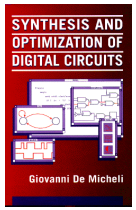
Timing Issues in Multi-level Logic Optimization

Giovanni De Micheli

Integrated Systems Centre

EPF Lausanne



Module 1

- **Objectives:**
  - **Timing verification:**
  - **Delay modeling**
  - **Critical paths**
  - **The false path problem**

Timing verification and optimization

- **Verification:**
  - Check that a circuit runs at speed
    - Satisfies I/O delay constraints
    - Satisfies cycle-time constraints
- **Optimization:**
  - Minimum *delay*
    - (subject to *area* constraints)
  - Minimum *area*
    - Subject to *delay* constraints

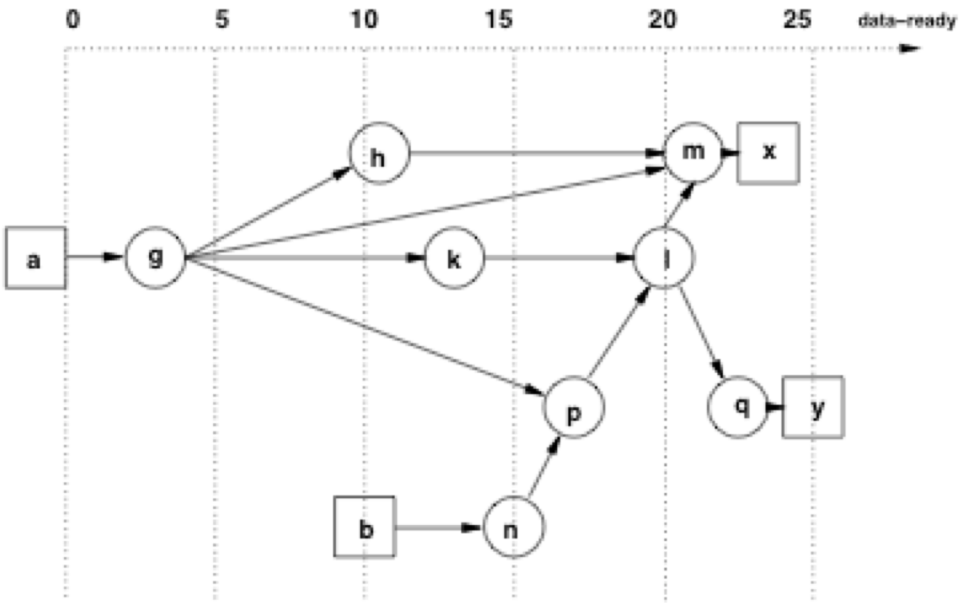
Delay modeling

- **Gate delay modeling:**
  - Straightforward for bound networks
    - Cell library models: d = a + b Cap
    - Cap due to fanout and wiring
  - Approximations for unbound networks
    - Virtual gates
- **Network delay modeling:**
  - Compute signal propagation
    - Topological methods
    - Logic/topological methods (false paths)

Network delay modeling

- For each vertex v_i
- Propagation *delay* d_i :
  - I/O propagation delays are usually zero
- *Data-ready time* t_i :
  - Input data-ready time denote when inputs are available
  - Computed elsewhere by *forward traversal*
  - $t_i = d_i + \max_j t_j \quad s.t. (v_j, v_i) \varepsilon E$

Example



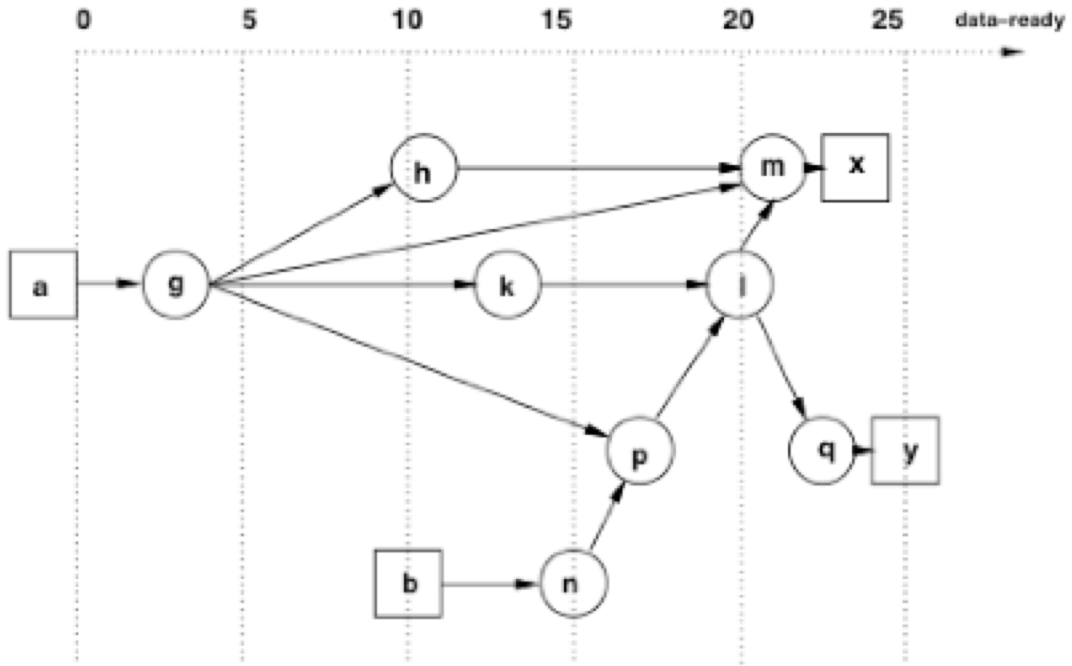
- **Propagation delays:**
  - $d_g = 3$; $d_h = 8$; $d_m = 1$; $d_k = 10$; $d_l = 3$
  - $d_n = 5$; $d_p = 2$; $d_p = 2$; $d_x = 2$; $d_y = 3$

