# Testing Digital Systems I

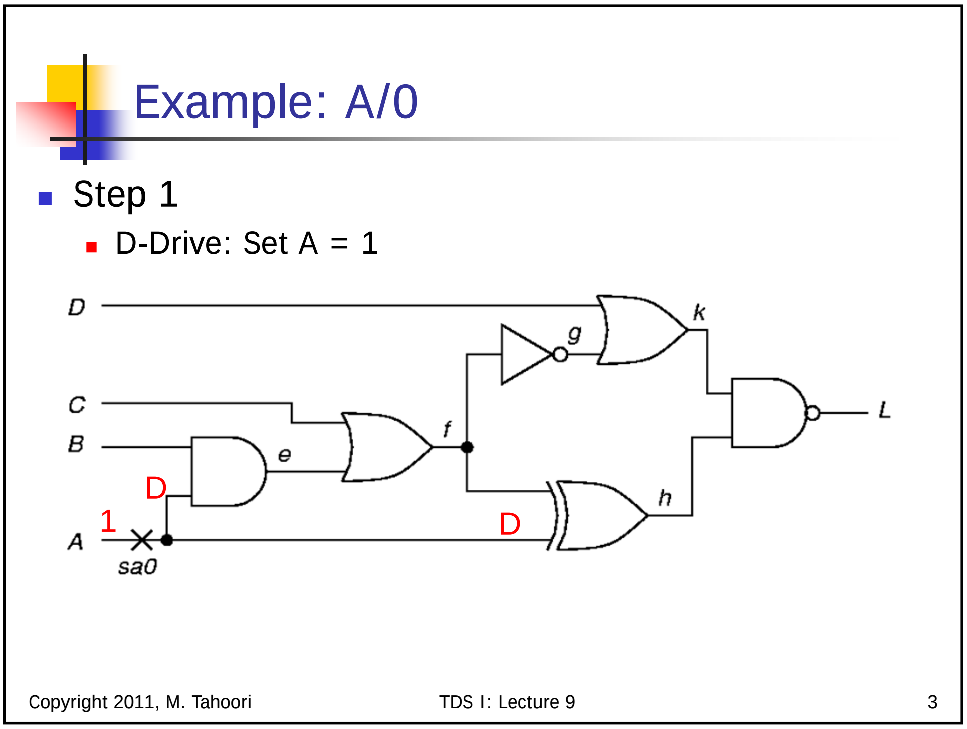
Lecture 9:

Boolean Testing Using Fault Models

(D-Algorithm, PODEM)

Instructor: M. Tahoori

## D Algorithm (More Examples)



## Example: A/0

- Step 1
  - D-Drive: Set A = 1

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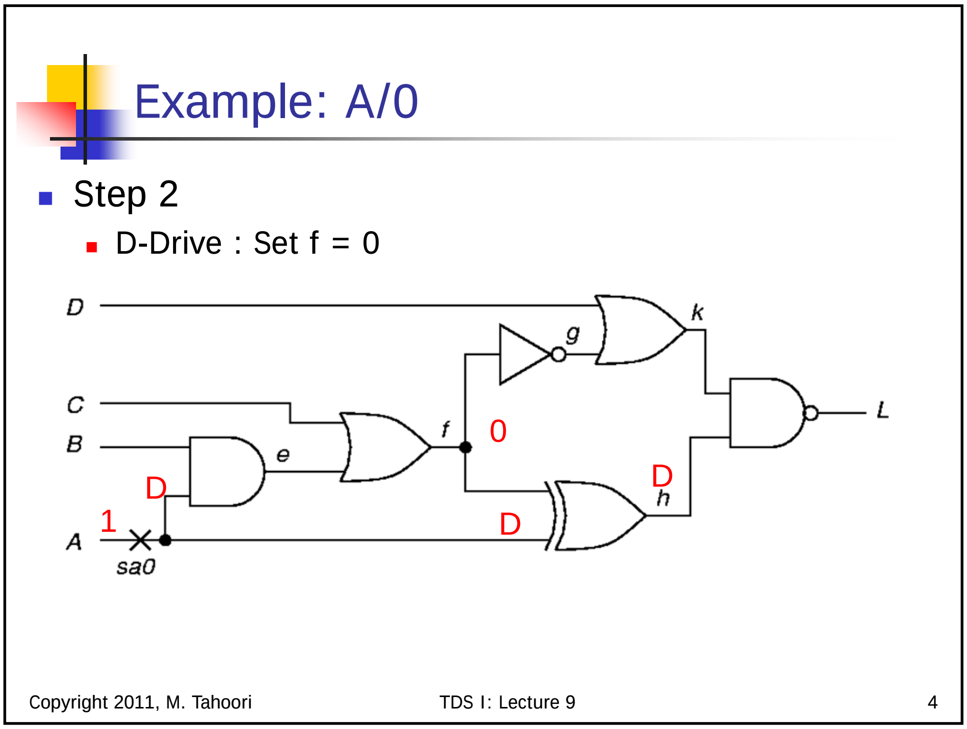

## Example: A/0

- Step 2
  - D-Drive : Set f = 0

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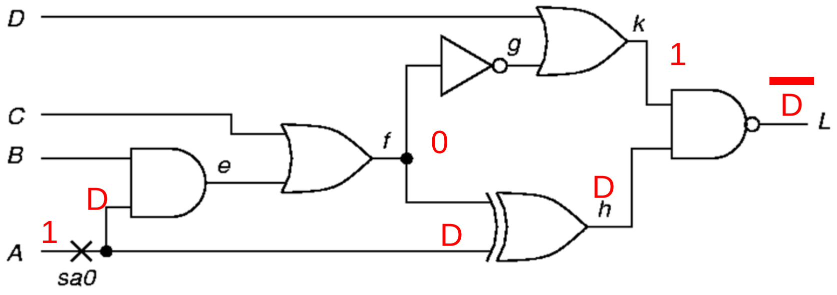
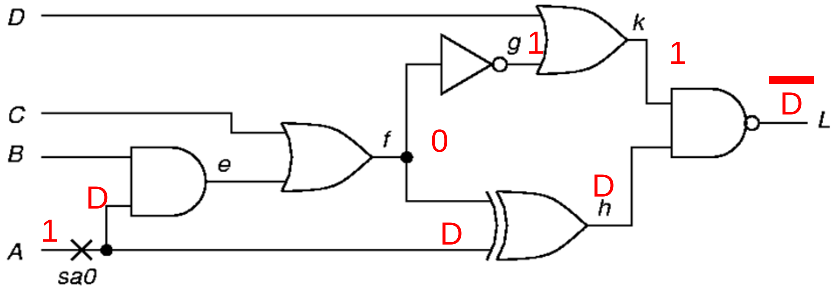
## Example: A/0

