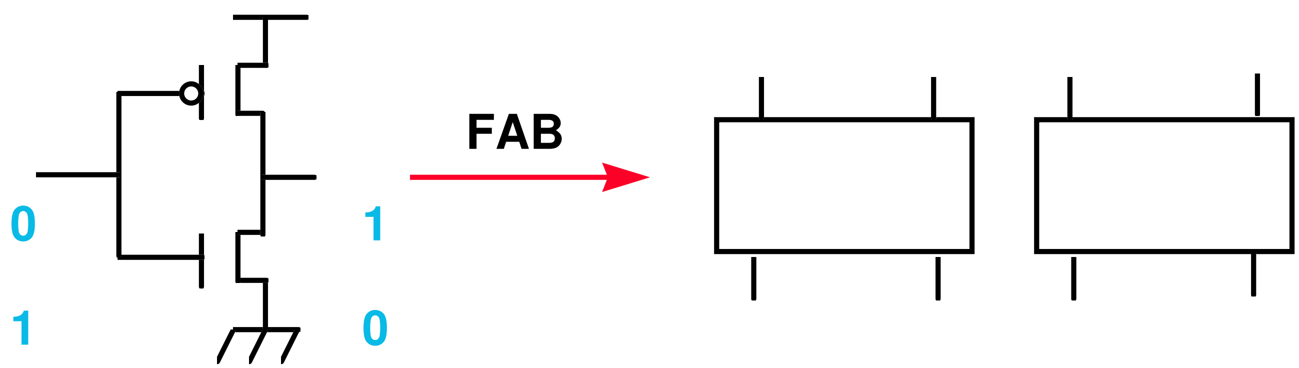
Testing

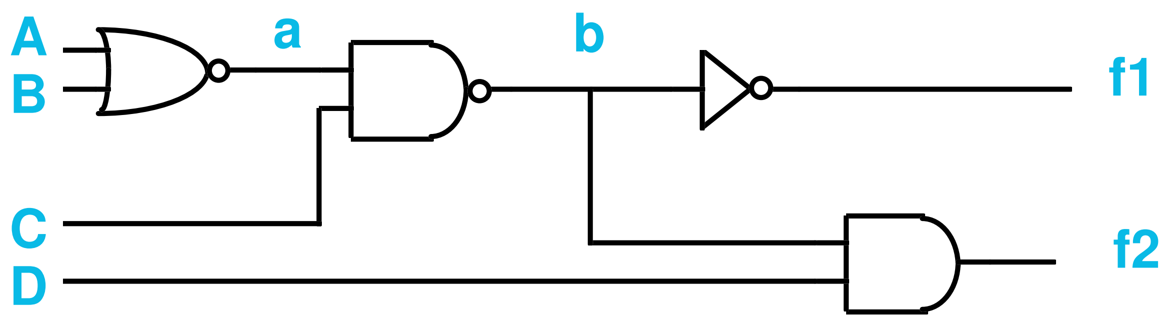
Apply a sequence of inputs to a circuit

Observe the output response and compare the response with a precomputed or “expected” response

Any discrepancy is said to constitute an error, the cause of which is a physical fault



Stuck-At Faults



Any input or internal wire in circuit can be stuck-at-1 or stuck-at-0

Single stuck-at-fault model: In the faulty circuit, a single line/wire is S-a-0 or S-a-1

Multiple stuck-at fault model: In the faulty circuit any subset of wires are S-a-0/S-a-1 (in any combination)

Test Generation

Choose a fault model, e.g., single stuck-at fault model

Given a combinational circuit which realizes the function $f(x_1, x_2, . . . x_n)$, a logical fault alters it to $f_\propto (x_1, x_2, . . . x_n)$

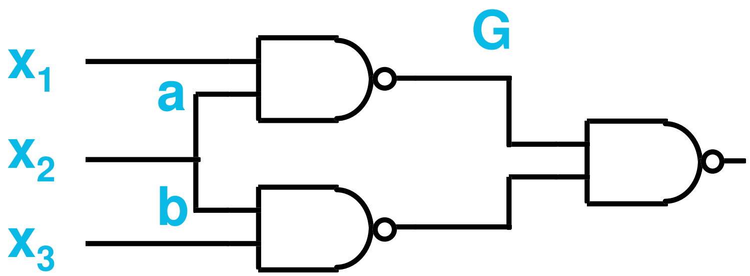
Inputs detecting $\propto$ are $f \oplus f_\propto$ ($= 1$)

Interested in <u>one</u> vector

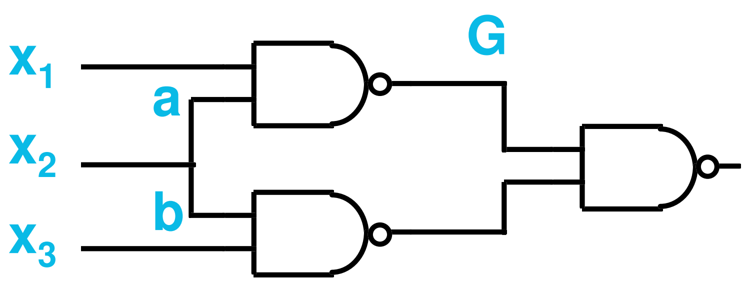
$A = (a_1, a_2, . . ., a_n) \in f \oplus f_\propto$

Single Stuck-At Faults

A fault is assumed to occur only on a single line.