Network delay modeling

- For each vertex v_i :
- Required *data-ready time* $\underline{t}_i$:
  - Specified at the primary outputs
  - Computed elsewhere by *backward traversal*
  - $\underline{t}_i = \min_j \; \underline{t}_j - d_j \quad s.t. \; (v_i, v_j) \; \varepsilon \; E$
- Slack s_i :
  - Difference between required and actual data-ready times

    $s_i = \underline{t}_j - t_i$

Example



$d_n=5$; $d_l=3$; $d_k=10$; $d_h=8$; $d_g=3$;

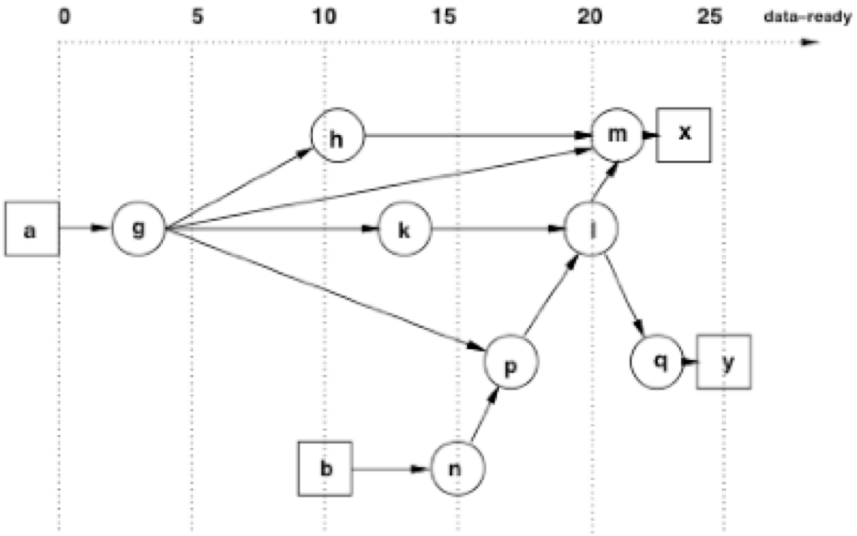
$d_x=2$; $d_y=3$; $d_q=2$; $d_m=1$; $d_p=2$;