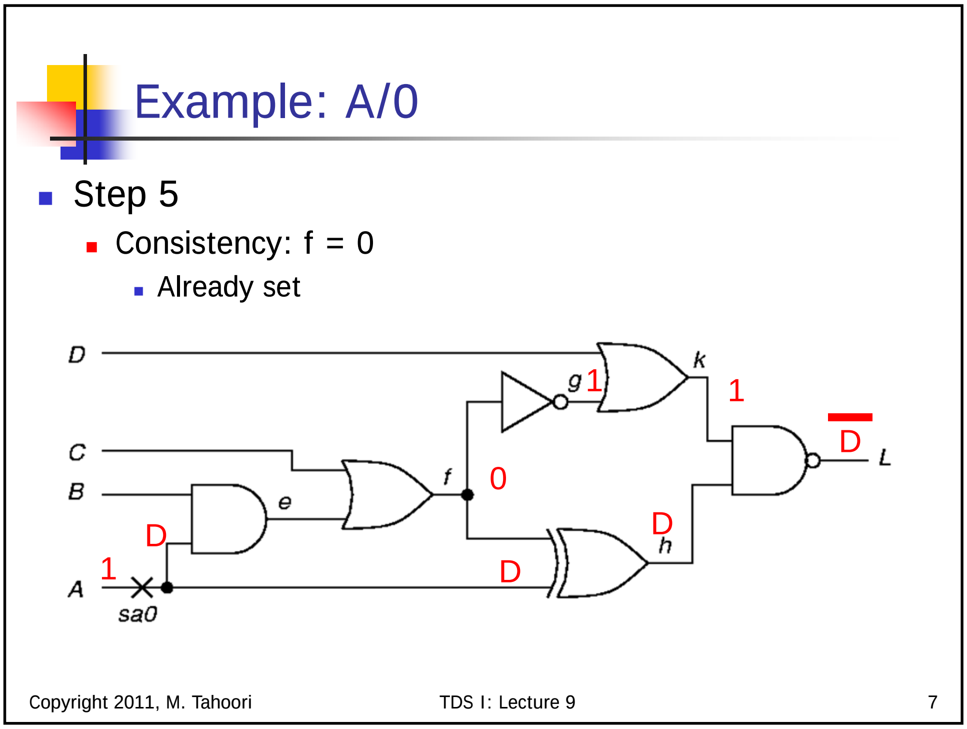
- Step 3
  - D-Drive : Set k = 1



## Example: A/0

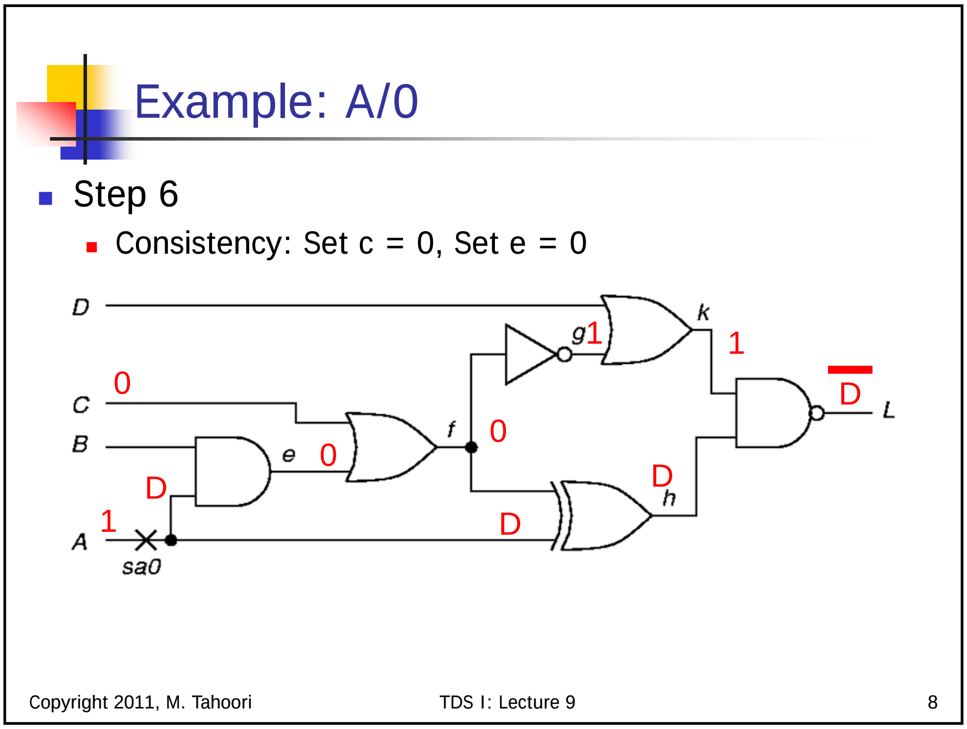
- Step 4
  - Consistency: Set g = 1





## Example: A/0

- Step 5
  - Consistency: f = 0
    - Already set

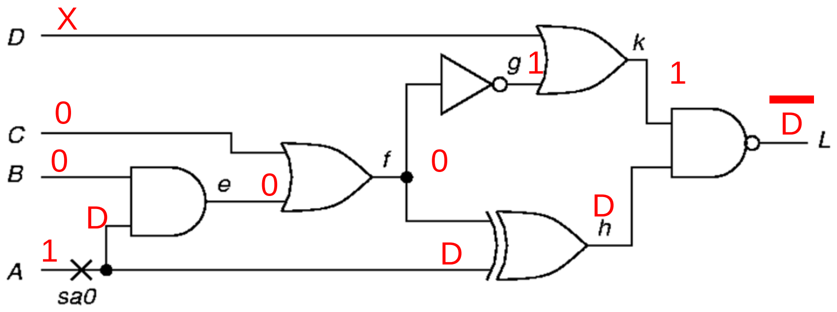


## Example: A/0

- Step 6
  - Consistency: Set c = 0, Set e = 0

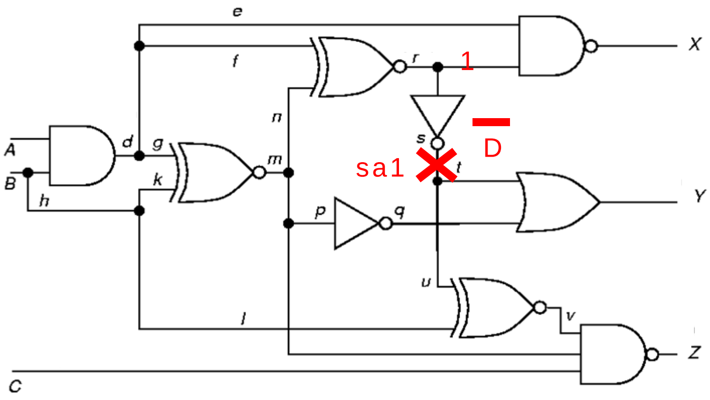
## Example: A/0

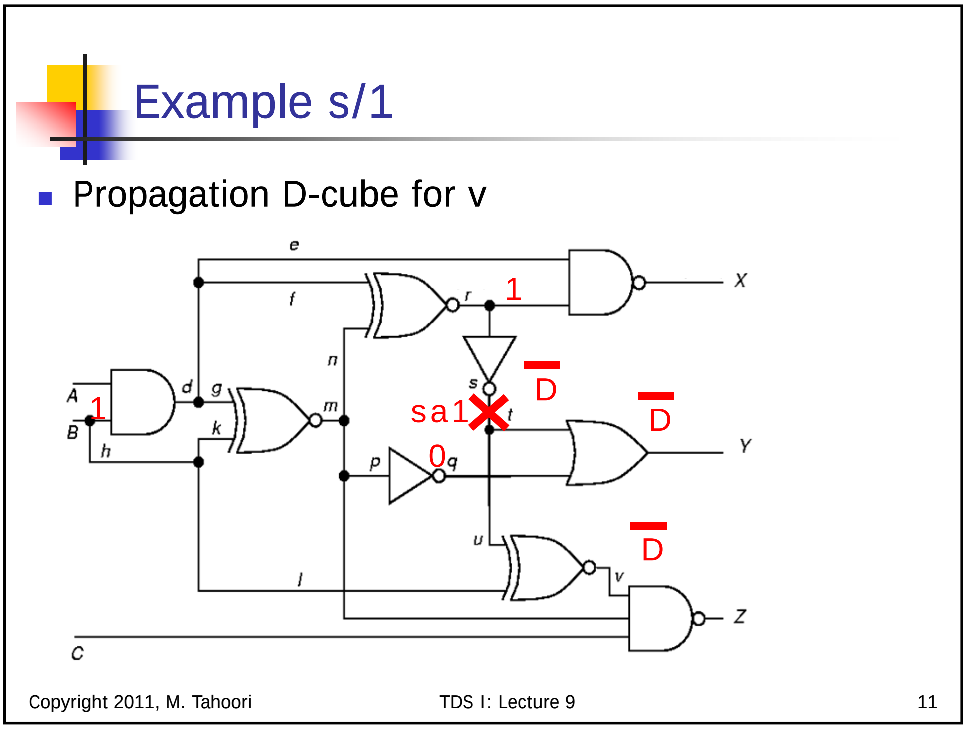
- Step 7
  - Consistency: Set B = 0
- Test found: ABCD = 100X



## Example s/1

- Primitive D-cube of Failure





## Example s/1

- Propagation D-cube for v

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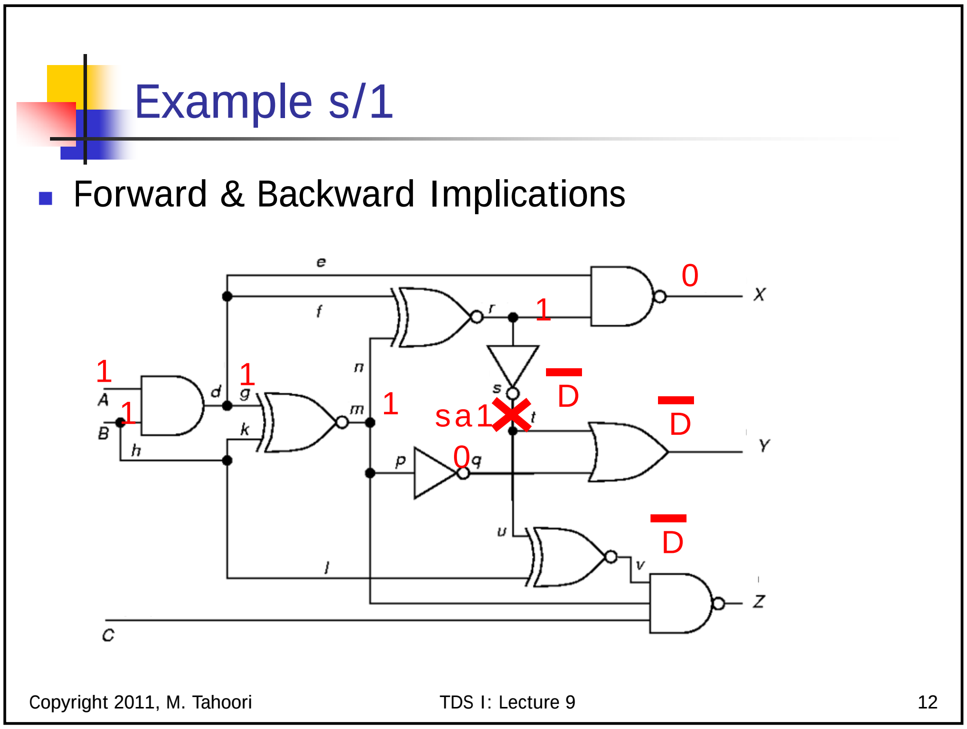

## Example s/1

- Forward & Backward Implications

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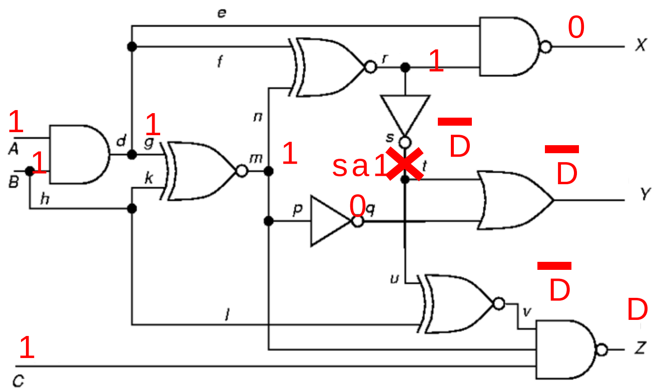
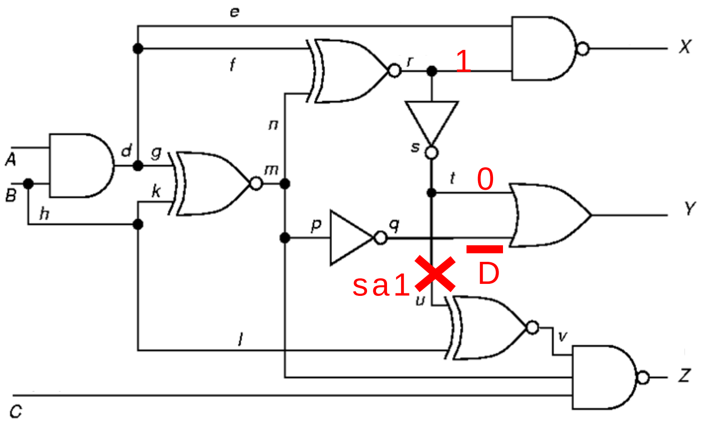
## Example s/1

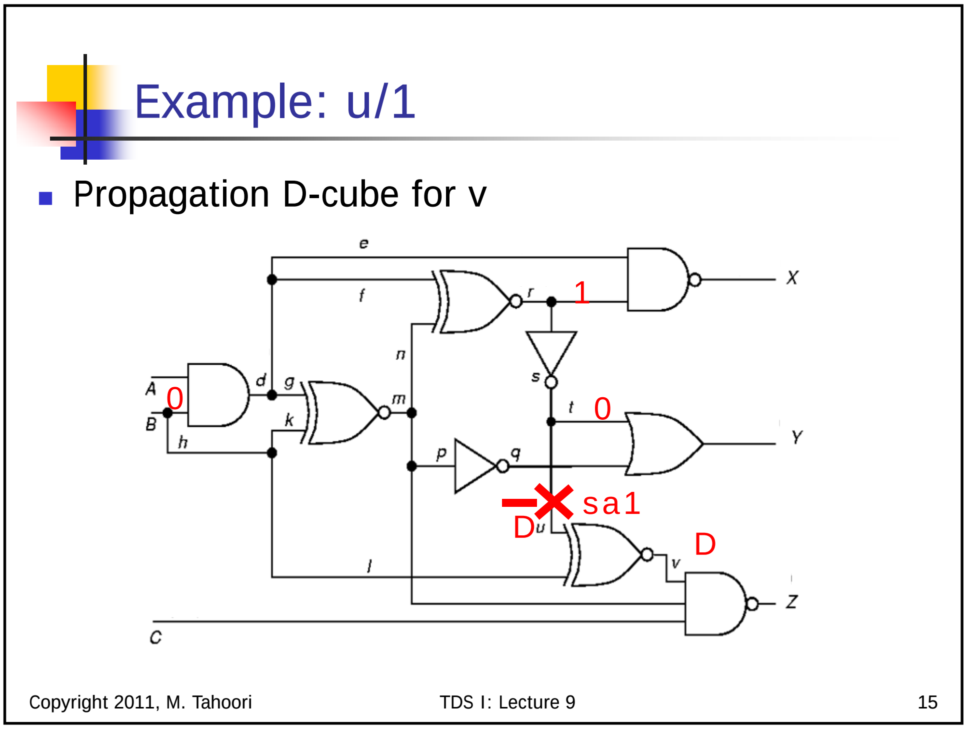
- Propagation D-cube for Z
- test found!



