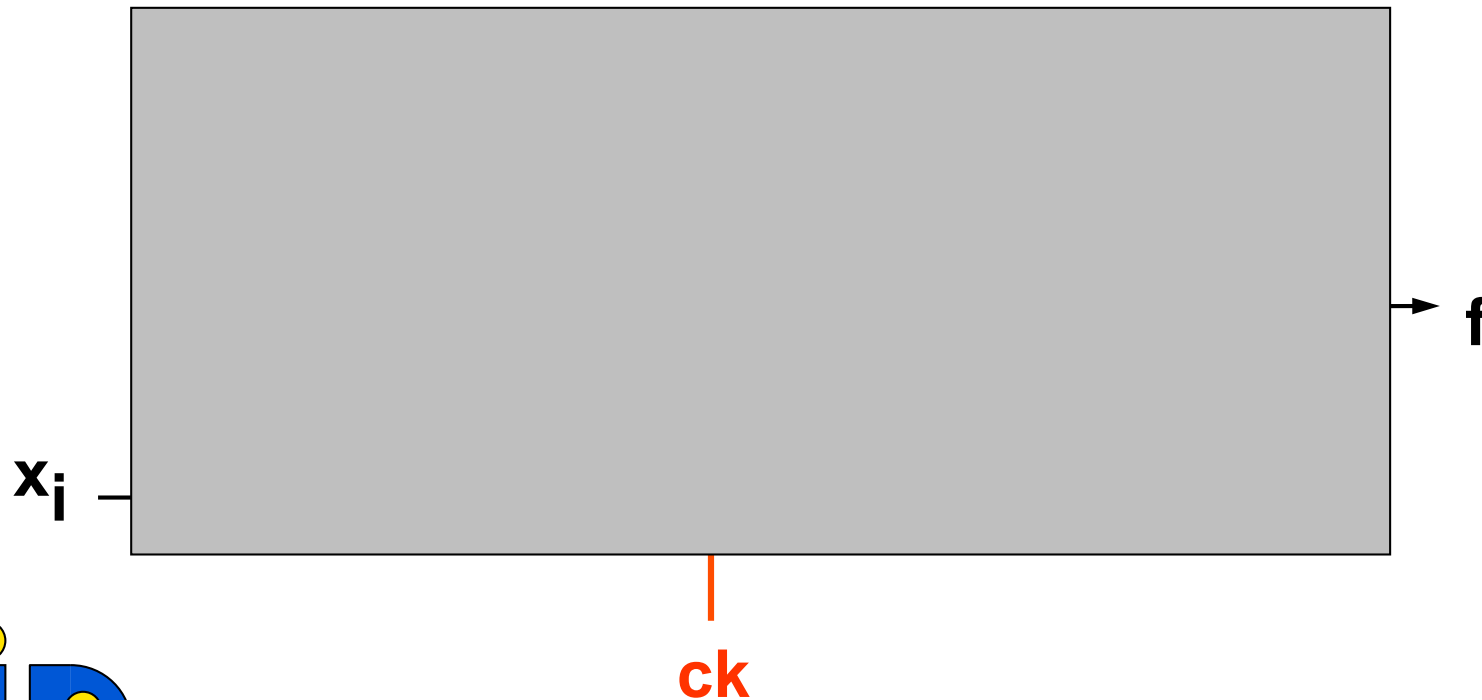
Combinational circuit : Boolean functions

Sequential circuit ?