- **Required data-ready times:**
  - $t_x = 25$ and $t_y = 25$

Example

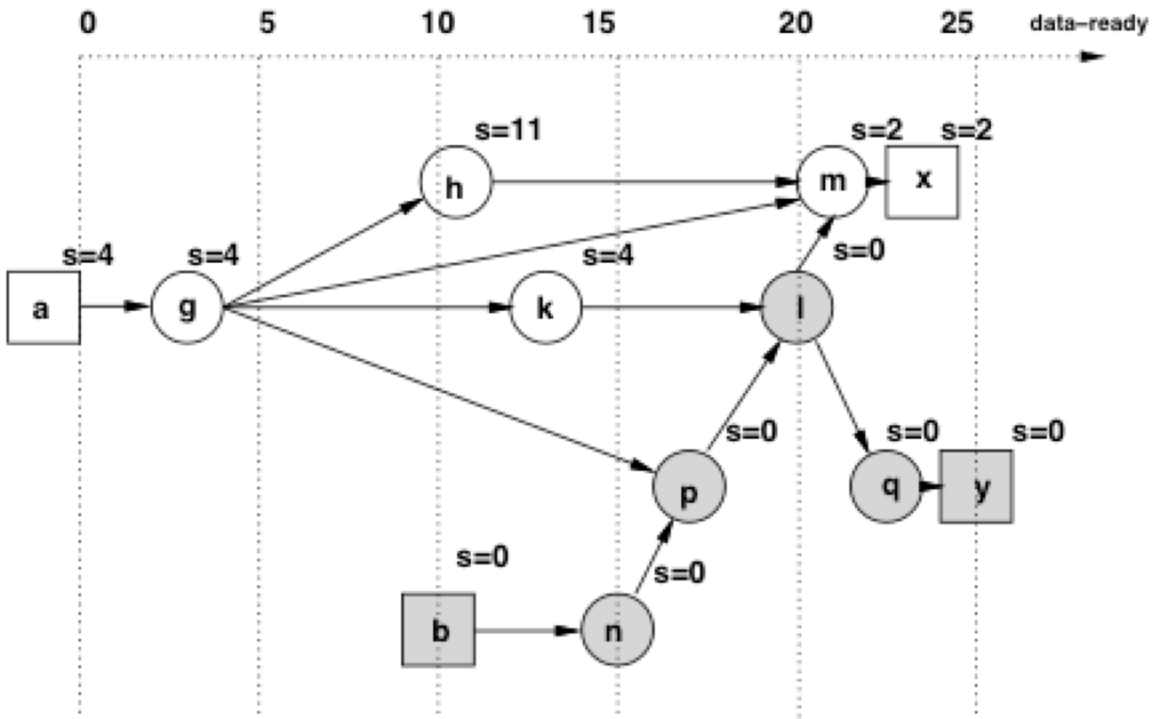
- $s_x = 2$; $s_y = 0$
- $t_m = 25 - 2 = 23$; $s_m = 23 - 21 = 2$
- $t_q = 25 - 3 = 22$; $s_q = 22 - 22 = 0$
- $t_l = \min\{23 - 1; 22 - 2\} = 20$; $s_l = 20 - 20 = 0$
- $t_b = 23 - 1 = 22$; $s_h = 22 - 11 = 11$
- $t_k = 20 - 3 = 17$; $s_k = 17 - 13 = 4$
- $t_p = 20 - 3 = 17$; $s_p = 17 - 17 = 0$
- $t_n = 17 - 2 = 15$; $s_n = 15 - 15 = 0$
- $t_b = 15 - 5 = 10$; $s_b = 10 - 10 = 0$
- $t_g = \min\{22 - 11; 17 - 10; 17 - 2\} = 7$; $s_g = 7 - 3 = 4$
- $t_a = 7 - 3 = 4$; $s_a = 4 - 0 = 4$

$d_x=2$; $d_y=3$; $d_q=2$; $d_m=1$; $d_p=2$;



$d_n=5$; $d_l=3$; $d_k=10$; $d_h=8$; $d_g=3$;

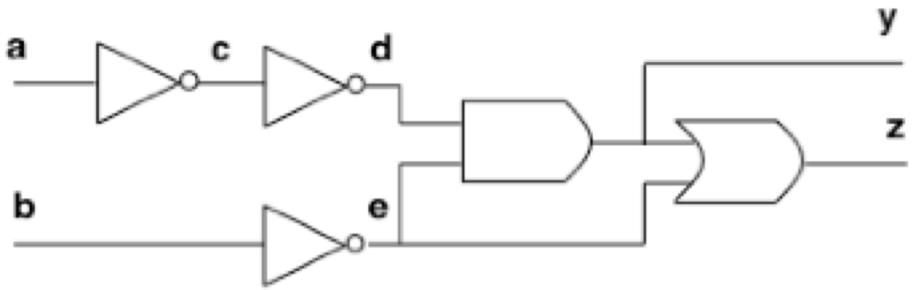
Example


0
5
10
15
20
25
data–ready
s=11
s=2
s=2
h
m
x
s=4
s=4
s=4
s=0
a
g
k
l
s=0
s=0
s=0
p
q
y
s=0
s=0
b
n

Topological critical path

- Assume topologic computation of :
  - *Data-ready* by forward traversal
  - *Required data-ready* by backward traversal
- *Topological critical path :*
  - Input/output path with zero slacks
  - Any increase in the vertex propagation delay affects the output data-ready time
- A topological critical path may be *false*:
  - No event can propagate along that path

Example



- All gates have unit delay
- All inputs ready at time 0
- Longest topological path : $(v_a, v_c, v_d, v_y, v_z)$:
  - Path delay: 4 units
- Critical true path: (v_a, v_c, v_d, v_y) :
  - Path delay: 3 units

Sensitizable paths

- A path in a logic network is *sensitizable* if an event can propagate from its tail to its head
- A critical *path* is a sensitizable path of maximum weight
- Only sensitizable paths should be considered
- Non-sensitizable paths are *false* and can be discarded