$Z = x_1 x_2 + x_2 x_3$



a s-a-1 $Z = x_1 + x_2x_3$

G s-a-1 $Z = x_2x_3$

Boolean Difference

Circuit C realizing $f(x_1, x_2, \ldots x_n)$

Input x_i s-a-0 (fault $\propto$)

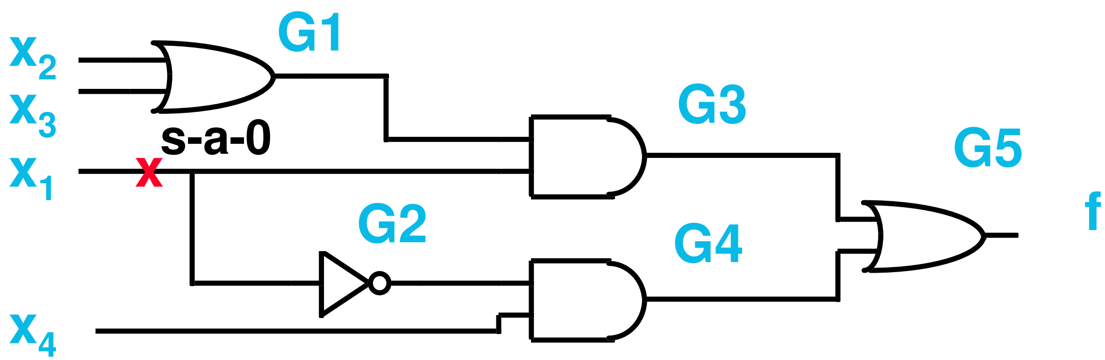
$f_\propto = f_{\overline{xi}}$ (cofactor of f w.r.t. $\overline{x_i}$)

Set of tests detecting $\propto$

$$
\begin{aligned}
T &= f \oplus f_\propto \\
&= (x_i f_{xi} + \overline{x_i} f_{\overline{xi}}) \oplus f_{\overline{xi}} \\
&= x_i (f_{xi} \oplus f_{\overline{xi}})
\end{aligned}
$$

$\dfrac{df}{dx_i} = f_{xi} \oplus f_{\overline{xi}}$ termed the Boolean difference of f w.r.t. x_i

Boolean Difference Example



$$f = (x_2 + x_3)x_1 + \overline{x_1}\, x_4$$

$$x_1 \text{ s-a-0} \quad x_1 \frac{df}{dx_1}$$

$$\frac{df}{dx_1} = f(0, x_2, x_3, x_4) \oplus f(1, x_2, x_3, x_4)$$

$$= x_4 \oplus (x_2 + x_3)$$

$$T = x_1\, \overline{x_2}\, \overline{x_3}\, \overline{x_4} + x_1\, x_2\, \overline{x_4} + x_1\, x_3\, \overline{x_4}$$

Internal Faults

Let C be a circuit for $f(X)$ and h be an internal signal in C.

Represent h as a Boolean function $h(X)$

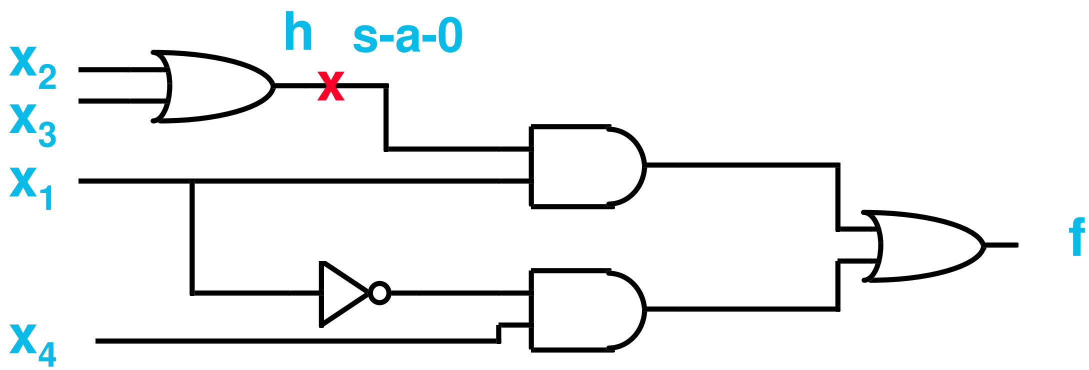
Express f as a function of inputs X and h