CMOS Circuits

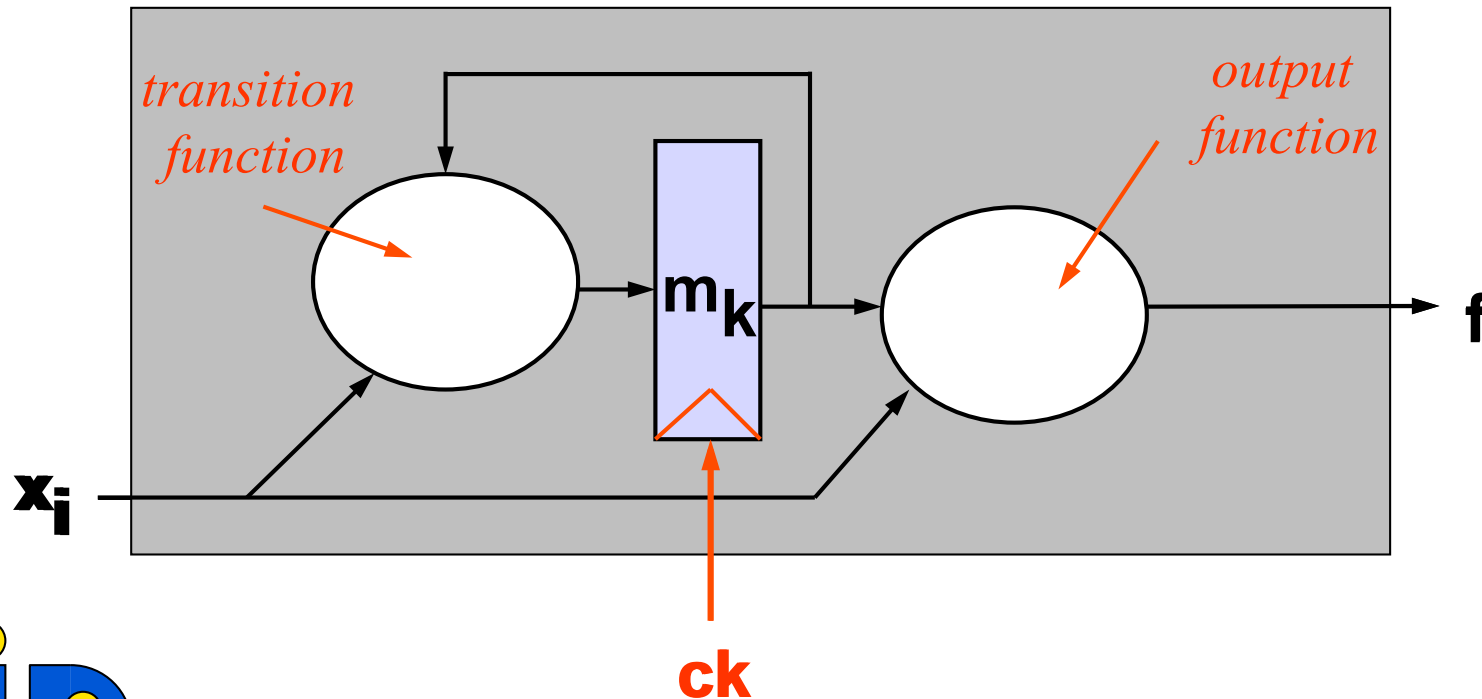
● Sequential Circuit



CMOS Circuits

How can I design a sequential circuit ?

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



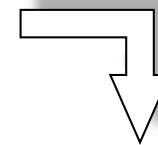
CMOS Circuits

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**, **t** = (**s**, **s'**, **f**)

s \in **S** : source state

s' \in **S** : target state

f \in **B**_n : transition condition

CMOS Circuits

● **G** = (**X**, **Y**, **S**, **T**,
O)

O : output set conditions

o \in **O**, **o** = (**y**, **s**, **c**)