## Example: u/1

- Primitive D-cube of Failure





## Example: u/1

- Propagation D-cube for v

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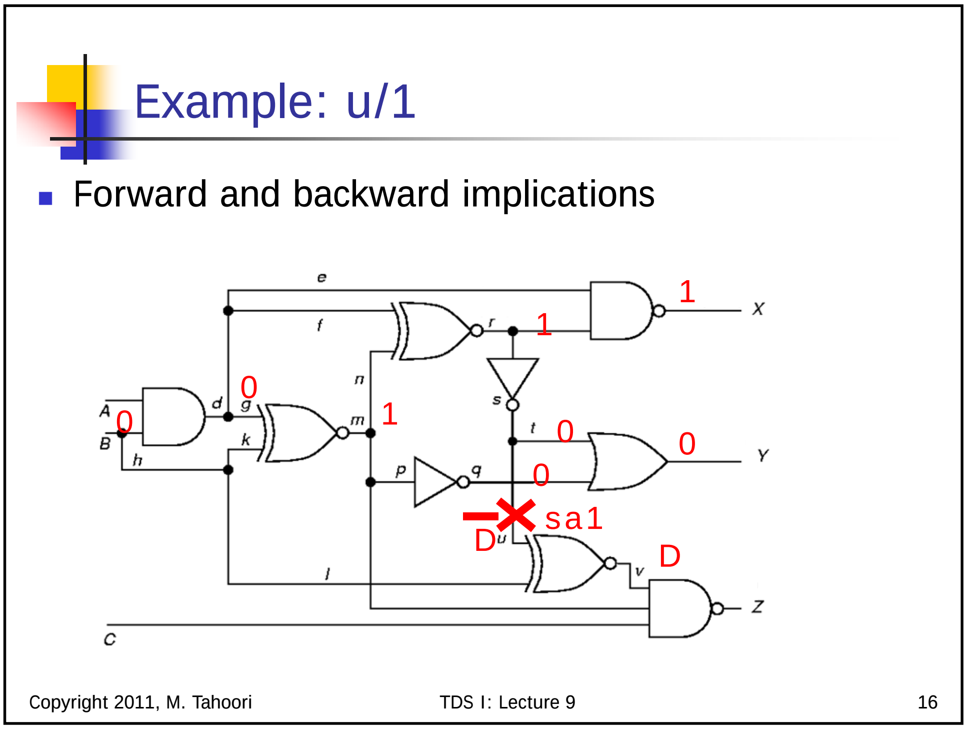

## Example: u/1

- Forward and backward implications

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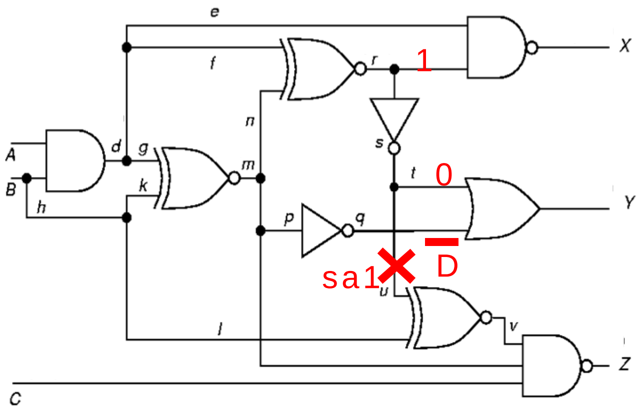
## Example: u/1

- Inconsistency
  - d = 0 and m = 1
    - cannot justify r = 1 (equivalence)
- Backtrack
  - Remove B = 0 assignment

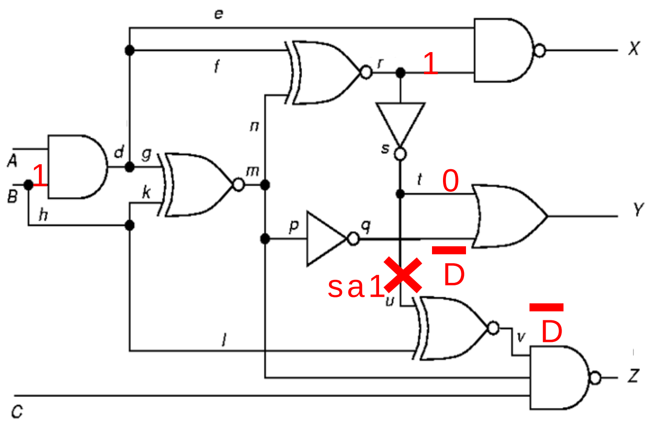
## Example: u/1

- Backtrack
  - Need alternate propagation D-cube for v



## Example: u/1

- Propagation D-cube for v



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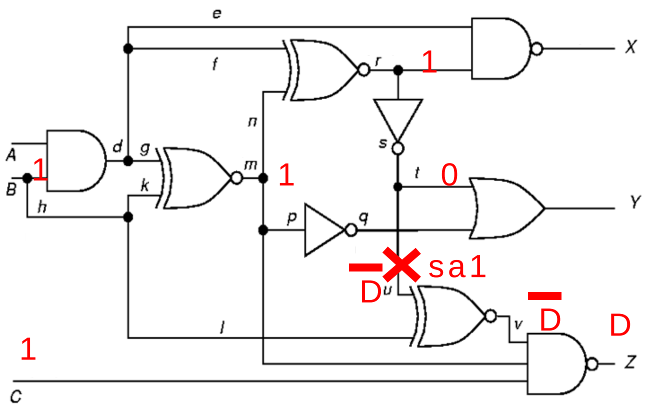
## Example: u/1

- Propagation D-cube for Z



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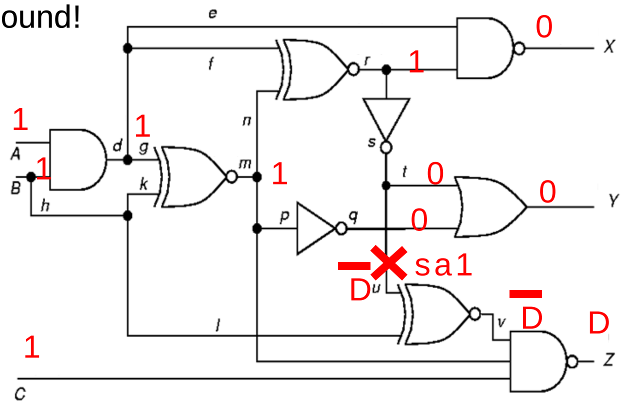
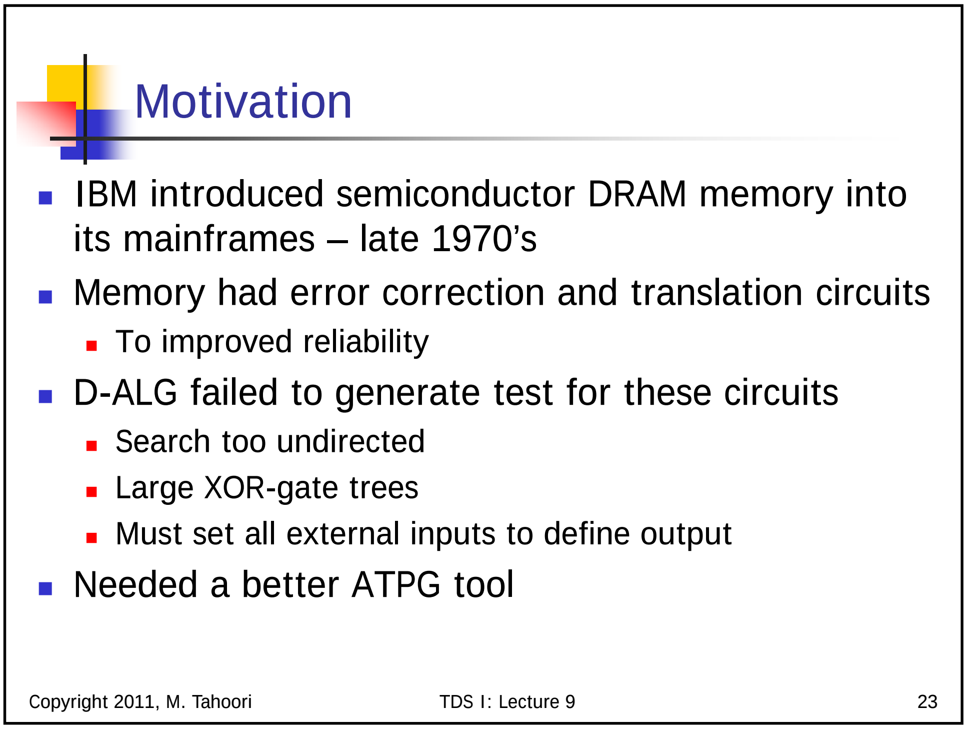
## Example: u/1

- Propagation D-cube for Z
- Implications
- Test Found!