$$f^*(X, h) \equiv f(X)$$

Set of all tests for h s-a-0

$$h(X) \bullet \frac{df^*(X, h)}{dh}$$

Internal Faults Example



$$f = (x_2 + x_3)x_1 + \overline{x_1}\, x_4$$

$$f^* = h\, x_1 + \overline{x_1}\, x_4 \qquad\qquad h = x_2 + x_3$$

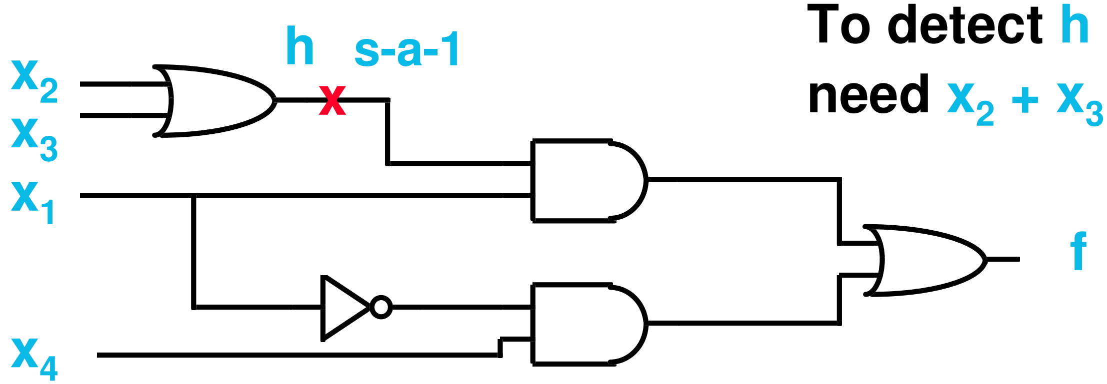
$$\frac{df^*}{dh} = f^*(x_1, x_4, 0) \oplus f^*(x_1, x_4, 1)$$

$$= \overline{x_1}\, x_4 \oplus (x_1 + \overline{x_1}\, x_4) = x_1$$

$$T = x_1\, x_2 + x_1\, x_3$$

Path Sensitization

In order for an input vector X to detect a fault a s-a-j, j = 0,1 the input X must cause the signal a in the normal (fault-free) circuit to take the value $\overline{j}$.

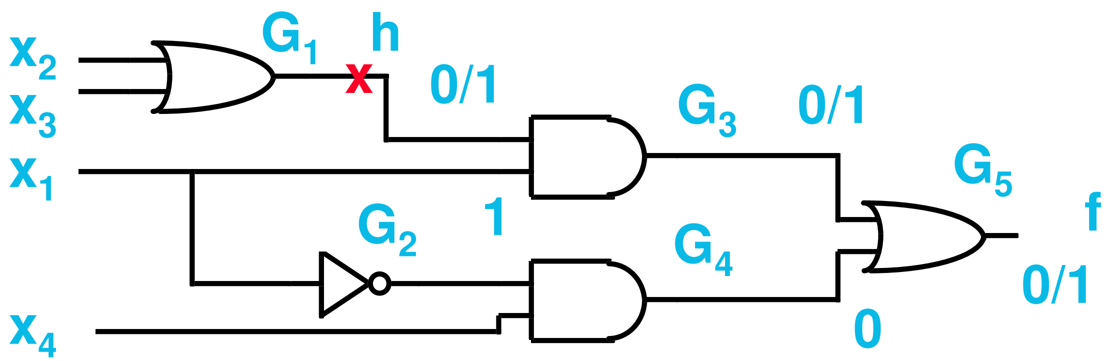


To detect h s-a-1,
need $x_2 + x_3 = 0$, i.e., $\overline{x_2}\ \overline{x_3}$

The condition is necessary but not sufficient.
Error signal must be propagated to output.

Error Propagation

The error signal must be propagated along some path from its origin to an output



h s-a-1, for h to be 0, need $x_2 = x_3 = 0$ $(\overline{x_2}\ \overline{x_3})$

Only one path G_3, G_5

In order to propagate an error through AND gate G_3, other input $x_1 = 1$. To propagate through G_5, need $G_4 = 0$, $x_1 + \overline{x_4}$