y \in **Y** : output variable

s \in **S** : state

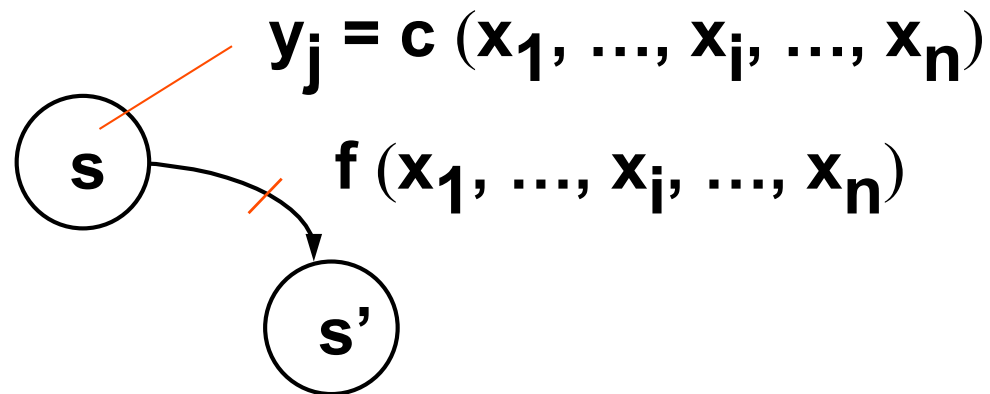
c \in **B**_n : output set condition



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

Graphic representation of \mathbf{G}



CMOS Circuits

Representation of a sequential circuit ?

- State graph

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

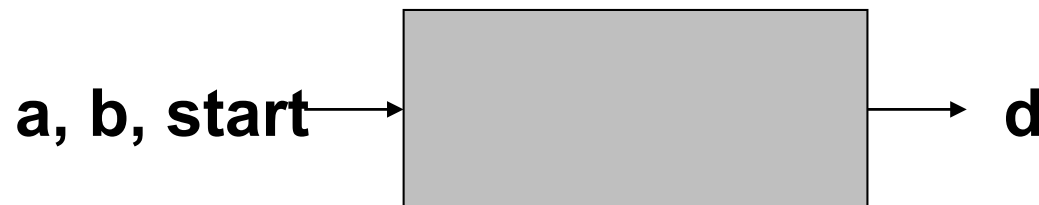
$$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T}, \mathbf{O})$$

CMOS Circuits

● Example

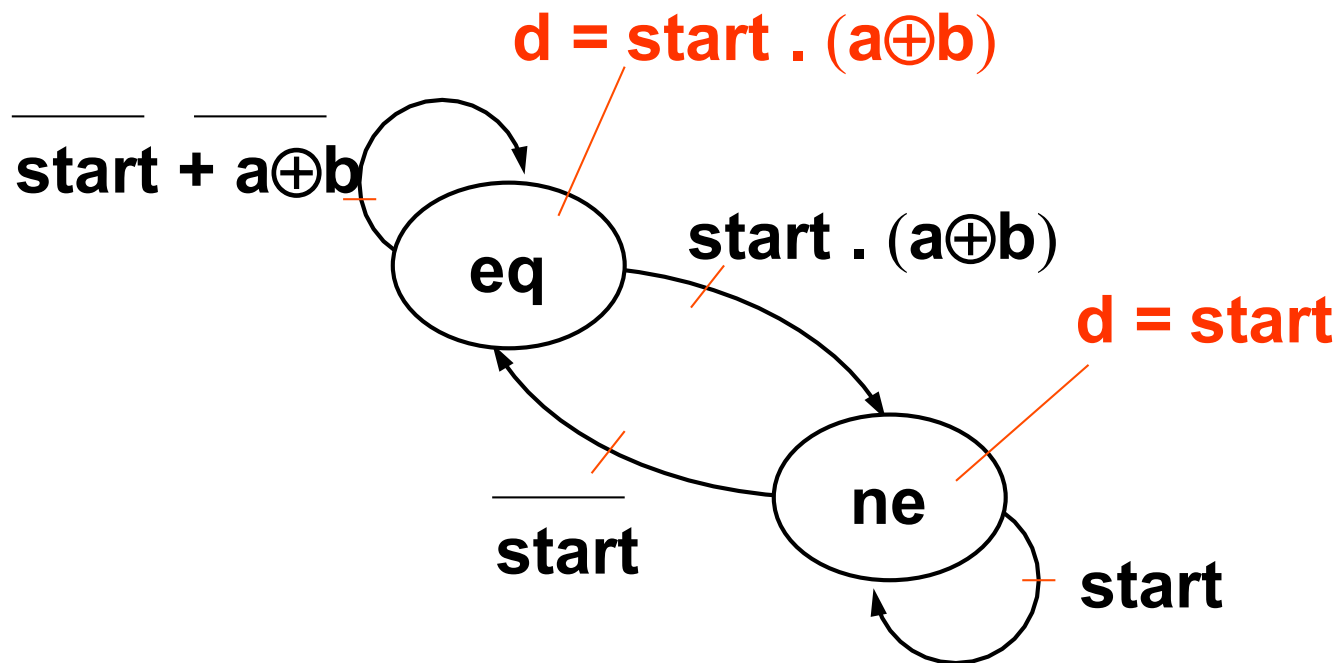
Two signals **a**, **b** each transmitting a series of bits (1 bit at a cycle)