Sensitizable paths

- **Path:**
  - Ordered set of vertices
- **Inputs to a vertex:**
  - Direct predecessors
- **Side-inputs of a vertex:**
  - Inputs not on the path

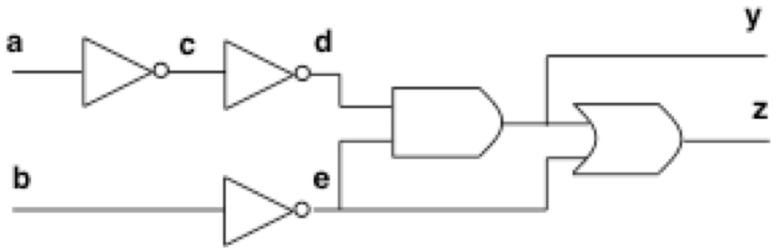
Sensitization condition

- **Path:** $P = (v_{xo}, v_{x1}, \ldots, v_{xm})$
- **An event propagates along** P ***if :***

$$\partial f_{xi} / \partial x_{i-1} = 1 \quad , i = 1, 2, \ldots, m$$

- **Remarks :**
  - **Boolean differences are function of the side-inputs and values on the side-inputs may change**
  - **Boolean differences must be true *at the time that the event propagates***

Example



- **Path: (v_a, v_c, v_d, v_y, v_z)**
  - $\partial f_y / \partial d = e = 1$ at time 2
  - $\partial f_z / \partial y = e' = 1$ at time 3
- **Not dynamically sensitizable because e settles at time 1**

Modes for delay computation

- Transition *mode:*
  - Variables assumed to hold previous values
    - Model circuit node capacitances
  - *Two test vectors* are needed
- *Floating mode:*
  - Circuit is assumed to be memoryless
    - Variables have unknown value until set by input test vector
  - Need *only one* test vector

Static co-sensitization

- **Assumption:**
  - Circuit modeled by *AND, OR, INV* gates
  - *INV* are irrelevant to the analysis
  - Floating mode
- **Controlling values:**
  - 0 for *AND* gate
  - 1 for *OR* gate
- **Gate has *controlled value* when controlling value is present**

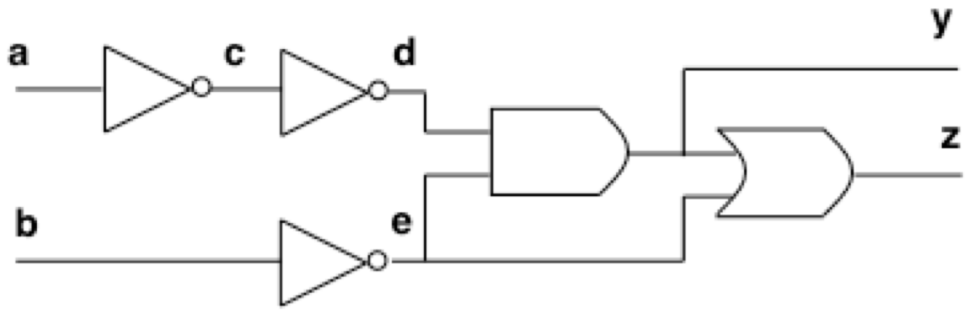
Static co-sensitization

- Path: $P = (v_{xo}, v_{x1}, \ldots\ldots, v_{xm})$
- A vector *statically co-sensitizes* a path to 1 (or to 0) if *:*
  - $x_m = 1$ (or 0) and
  - v_{xi-1} has a controlling value whenever v_{xi} has a controlled value
- Necessary condition for a path to be true
- Sufficient conditions are based on the *timing* of the signal

False path detection test

- For all input vectors, one of the following is true:
  - (1) A gate is controlled and
    - the path provides a non-controlling value
    - a side-input provides a controlling value
  - (2) A gate is controlled and
    - The path and a side-input have controlling values
    - The side-input presents the controlling value first
  - (3) A gate is not controlled and
    - A side-input presents the non-controlling value last

Example



- Path: (v_a, v_c, v_d, v_y, v_z)
- For $a = 0$, $b = 0$:
  - Condition (1) occurs at the OR gate
- For $a = 0$, $b = 1$:
  - Condition (2) occurs at the AND gate
- For $a = 1$, $b = 0$:
  - Condition (2) occurs at the OR gate
- For $a = 1$, $b = 1$:
  - Condition (1) occurs at the AND gate

Important problems

- Check if circuit works at speed t :
  - Verify that all true paths are faster than t
  - Show that all paths slower than t are false
- Compute groups of false paths
- Compute critical true path:
  - Binary search for values of t
  - Show that all paths slower that t are false