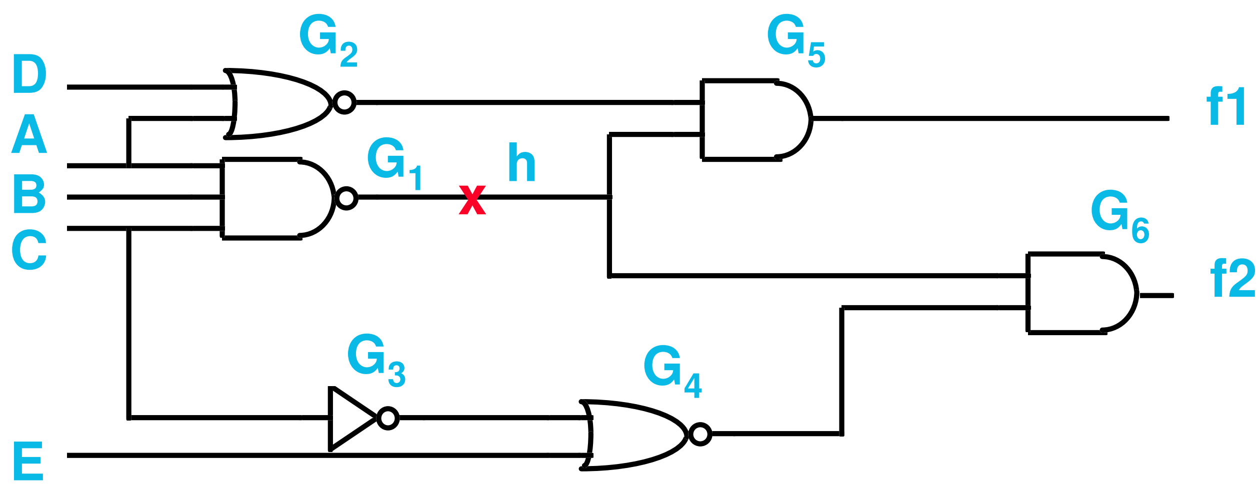
Single Path Sensitization (SPS)

1. Specify inputs so as to generate the appropriate value (0 for s-a-1, 1 for s-a-0) at the site of the fault.

2. Select <u>a</u> path from the site of the fault to an output and specify additional signal values to propagate the fault signal along this path to the output (error propagation).

3. Specify input values so as to produce the signal values specified in (2) (line justification).

Sensitization Example



h s-a-1

To generate $h = 0$, need $A = B = C = 1$

Have a choice of propagating through G_5 or via G_6.

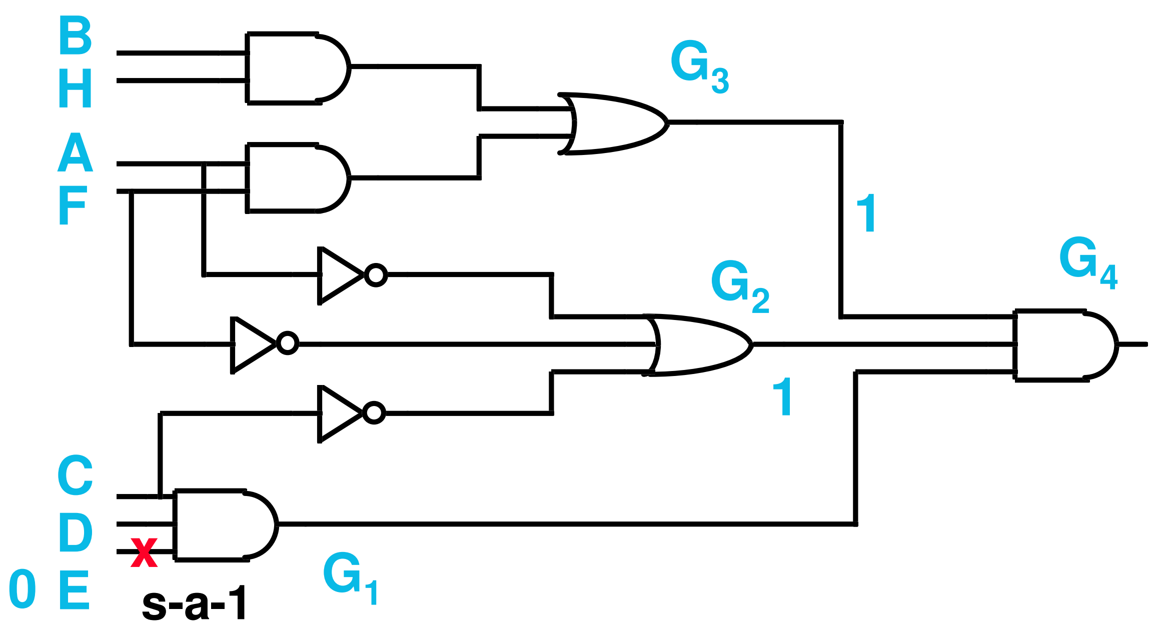
Propagating through G_5 requires $G_2 = 1$

$\Rightarrow$ $A = D = 0$ Contradiction

Propagating through G_6 requires $G_4 = 1$ $\Rightarrow$ $C = 1, E = 0$.