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 ?

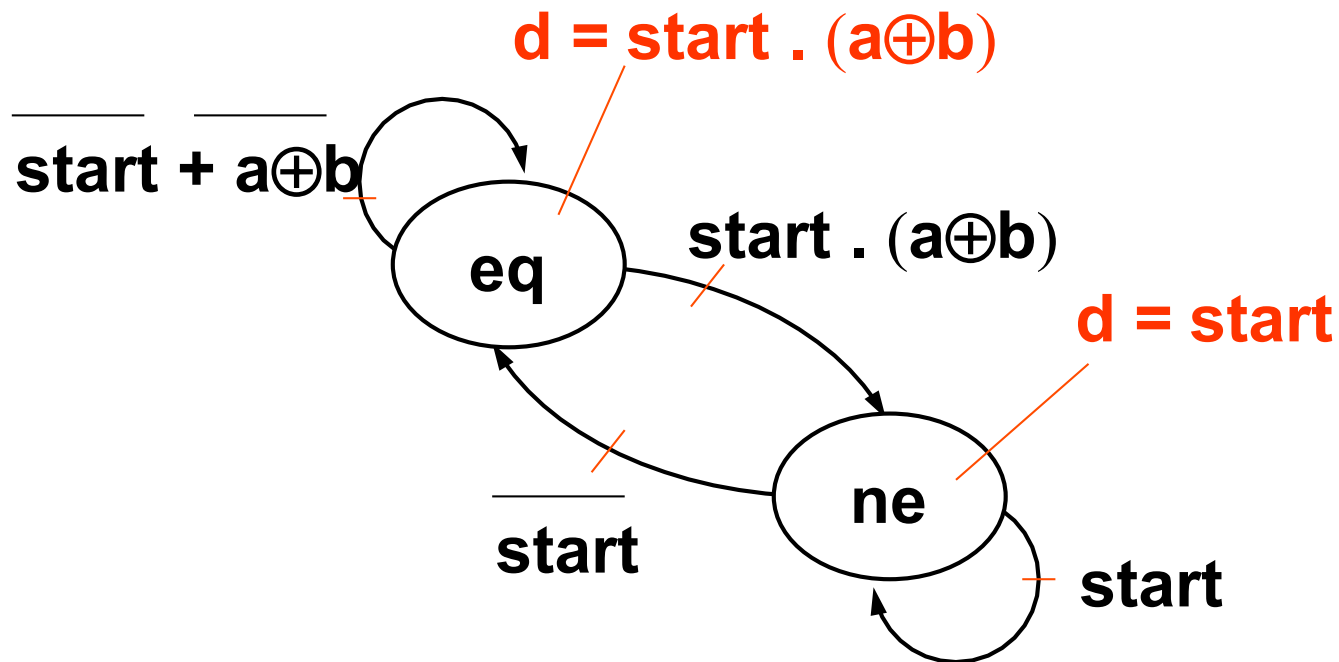
- State graph

$$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T}, \mathbf{O})$$

define the number of memory elements required to represent $\mathbf{S} : \mathbf{M}$

CMOS Circuits

Example



CMOS Circuits

Representation of a sequential circuit ?

