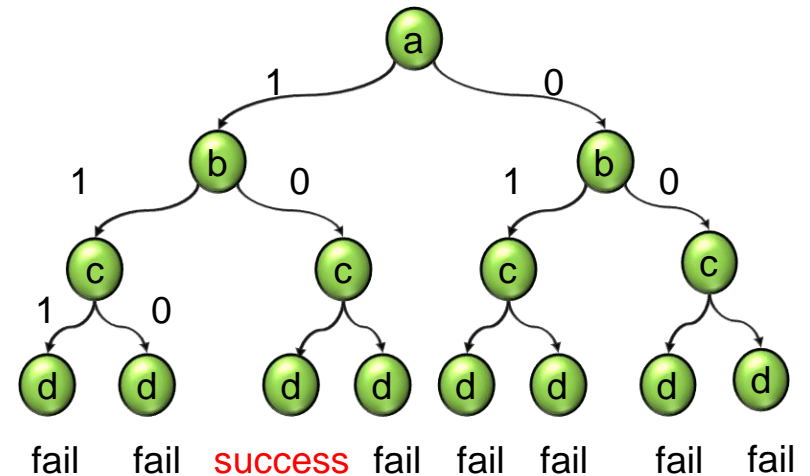# Combinational ATPG

- **Introduction**
- **Deterministic Test Pattern Generation**
  - ◆ Boolean difference *
  - ◆ **Path sensitization ****
  - ◆ D-Algorithm**
  - ◆ PODEM**
  - ◆ FAN**
  - ◆ SAT-based *
- **Acceleration Techniques**
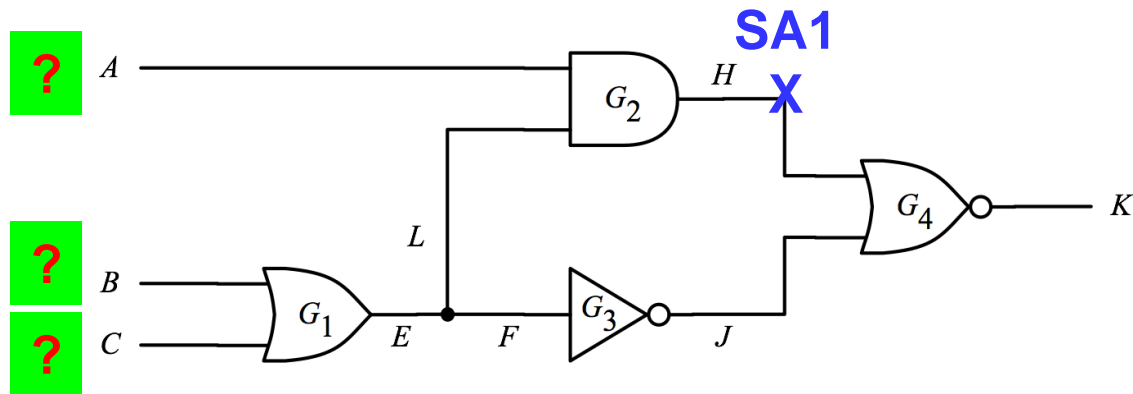- **Concluding Remarks**

Two ATPG categories:

***Boolean-based methods**

****Path-based methods**

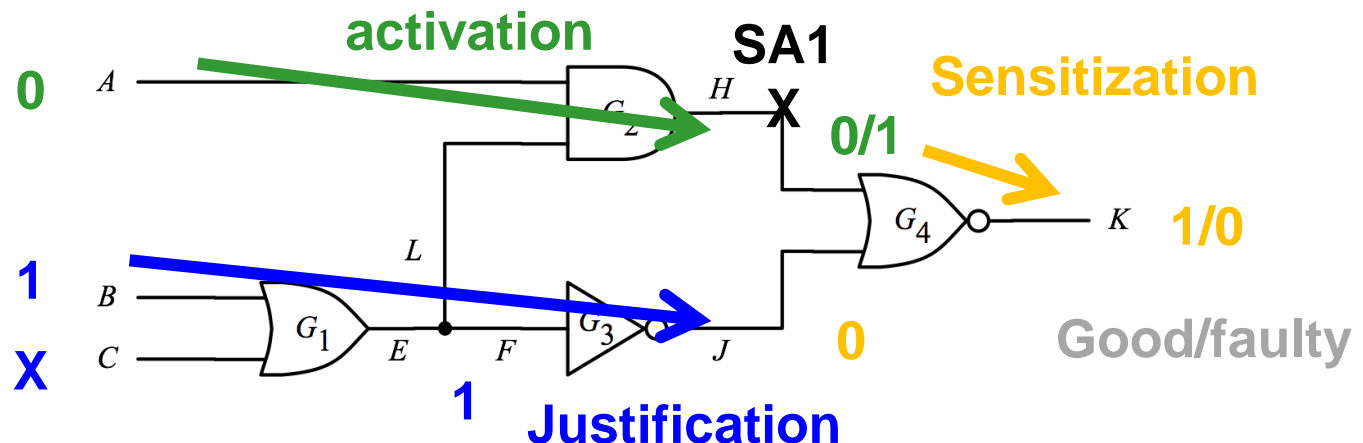fail   fail   success fail   fail   fail   fail   fail

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Motivating Problem

- **We do not need to know Boolean expression**
  - **we can just find a test from circuit netlist**

Let's Analyze What We Did

- *Fault activation:* **Assign gate inputs to generate appropriate value at fault site (*H*)**
  - ♦ *A=0*

- *Sensitization:* **Assign side-inputs to non-controlling value to propagate fault effect forward**
  - ♦ *J=0*

- *Justification:* **Assign primary inputs to achieve desired values**
  - ♦ *B=1*

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Single Path Sensitization

● **Single path sensitization (SPS) Algorithm:**

① *Fault activation* **(aka.** *Fault excitation***)**

   Assign gate inputs to generate value at fault site

   Desired value opposite to the faulty value (*e.g.* **0 for SA1)**

② *Fault effect propagation***:**

   Select one single path **from fault site to an output**

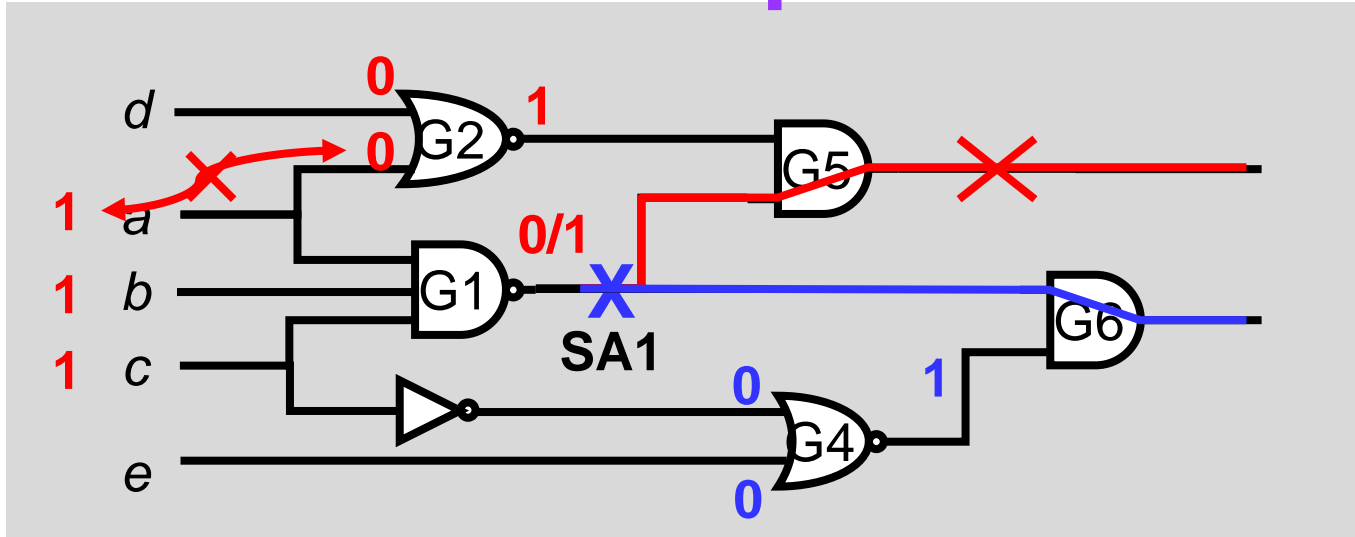   **Assign side inputs to sensitize fault effect along the path**