Test $ABC\overline{E}$

Line Justification

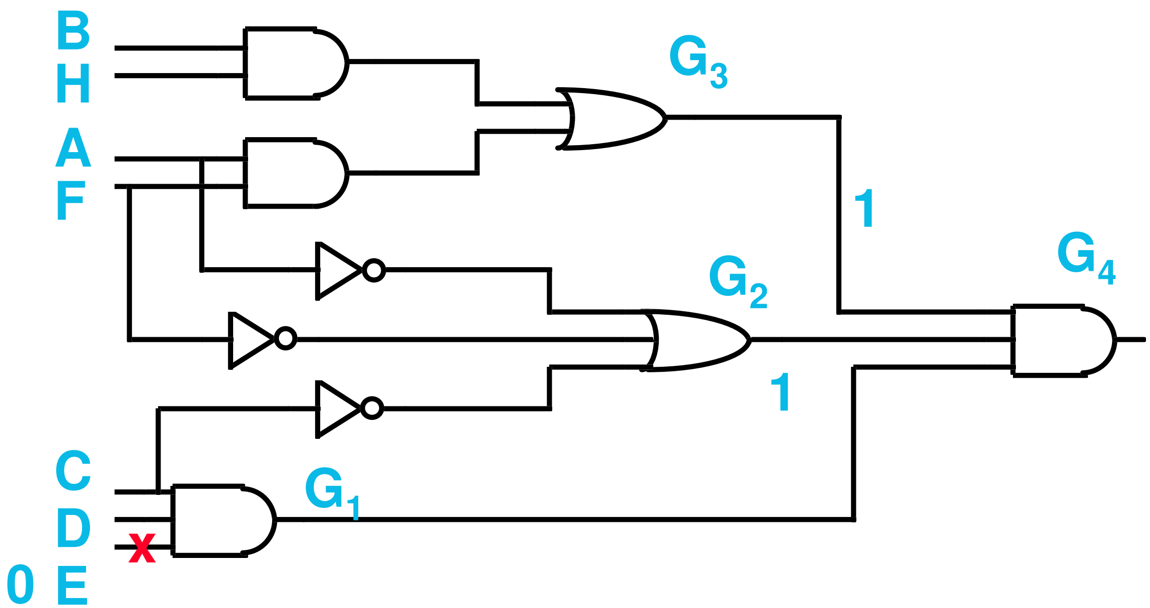


E **s-a-1** $\Rightarrow$ E = 0

C = D = 1 **to propagate through** G_1.

To propagate through G_4**, need** $G_2 = G_3 = 1$

Line Justification - 2



Attempt to <u>line justify</u> $G_2 = G_3 = 1$

$G_3 = 1$ possible if $A = F = 1$ or $B = H = 1$

If $A = C = 1$, then $G_2 = 0$.

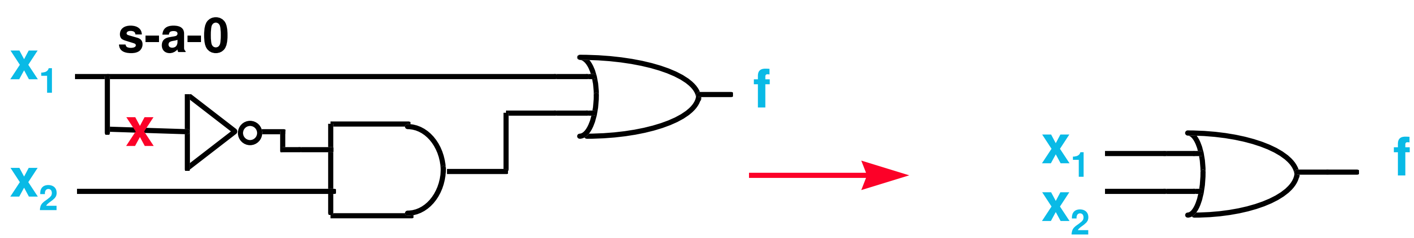
$G_3 = 1 \Rightarrow B = H = 1$

$G_2 = 1$ needs $A = 0$ or $F = 0$

Tests are $\bar{A}BCD\bar{E}H$, $BCD\bar{E}\bar{F}H$

Redundancy

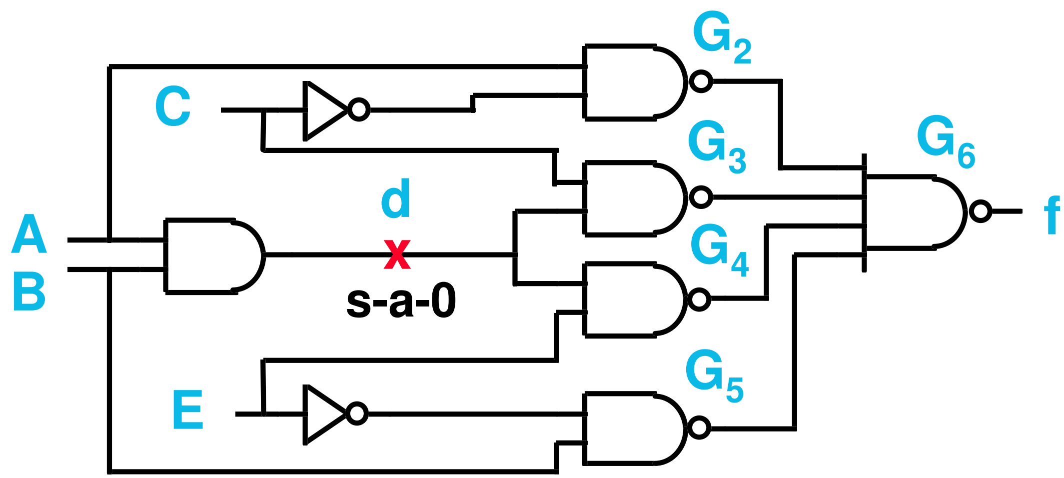
Existence of a fault does not change the functionality of a circuit ⇒ redundant fault