- State graph

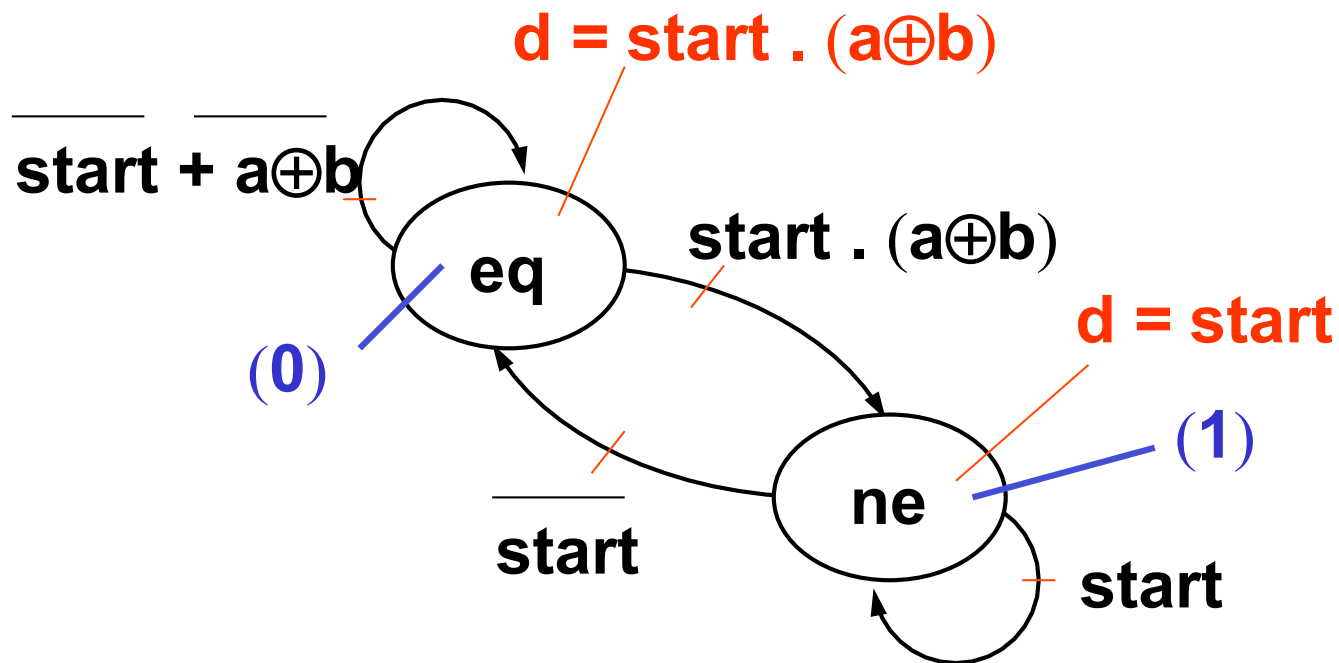
$$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T}, \mathbf{O})$$

define the number of memory elements required to represent $\mathbf{S} : \mathbf{M}$

represent each state \mathbf{s} by a vector of \mathbf{M}

CMOS Circuits

Example



CMOS Circuits

Representation of a sequential circuit ?