③ *Justification***:**

   Assign primary inputs to justify desired values assigned in ①**&**②

   If justification fails, backtrack**.**

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Example

Consider stuck-at-1 fault

① **Fault activation**

- $a = b = c = 1$

② **Fault effect propagation: two propagation paths**

- **Choose path {G5}.   Want G2 = 1**

③ $a = d = 0$ → justification fails!

② **Backtrack! Choose another path {G6}. Want G4 = 1**

③ $c = 1, e = 0$ → justification succeeds
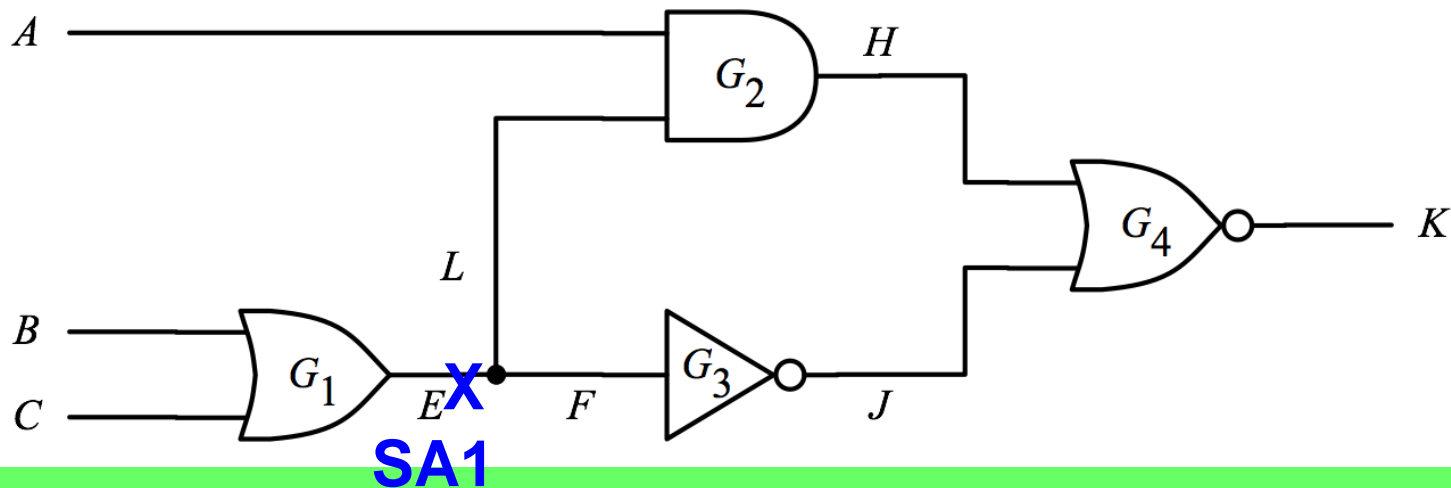
- test pattern: *abce'* generated

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Quiz

Q1: Generate a test pattern for *E* SA1 fault. Choose path *ELHK*.
A:

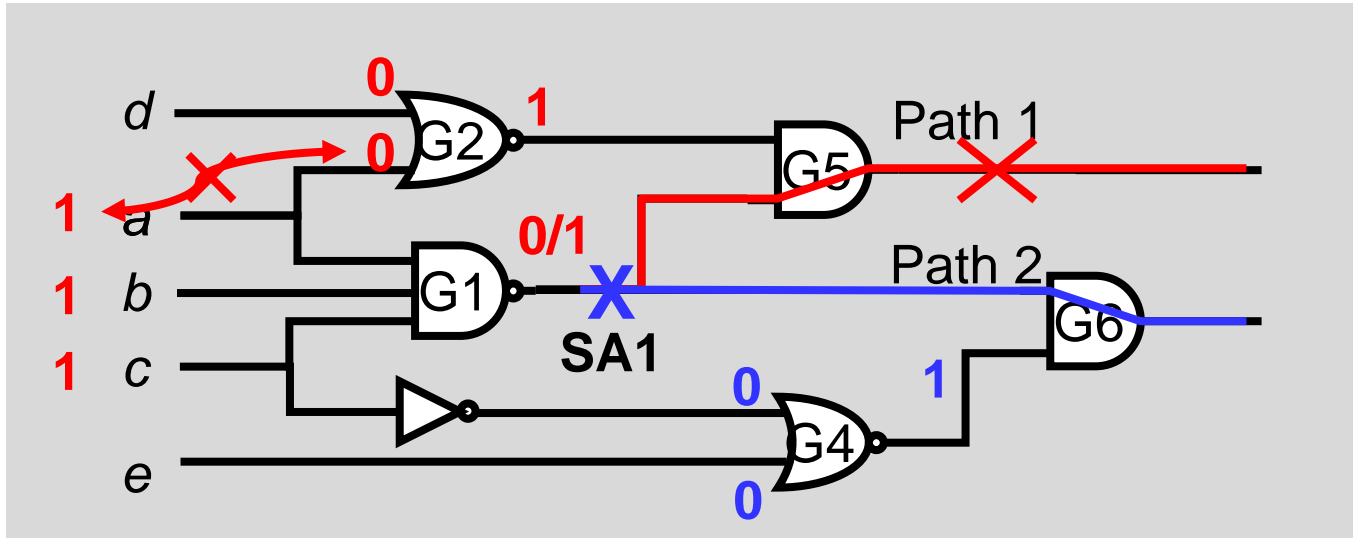Q2: (Cont'd) Backtrack to another path *EFJK*.
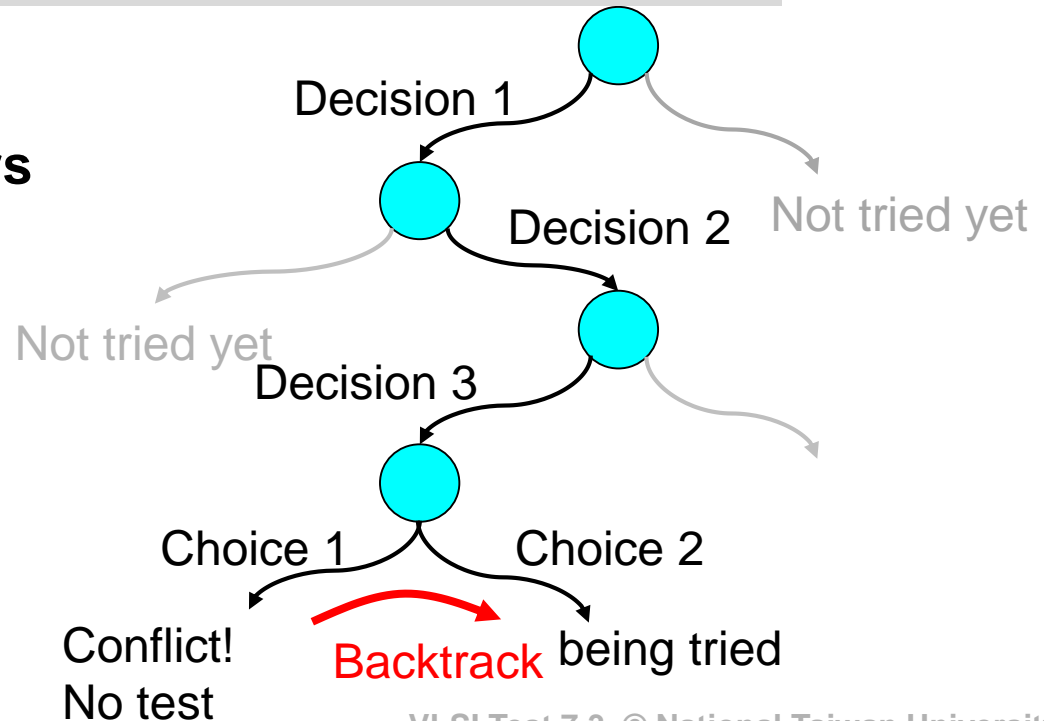A:

Important to Choose Correct Path
But it is difficult…

Backtrack

- **When we made a mistake in decision tree, conflict occurs**
  - ♦ **Go back to a previous decision point**
  - ♦ **Change decision**
  - ♦ **Redo the rest**

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Pros and Cons

☺ **Pros**

- ◆ **Easy to implement**
- ◆ **No Boolean equation needed**
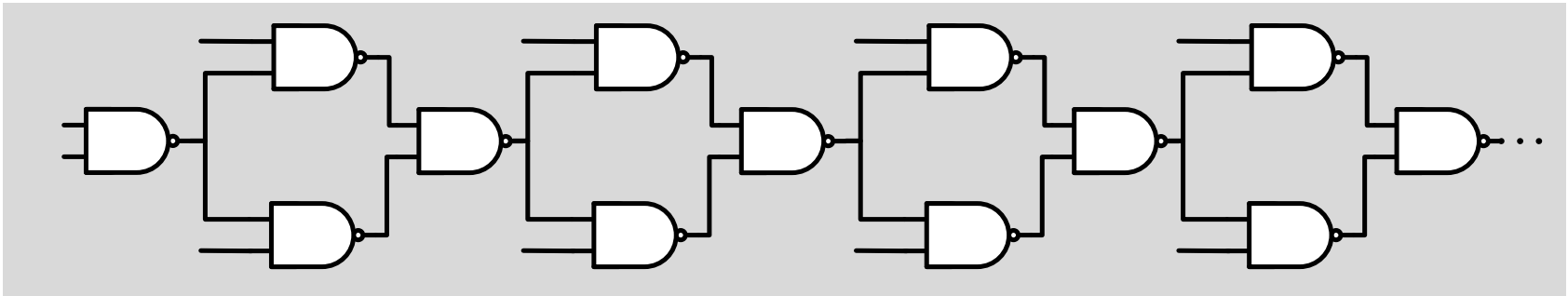
☹ **Cons**

- ◆ **Q1: Too many paths to choose, which one is correct?**
- ◆ **Q2: Single-path sensitization not enough to detect all faults**

● **Single path sensitization (SPS) Algorithm:**

① *Fault activation* (aka. *Fault excitation*)
   Assign internal signals to generate value at fault site
   Desired value opposite to the faulty value

② *Fault effect propagation*:
   Select one single path from fault site to an output
   Assign internal signals to sensitize fault effect along the path

③ *Justification*:
   Assign primary inputs to justify signal values assigned in ①&②
   If justification fails, backtrack.

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Q1: Too Many Paths !