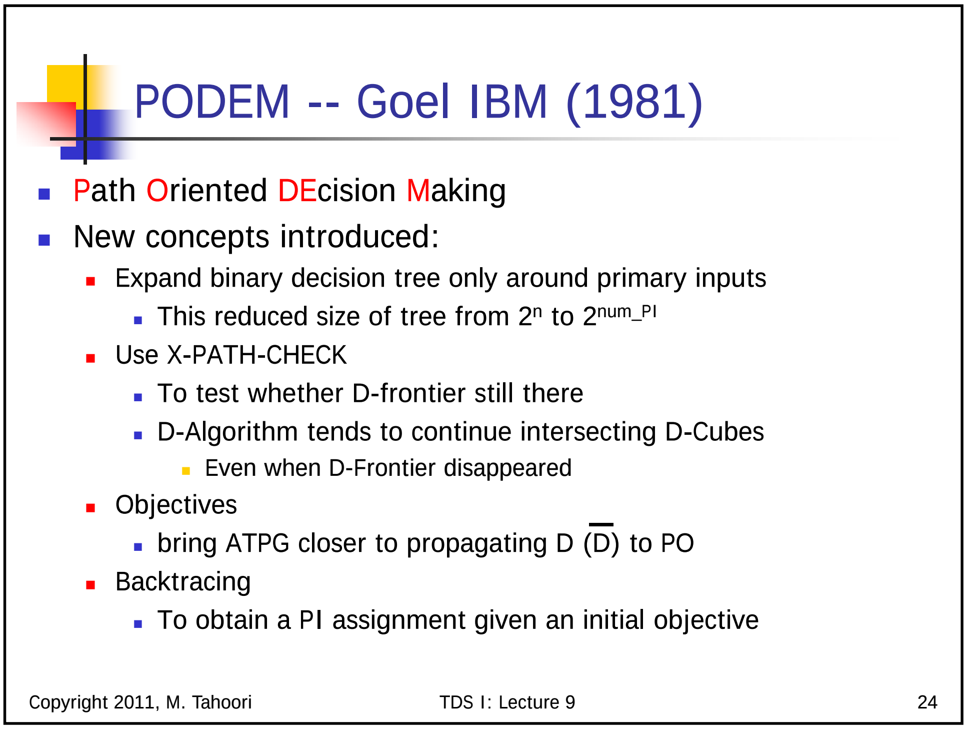


# PODEM



## Motivation

- IBM introduced semiconductor DRAM memory into its mainframes – late 1970's
- Memory had error correction and translation circuits
  - To improved reliability
- D-ALG failed to generate test for these circuits
  - Search too undirected
  - Large XOR-gate trees
  - Must set all external inputs to define output
- Needed a better ATPG tool



## PODEM -- Goel IBM (1981)

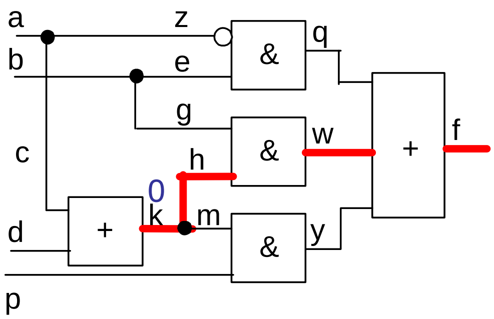
- Path Oriented DEcision Making
- New concepts introduced:
  - Expand binary decision tree only around primary inputs
    - This reduced size of tree from $2^n$ to $2^{num\_PI}$
  - Use X-PATH-CHECK
    - To test whether D-frontier still there
    - D-Algorithm tends to continue intersecting D-Cubes
      - Even when D-Frontier disappeared
  - Objectives
    - bring ATPG closer to propagating D ($\overline{D}$) to PO
  - Backtracing
    - To obtain a PI assignment given an initial objective

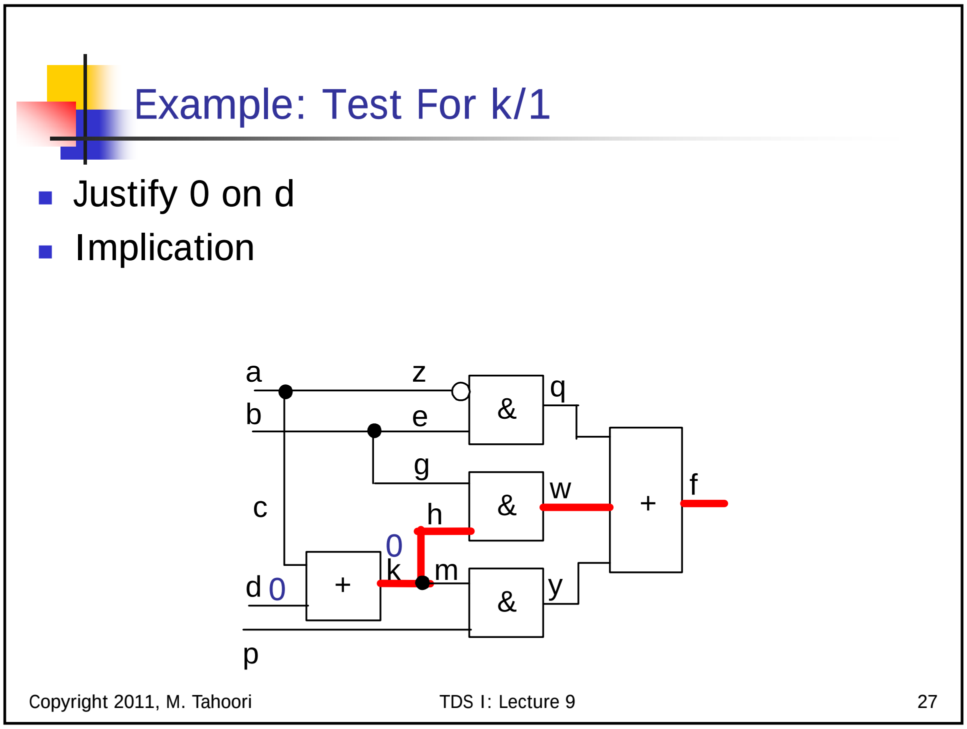
## Assigning Input Values ( PODEM)

1. Assign value to an unassigned primary input
2. Determine all implications of assignment
3. If test is generated, exit; else
4. Is test is possible with additional input assignments ?
    - fault site doesn't have fault value assigned
    - Path of unassigned leads from D ($\overline{D}$) to an output
   - If yes, go to 1, if no
5. Change input assignments to untried combination, go to 2
   - If no untried combination exists — untestable fault

## Example: Test For k/1

- Put D’ on k
  - D-Alg: assigned a D′ to k and propagate it to output f
  - PODEM: try to justify 0 on k





## Example: Test For k/1

- Justify 0 on d
- Implication

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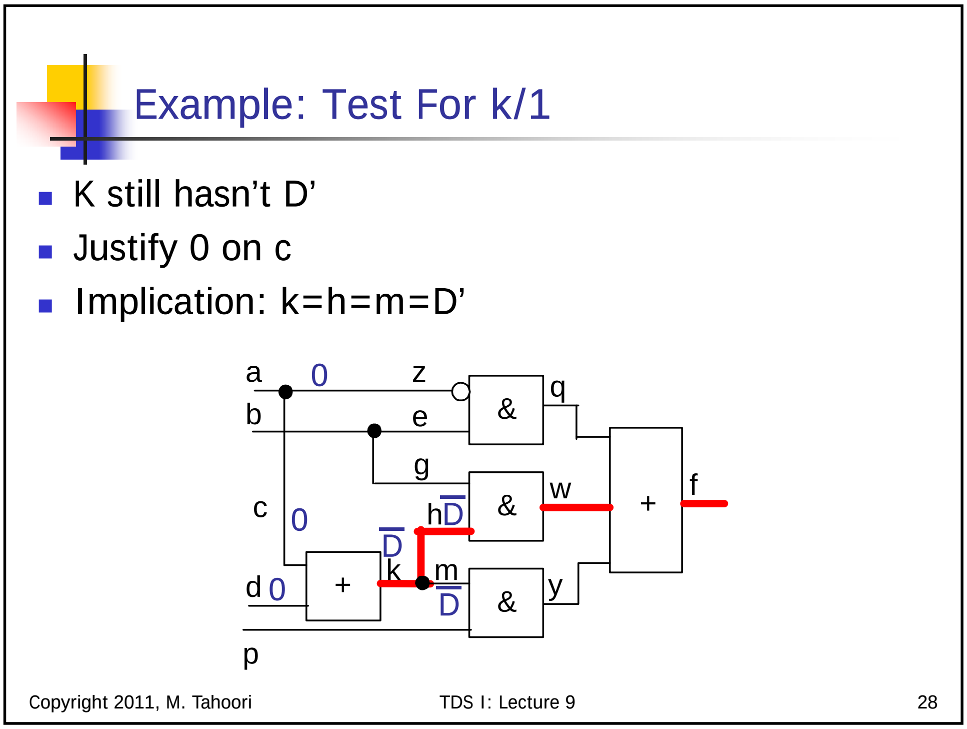

## Example: Test For k/1

- K still hasn't D'
- Justify 0 on c
- Implication: k=h=m=D'

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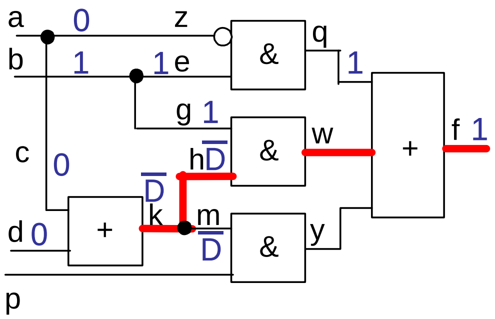
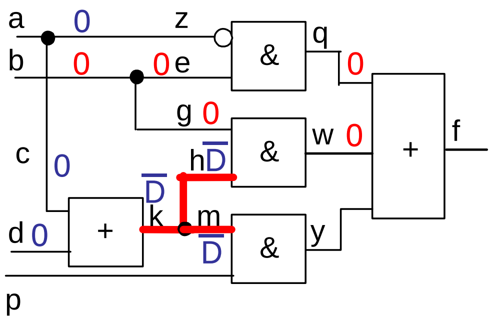
## Example: Test For k/1

- Propagate through w
- Set g = 1
- Implication



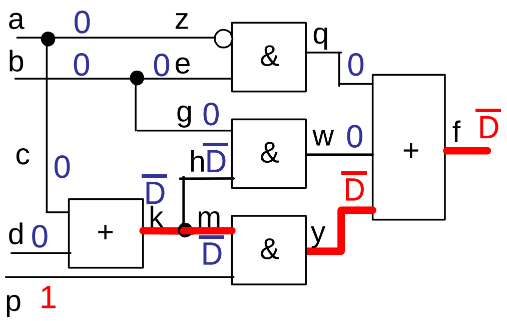
## Example: Test For k/1

- Conflict
  - f is 1 so propagation is blocked
- Reverse the last assignment made to a PI
  - Set b = 0
- Implication