$f = x_1 + \overline{x_1}\, x_2$ $\qquad$ $f = x_1 + x_2$

A test generation algorithm is deemed complete if it either finds a test for any fault or proves its redundancy, upon terminating.

Completness of SPS method



d s-a-0 $\Rightarrow$ A = B = 1

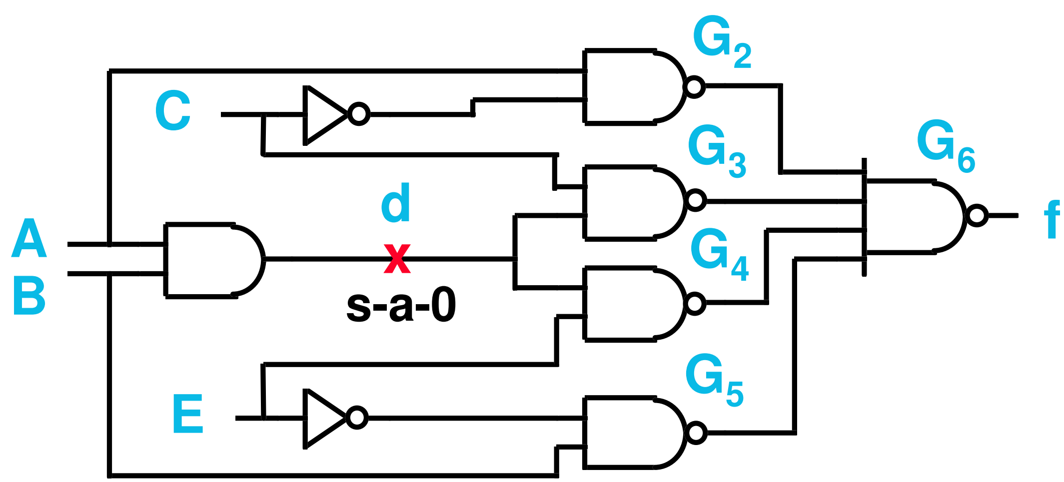
Propagate along G_3, G_6 $\Rightarrow$ C = 1

$G_2 = G_4 = G_5 = 1$

For $G_4 = 1$ either $G_1 = 0$ or E = 0

E = 0, B = 1 $\Rightarrow$ $G_5 = 0$ Inconsistency

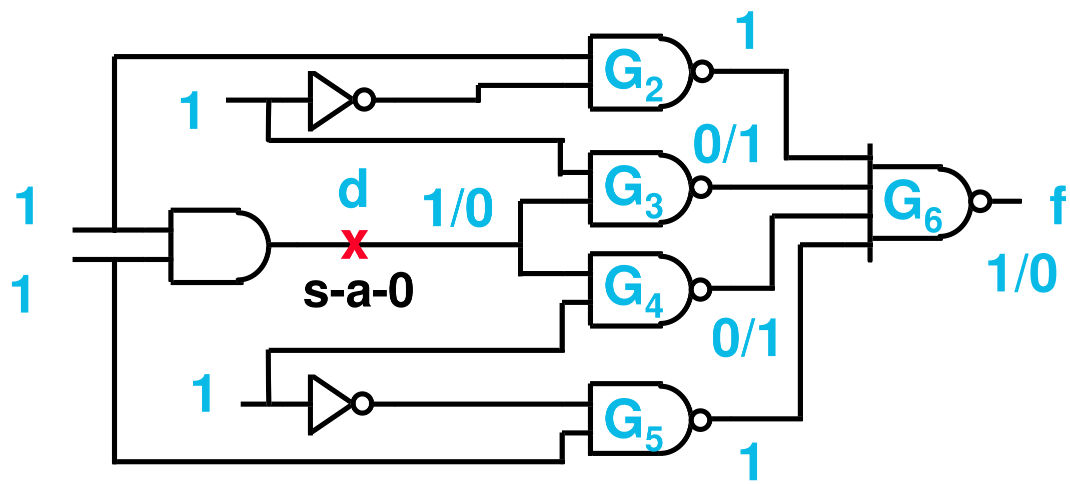
Completeness of SPS - 2



Propagation along G_4, G_6 also results in inconsistencies

Is there no test?