- **How to choose correct path?**
  - ♦ **No smart algorithm**
  - ♦ **Simple idea: exhaustively try all paths**
- **How many paths in a circuit?**
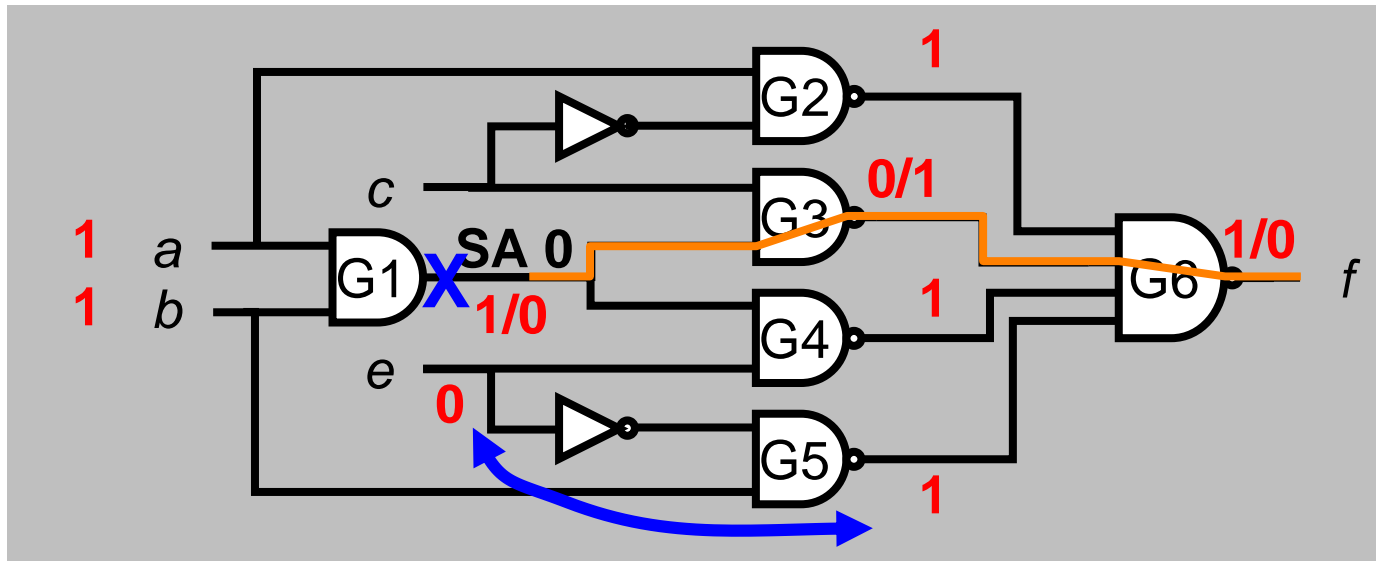 - ♦ **Worst case example: $3n$ gates, 2^n paths! (n = # of stages)**

of Paths is Exponential to Circuit Size! Impossible to Try All
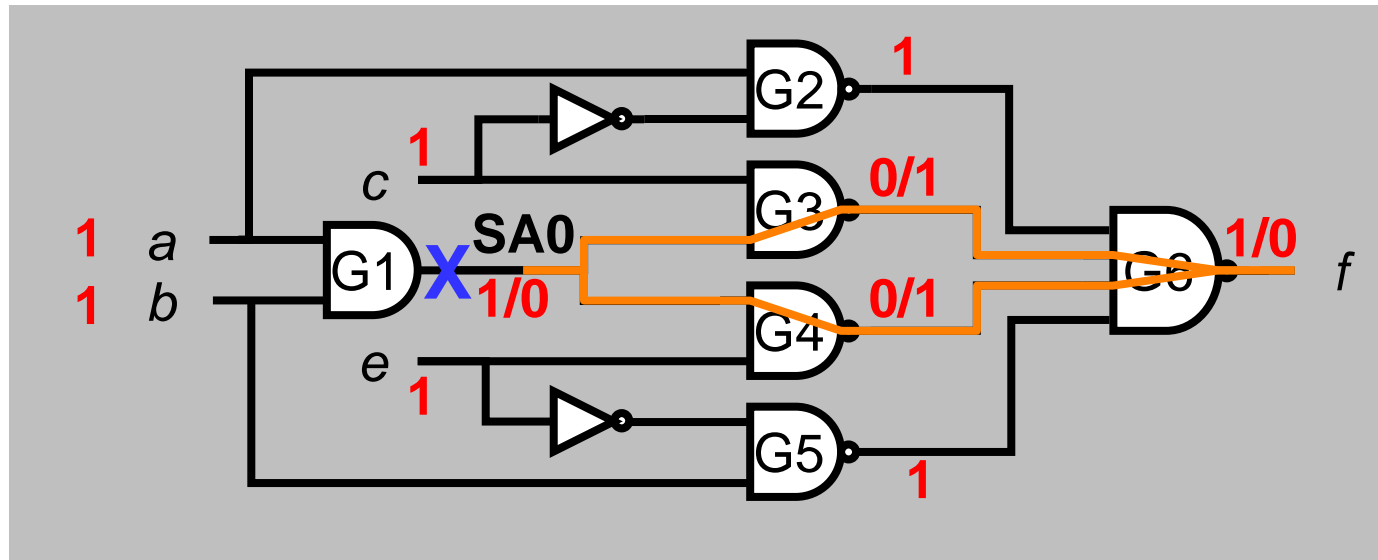
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Q2: Single Path Not Enough