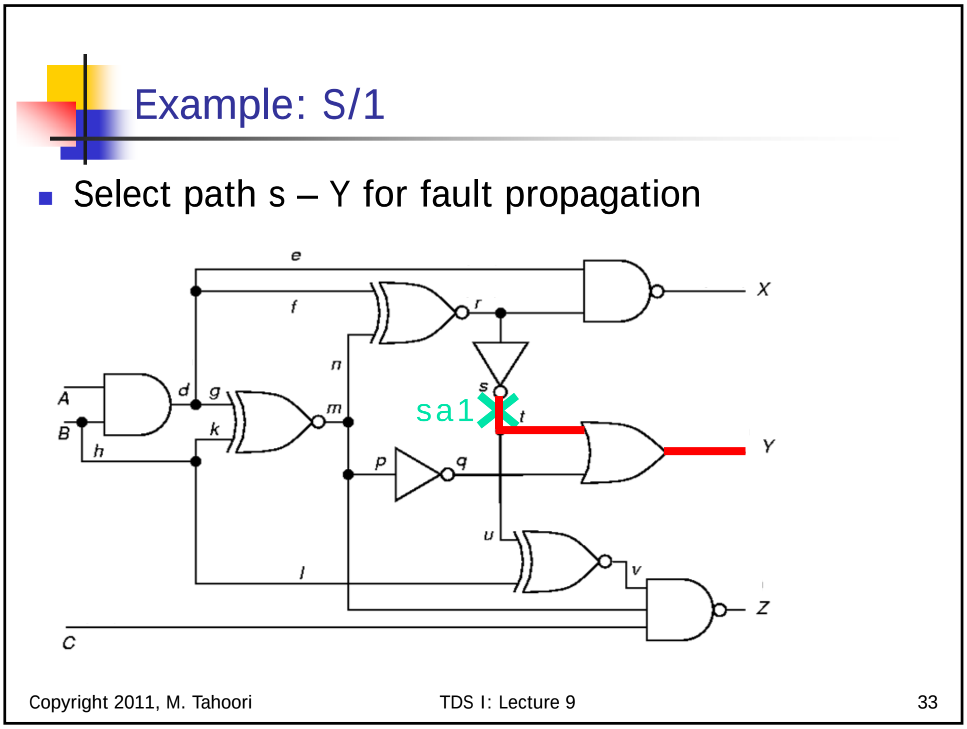


## Example: Test For k/1

- There is a propagation path from m to f
  - Set p = 1
- Implication
- Test found
  - abcd = 0001



# Another Example



## Example: S/1

- Select path s – Y for fault propagation

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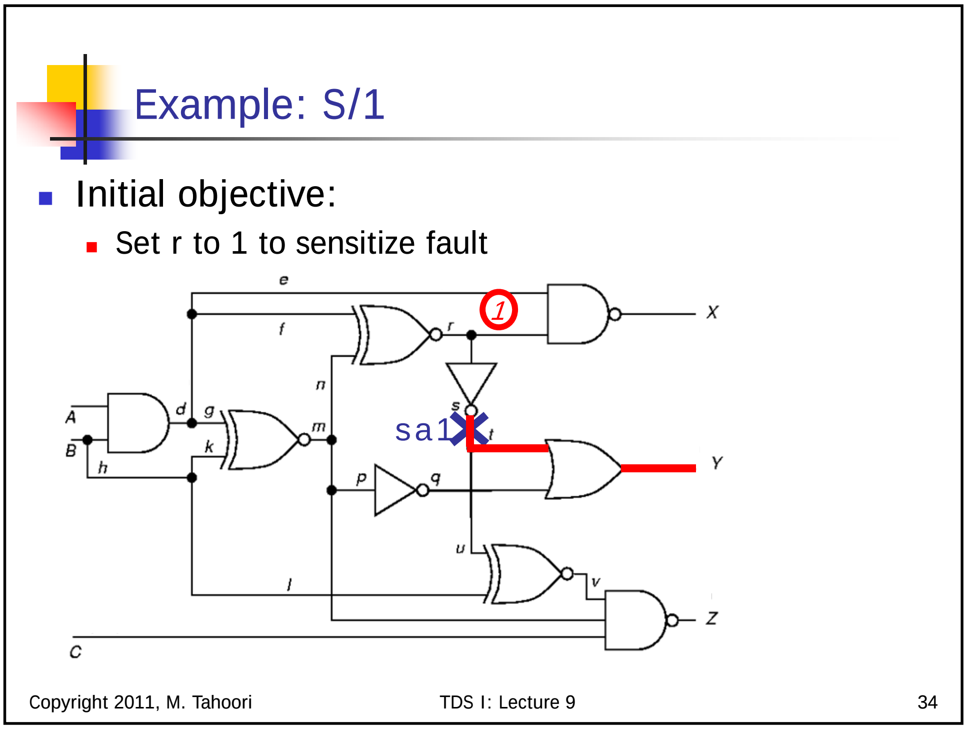

## Example: S/1

- Initial objective:
  - Set r to 1 to sensitize fault

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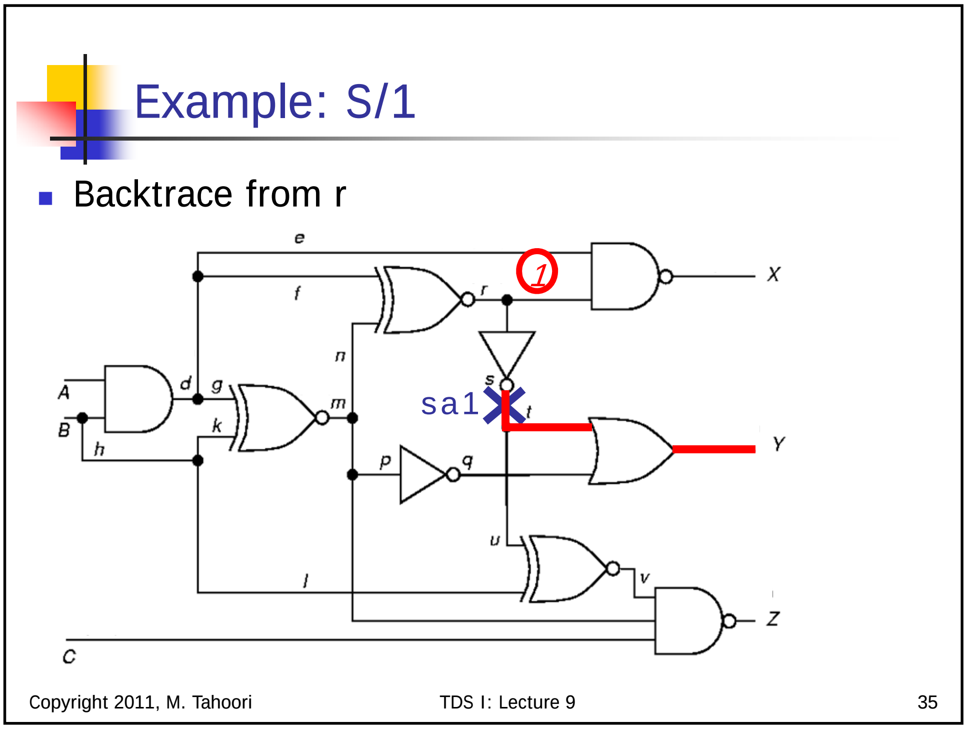
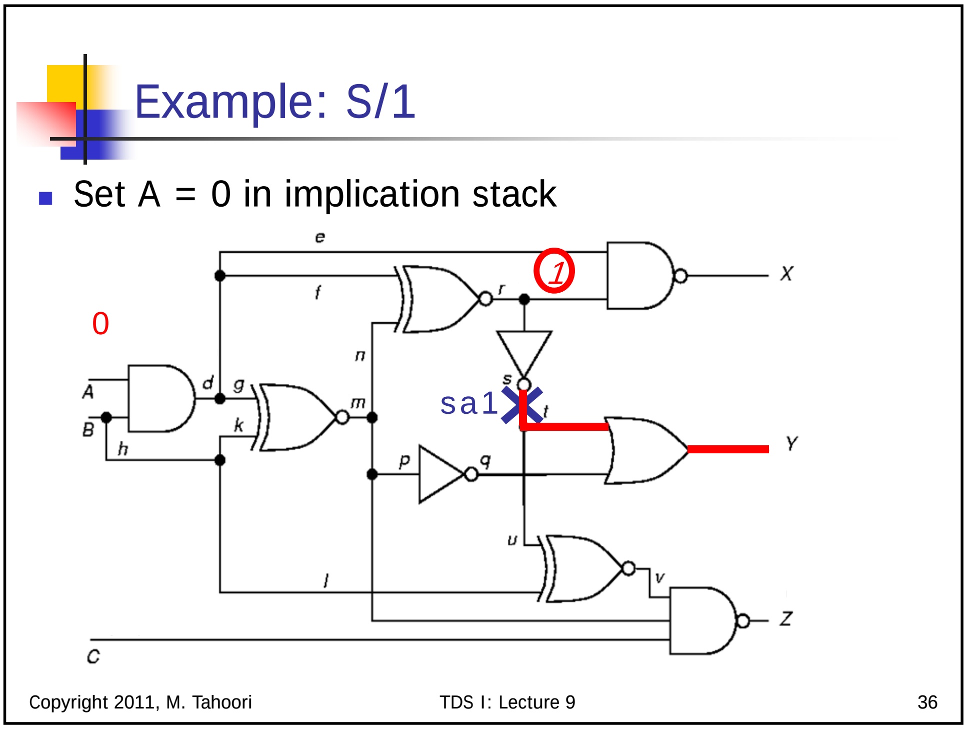