Multiple Path Sensitization



Error propagates down two paths G_3, G_6 and G_4, G_6 to output

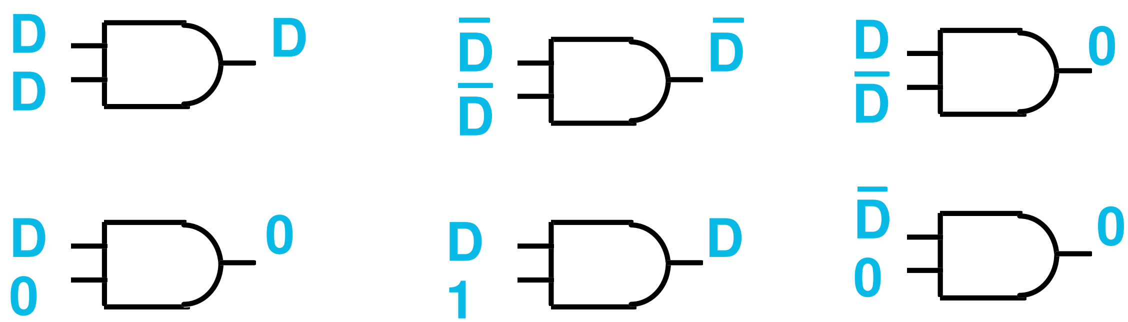
Attempting to sensitize a single path will not find the test

D-Algebra

Need to be able to deal with multiple "errors" at the inputs to a gate

D represents a signal which has value 1 in normal circuit, and value 0 in faulty circuit.

$\overline{D} \equiv 0/1$



D, $\overline{D}$ behave like Boolean variables

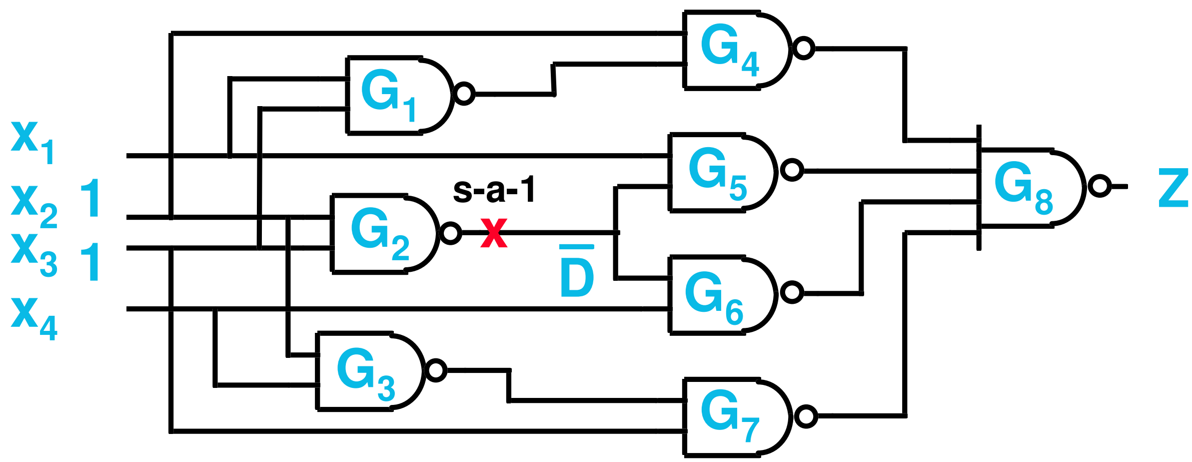
Path-Oriented Decision Making

1. Determine an initial objective. If the faulty signal has not appeared at the site of a fault, the initial objective is determined as providing the faulty signal on the associated line.

2. Given an initial objective, a primary input and a logic value are chosen that have a strong likelihood of meeting the objective