- **Example**
  - ① **Fault activation: *a* = *b* = 1**
  - ② **Fault propagation: Choose path {G3-G6}. want G2 = G4 = G5 = 1**
  - ③ **G4 = 1 → *e* = 0 → G5 = 0 → justification fails**
  - ② **Choose another path {G4-G6}. Justification also fails.**
  - ♦ **SPS algorithm fails**
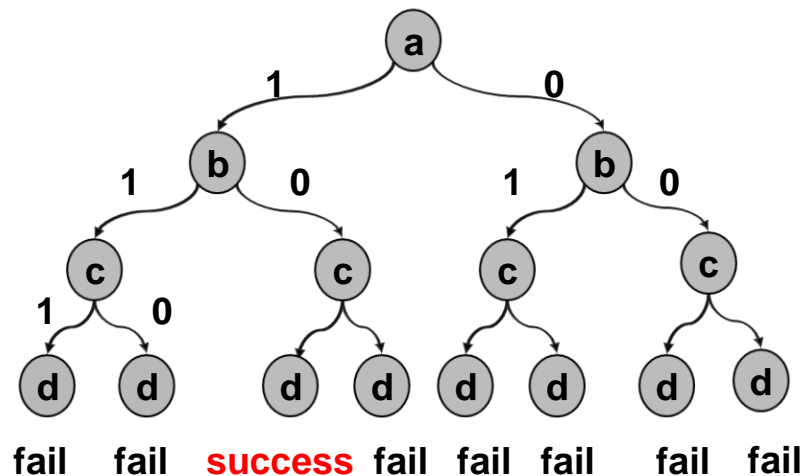

This Fault Is Actually Testable. Why SPS Fail?

Solution: Multiple Path Sensitization

- **This fault requires *multiple path sensitization***
- **Both two paths {G3-G6} and {G4-G6} are sensitized**
  - **Error is propagated along both paths simultaneously**
  - **G2 = G5 = 1 , $c = e = 1$**
  - **Test generated successfully**
- **FFT: can we extend 1-path to 2, 3, 4, 5…path sensitization?**