- State graph

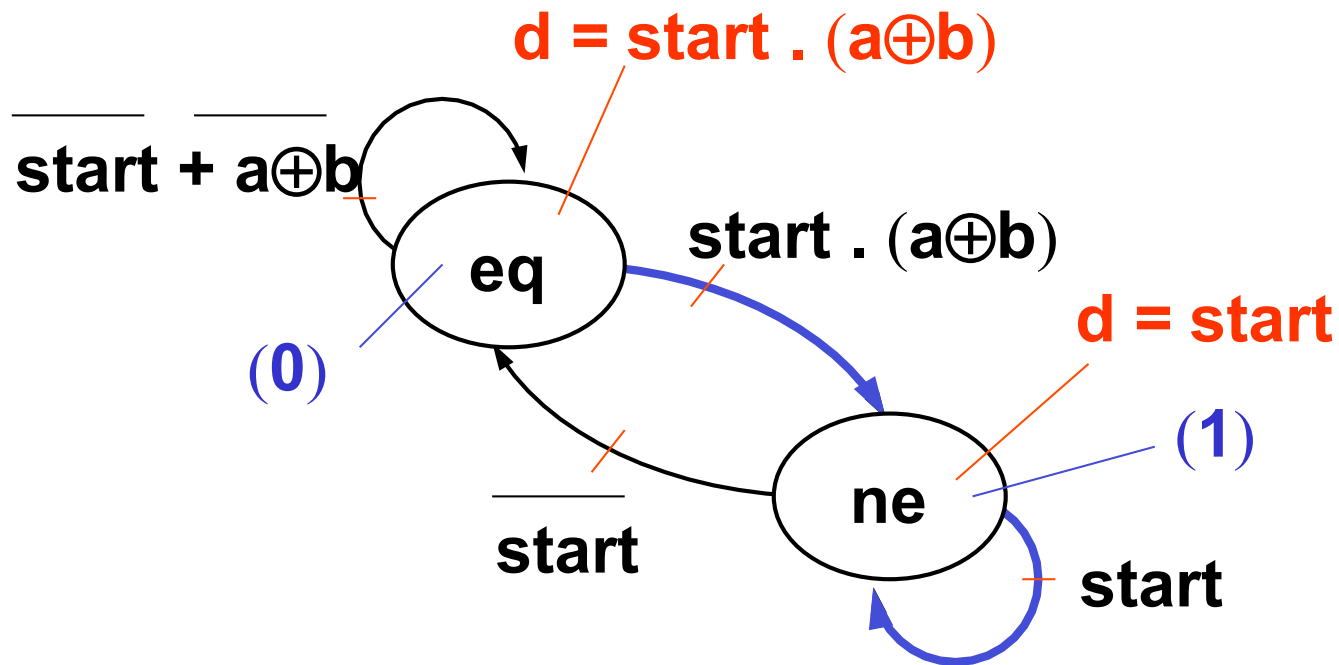
$$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T},$$

0)
define the *transition function* : \mathbf{m}_k

\mathbf{m}_k = sum of the Boolean function of the transitions
that have as target a state where $\mathbf{m}_k=1$

CMOS Circuits

Example



CMOS Circuits

Representation of a sequential circuit ?