## Example: S/1

- Backtrace from r

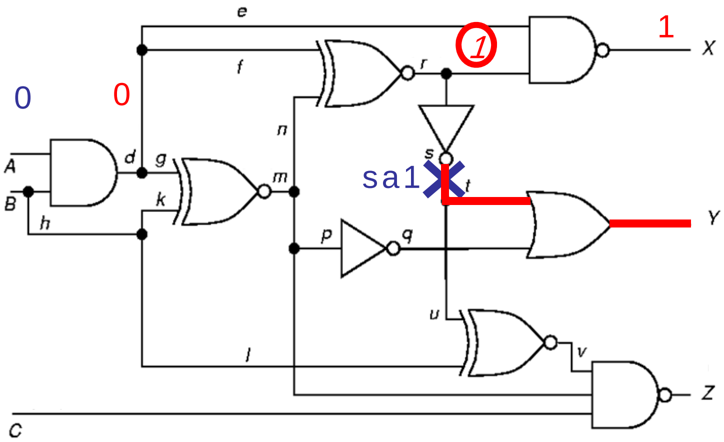


## Example: S/1

- Set A = 0 in implication stack

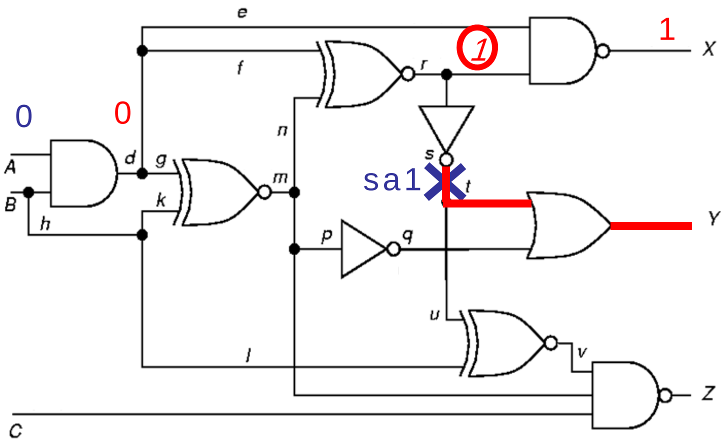
## Example: S/1

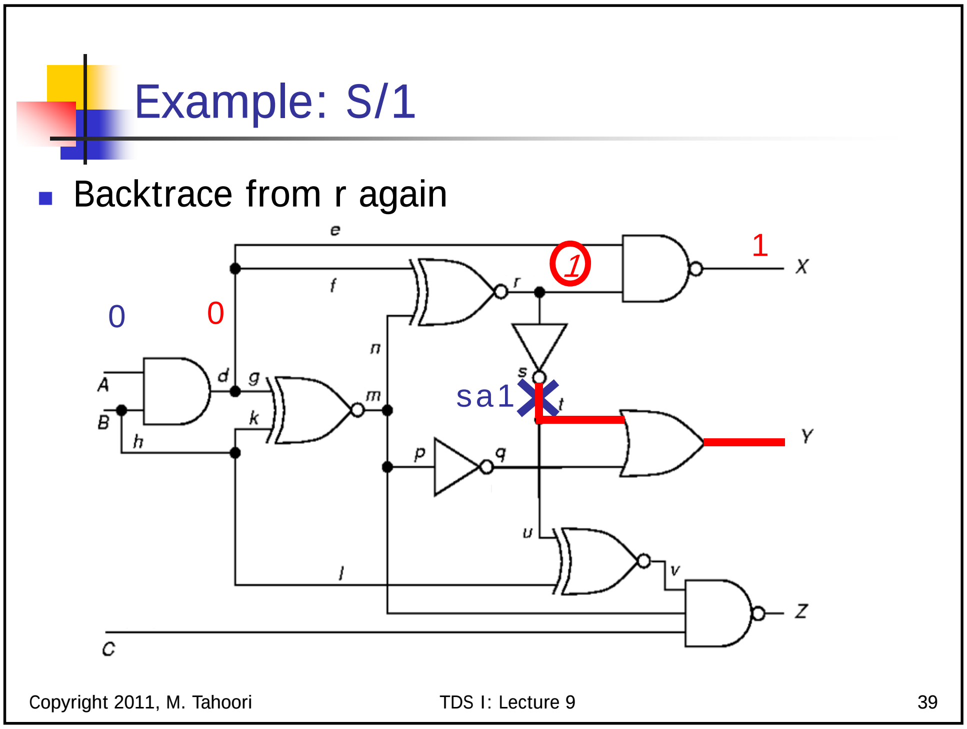
- Forward implications: d = 0, X = 1



## Example: S/1

- Initial objective: set r to 1





## Example: S/1

- Backtrace from r again

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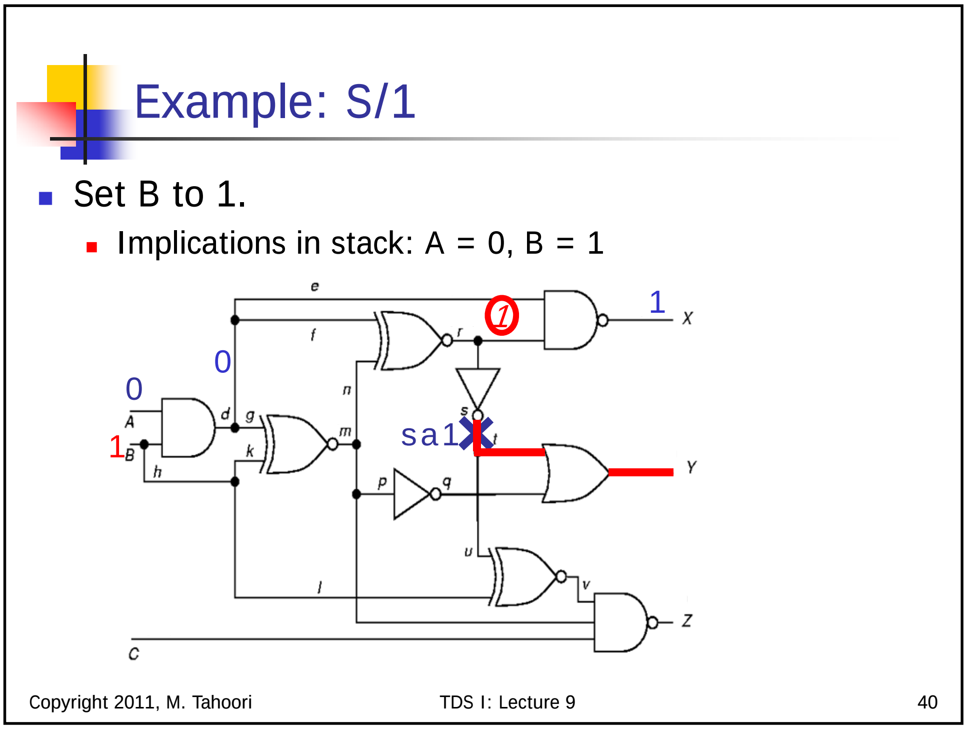

## Example: S/1

- Set B to 1.
  - Implications in stack: A = 0, B = 1

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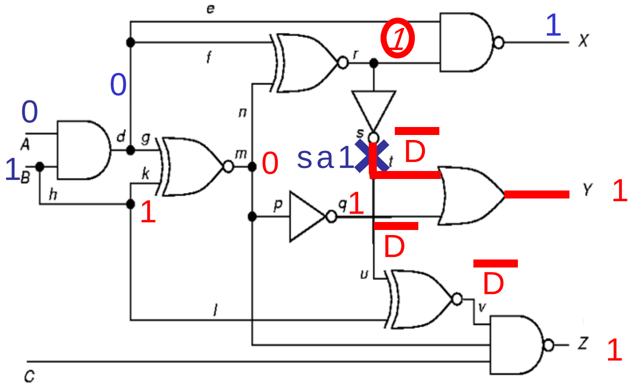
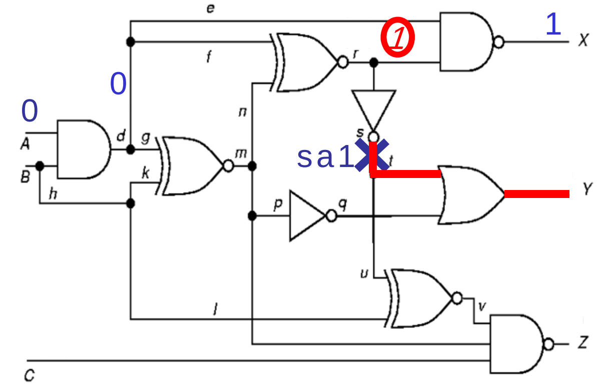
## Example: S/1

- Forward implications:
- k = 1, m = 0, r = 1, q = 1,Y = 1, s = $\overline{D}$, u = $\overline{D}$, v=$\overline{D}$, Z = 1



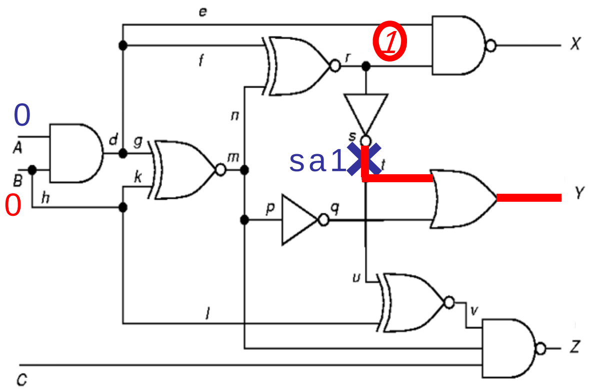
## Example: S/1

- X-PATH-CHECK
  - paths s – Y and s – u – v – Z blocked



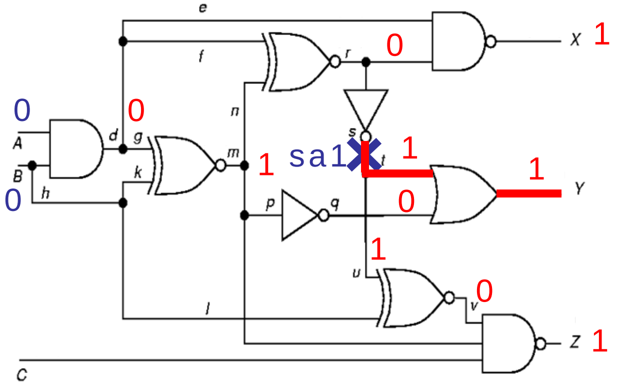
## Example: S/1

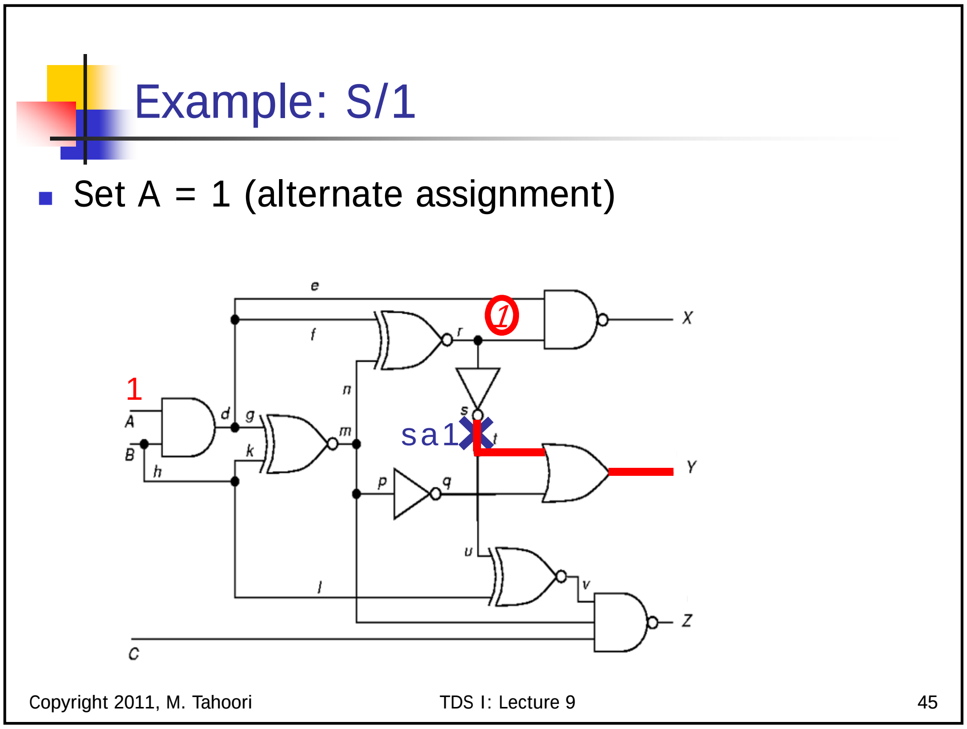
- Set B = 0 (alternate assignment)