Complete ATPG Algorithm

- **A *complete* ATPG exhausts the whole input space (2^n)**
  - ♦ **If a test pattern exists, complete ATPG will find it for sure**
- **An *incomplete* ATPG does NOT exhaust the whole input space**
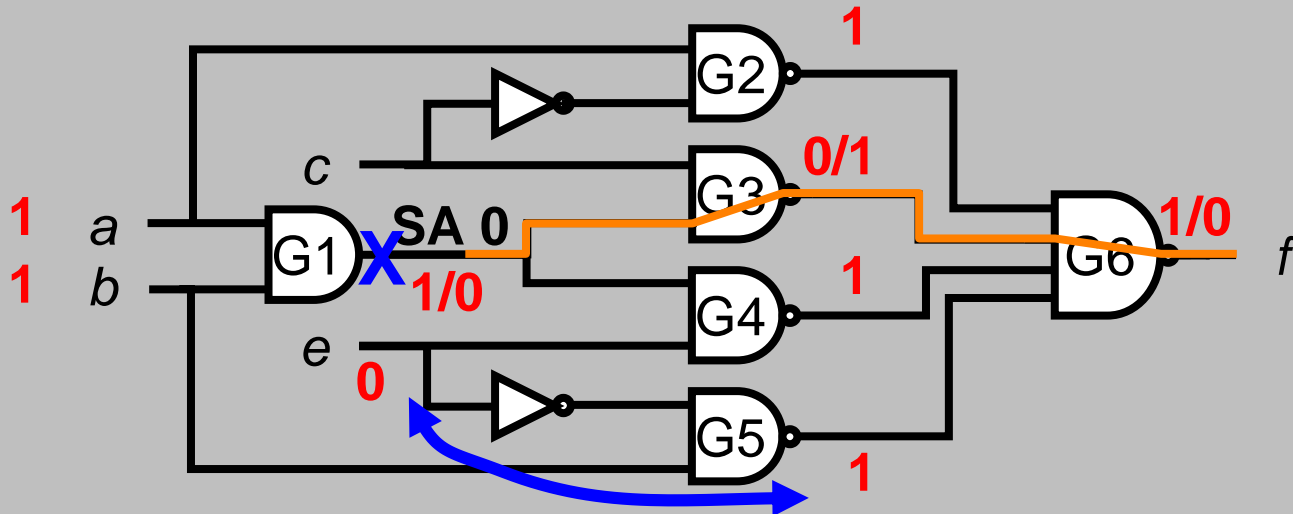 - ♦ **ATPG may fail even though a test pattern DOES exist**

Complete ATPG Guarantees to Find Solution
if it exists

Quiz

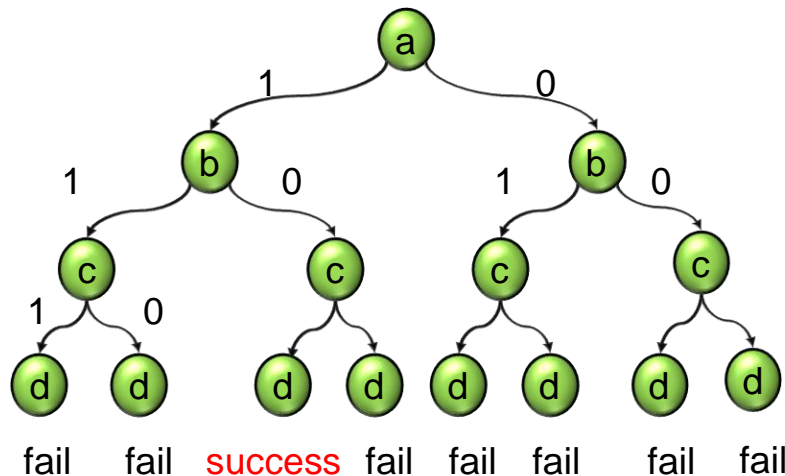**Q: Is Single Path Sensitization a complete ATPG algorithm?**

Hint: recall this example

- Single path sensitization (SPS) Algorithm:

① *Fault activation* (aka. *Fault excitation*)
   Assign internal signals to generate value at fault site
   Desired value opposite to the faulty value
② *Fault effect propagation*:
   Select **one single path** from fault site to an output
   Assign internal signals to sensitize fault effect along the path
③ *Justification*:
   Assign primary inputs to justify signal values assigned in ①&②
   If justification fails, **backtrack**.

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VLSI Test 7.3 © National Taiwan University

Summary

- **Single Path Sensitization Algorithm**
  - ① **Fault activation**
  - ② **Fault effect propagation**
  - ③ **Justification**
- **Complete ATPG: guarantee to find solution if one exists**
- **Disadvantages of SPS algorithm**
  - ♦ **Number of paths is exponential to circuit size. Too many!**
  - ♦ **Single path sensitization is incomplete ATPG**

FFT

- **Q1: If SPS fails, can we extend 1-path to 2, 3, 4, 5… paths?**
  - **What is the problem for multiple path sensitization algorithm?**
- **Q2: Pros and Cons of complete ATPG algorithm?**
  - **in terms of run time and fault coverage**