- State graph

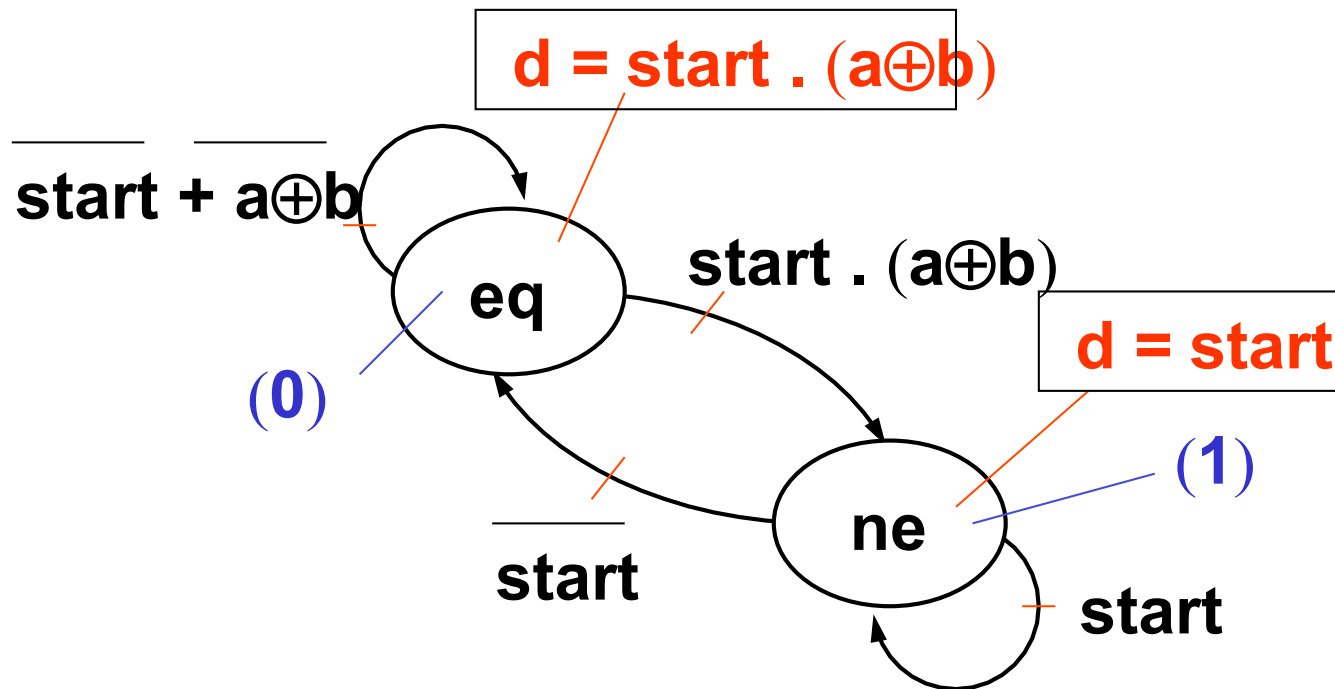
$$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T},$$

$\mathbf{O})$
define the *output function* : $\mathbf{y_j}$

$\mathbf{y_j}$ = sum of the output conditions concerning $\mathbf{y_j}$

CMOS Circuits

Example



CMOS Circuits

Representation of a sequential circuit ?

- State graph

$\mathbf{G} = (\mathbf{X}, \mathbf{Y}, \mathbf{S}, \mathbf{T}, \mathbf{O})$
implement the Boolean functions : $\mathbf{m}_k, \mathbf{y}_j$

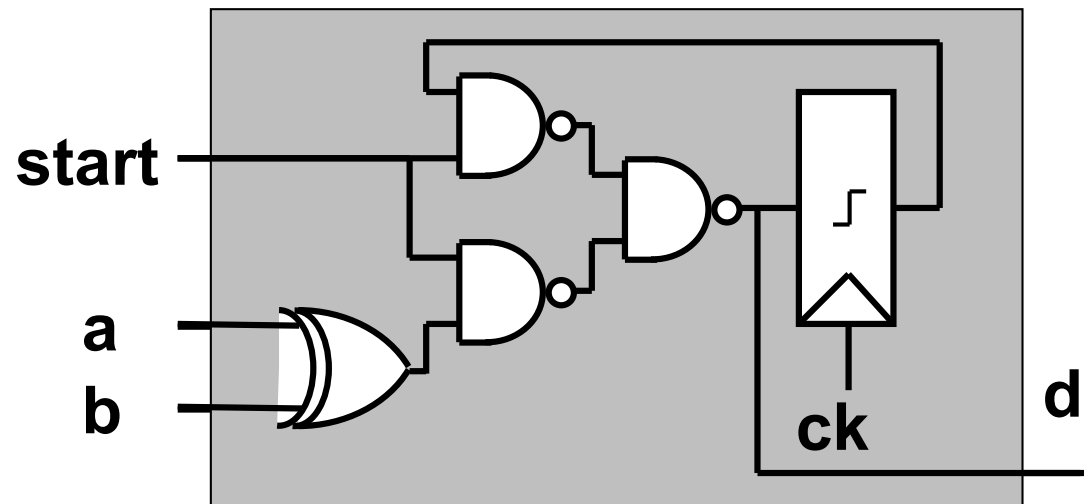
CMOS Circuits

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**,



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