## Example: S/1

- Forward implications:
- d = 0, X=1, m = 1, r = 0, s = 1, q = 0, Y = 1, v = 0, Z = 1
- Fault not sensitized





## Example: S/1

- Set A = 1 (alternate assignment)

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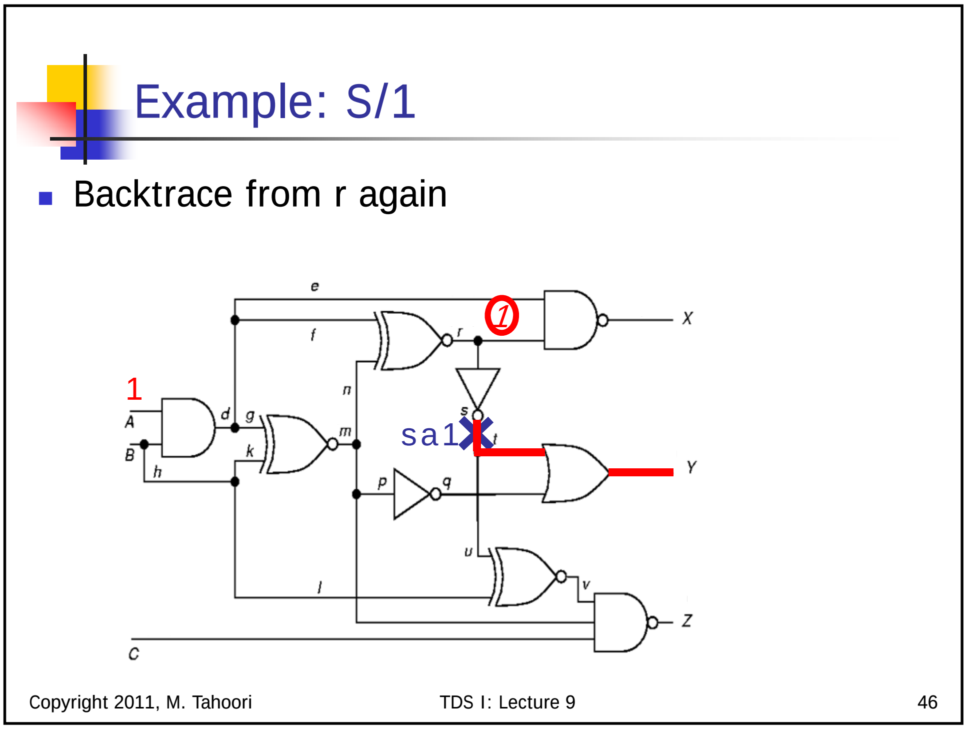

## Example: S/1

- Backtrace from r again

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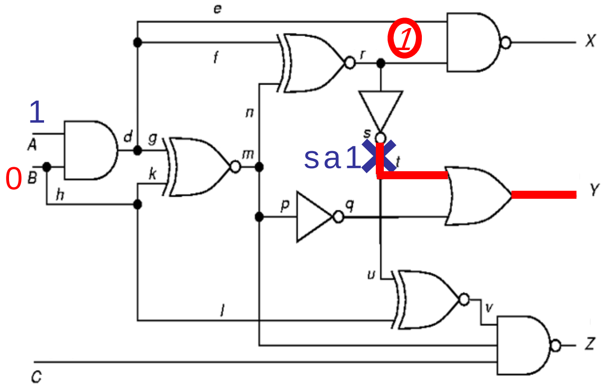
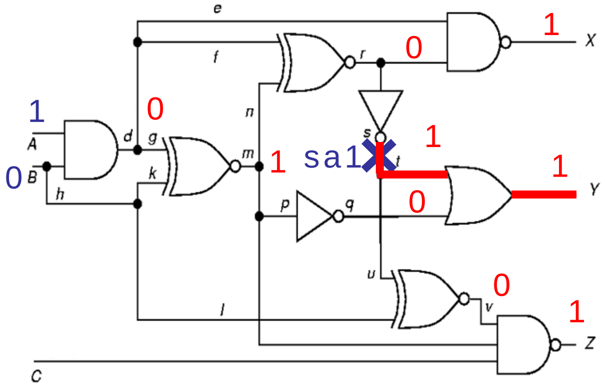
## Example: S/1

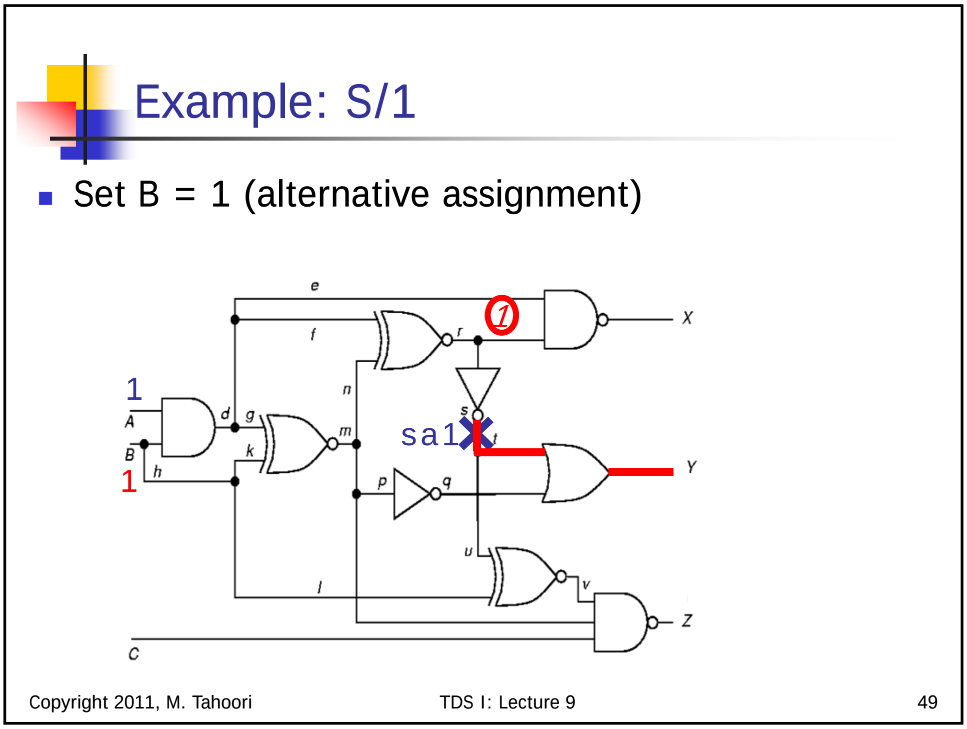
- Set B = 0.
- Implications in stack: A = 1, B = 0



## Example: S/1

- Forward implications:
  - d = 0, X = 1, m = 1, r = 0.
- Conflict: fault not sensitized. Backtrack





## Example: S/1

- Set B = 1 (alternative assignment)

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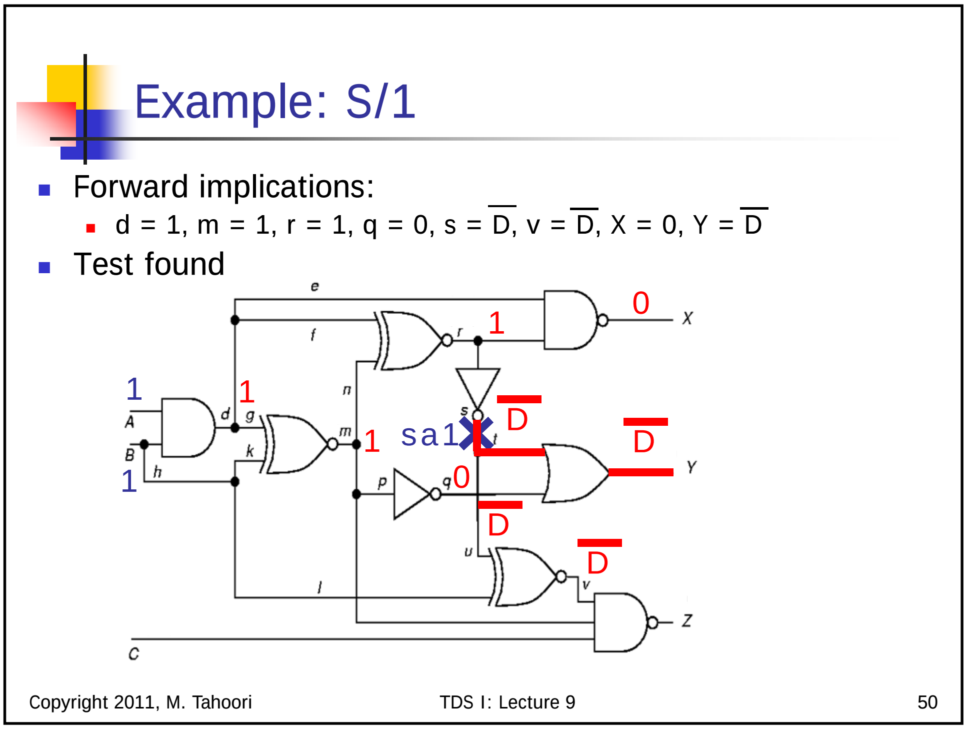

## Example: S/1

- Forward implications:
  - d = 1, m = 1, r = 1, q = 0, s = $\overline{D}$, v = $\overline{D}$, X = 0, Y = $\overline{D}$
- Test found

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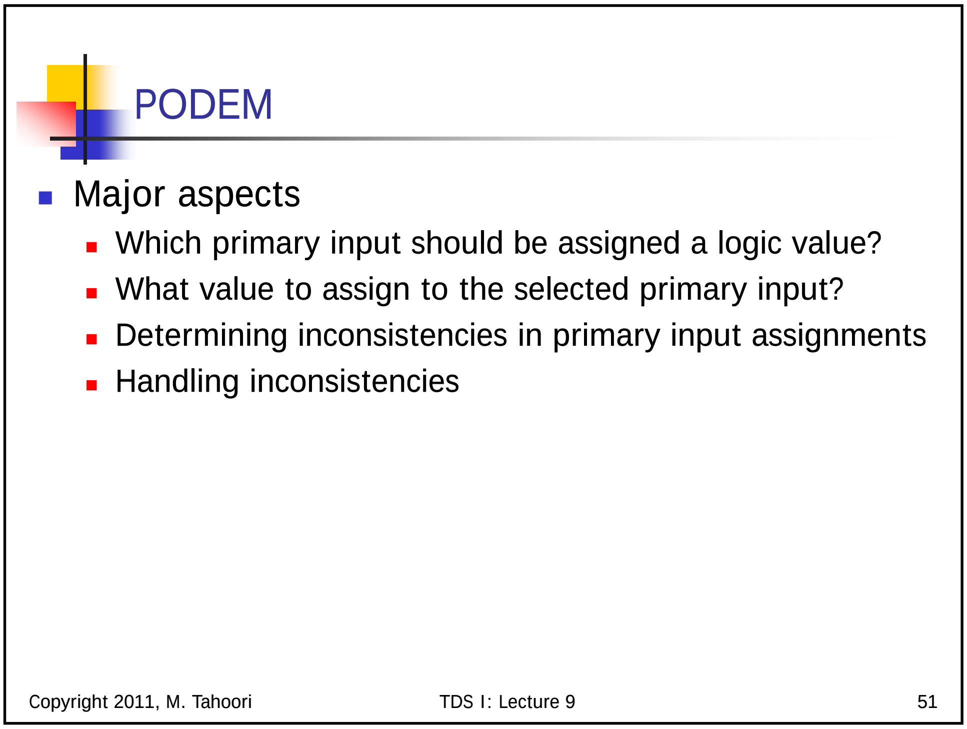
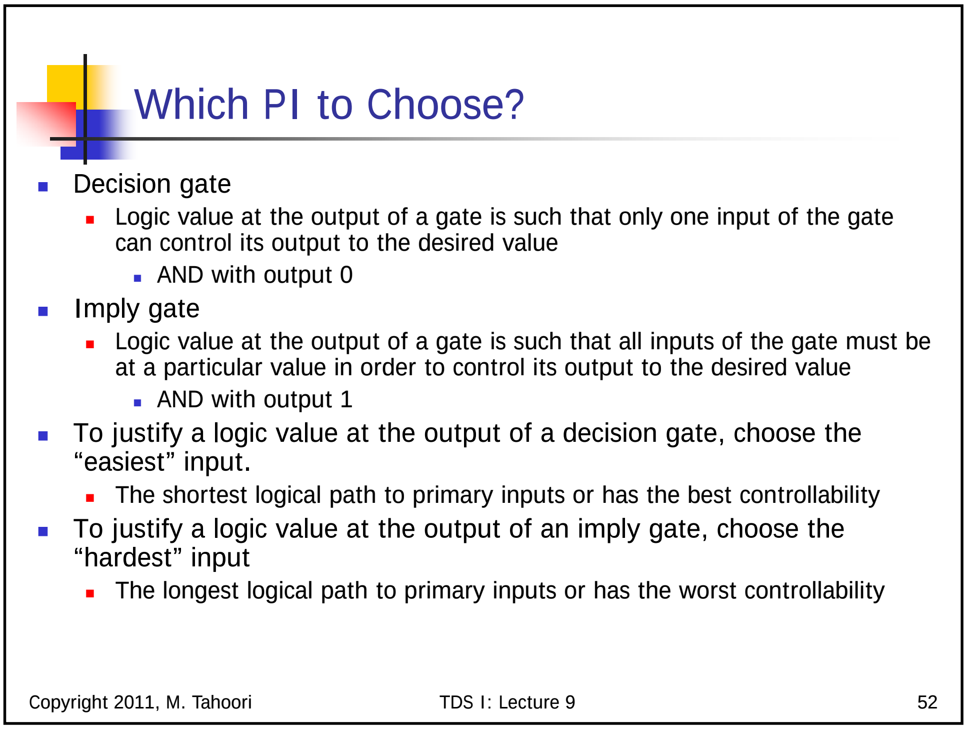


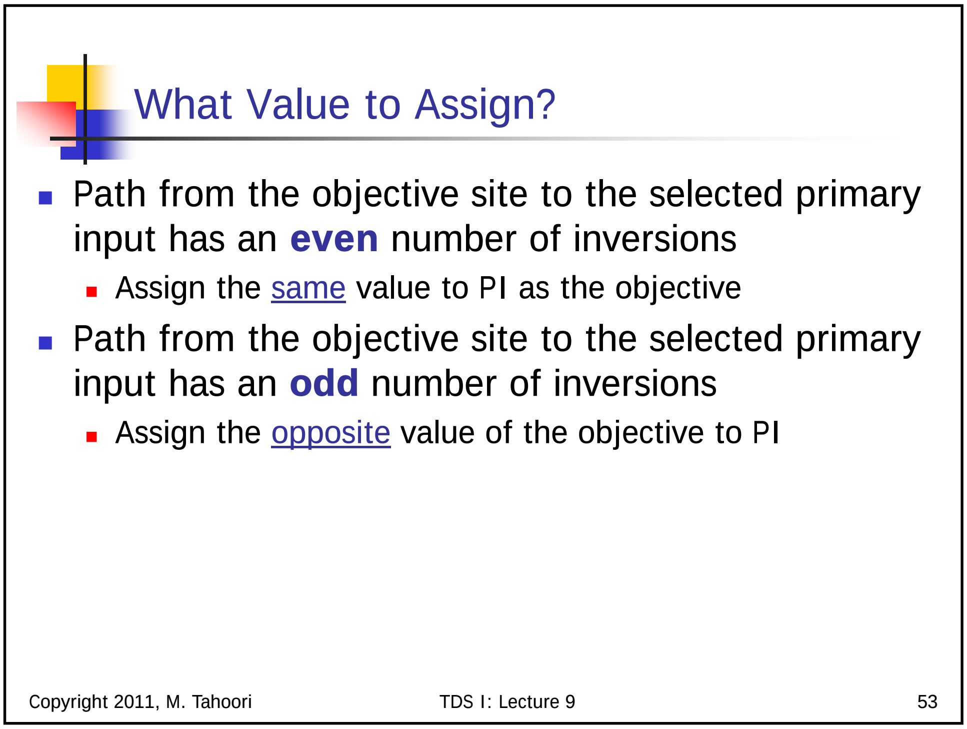
## PODEM

- Major aspects
  - Which primary input should be assigned a logic value?
  - What value to assign to the selected primary input?
  - Determining inconsistencies in primary input assignments
  - Handling inconsistencies



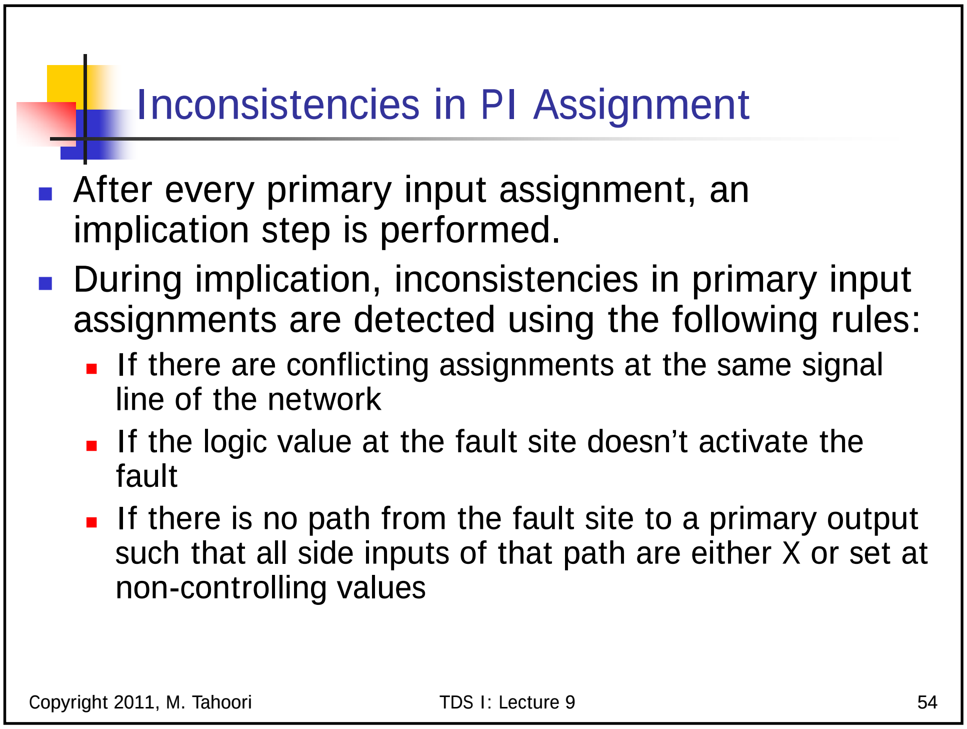
## Which PI to Choose?

- Decision gate
  - Logic value at the output of a gate is such that only one input of the gate can control its output to the desired value
    - AND with output 0
- Imply gate
  - Logic value at the output of a gate is such that all inputs of the gate must be at a particular value in order to control its output to the desired value
    - AND with output 1
- To justify a logic value at the output of a decision gate, choose the “easiest” input.
  - The shortest logical path to primary inputs or has the best controllability
- To justify a logic value at the output of an imply gate, choose the “hardest” input
  - The longest logical path to primary inputs or has the worst controllability



## What Value to Assign?

- Path from the objective site to the selected primary input has an **even** number of inversions
  - Assign the same value to PI as the objective
- Path from the objective site to the selected primary input has an **odd** number of inversions
  - Assign the opposite value of the objective to PI



## Inconsistencies in PI Assignment

- After every primary input assignment, an implication step is performed.
- During implication, inconsistencies in primary input assignments are detected using the following rules:
  - If there are conflicting assignments at the same signal line of the network
  - If the logic value at the fault site doesn't activate the fault
  - If there is no path from the fault site to a primary output such that all side inputs of that path are either X or set at non-controlling values

## Handling Inconsistencies

- Backtracking
  - Flip the logic value at the primary input
    - Which was the last one to be assigned a value
  - Stack of primary inputs that have been assigned values
  - After flipping implication step is performed
    - No inconsistency detected
      - Continue
    - Otherwise
      - That primary input is removed from the stack and
        - X is assigned to that primary input
      - POP the next assigned PI from stack and repeat