   $\Rightarrow$ Done using the backtrace procedure

PODEM Example



Initial objective: $(0, G_2)$

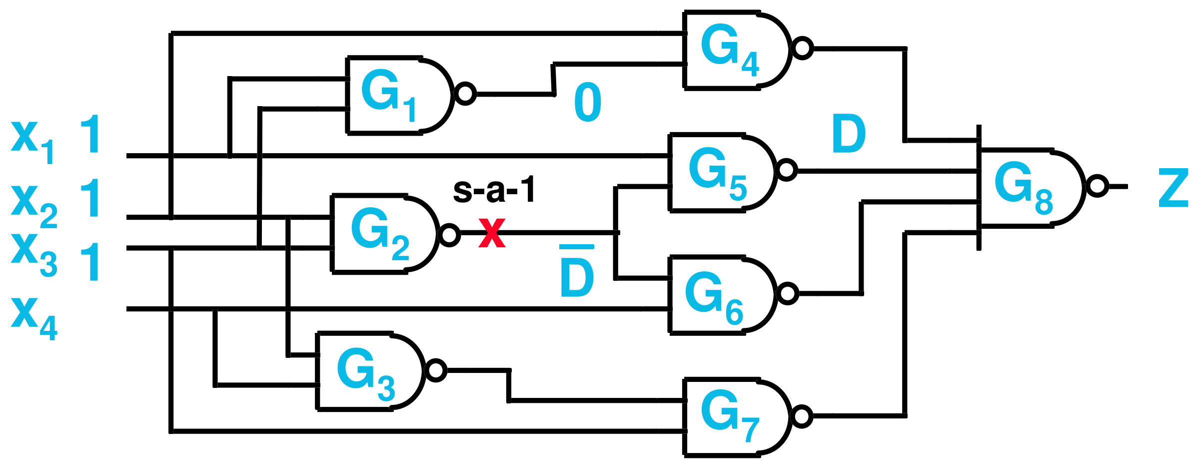
Backtrace to PIs: $x_2 = 1$

Objective: $(0, G_2)$

Backtrace: $x_3 = 1$

Implication: $G_2 = \overline{D}$

Example - 2



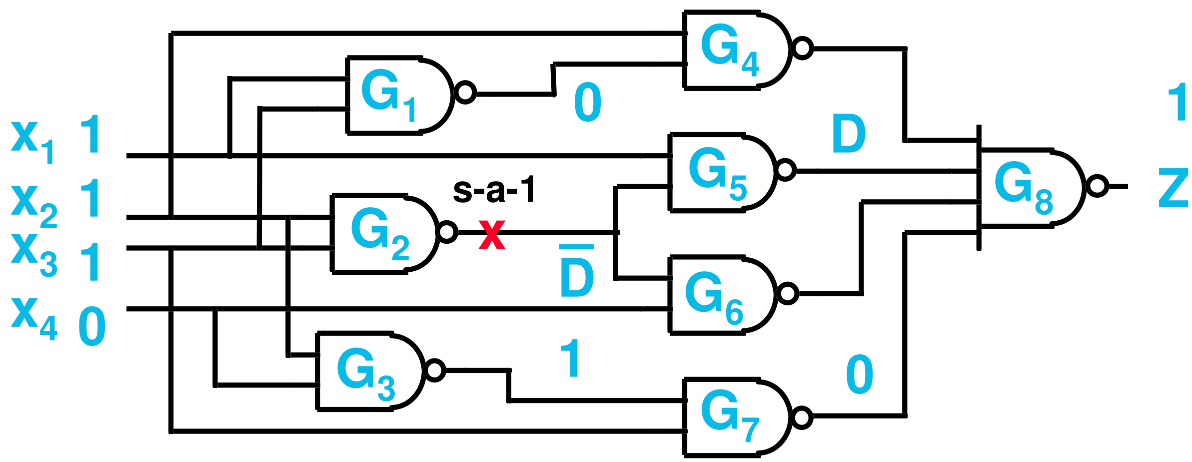
D-frontier is $\{G_5, G_6\}$

Attempt to propagate through G_5

Require $x_1 = 1$

Implication $G_1 = 0$, $G_4 = 1$, $G_5 = D$

Example - 3



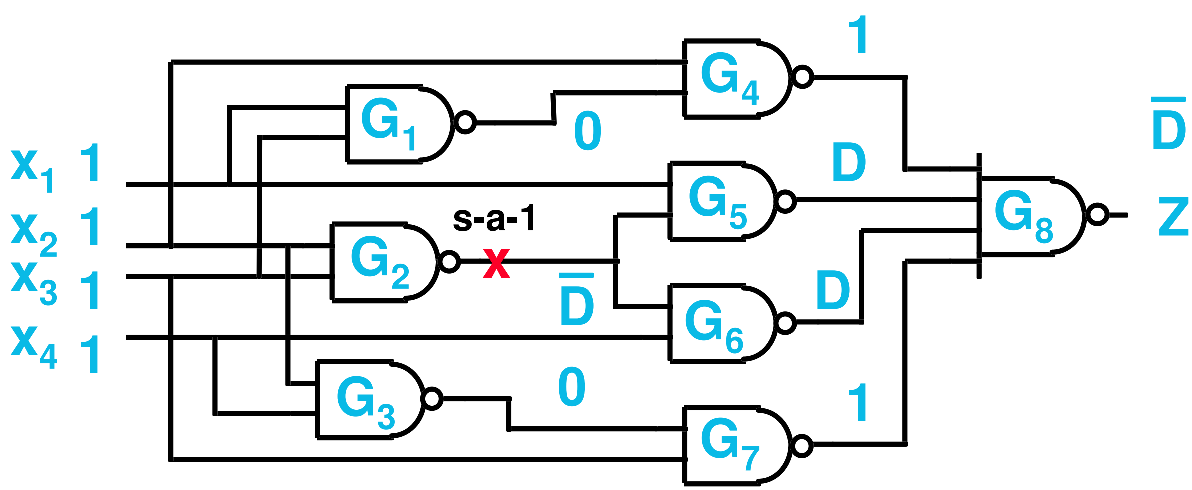
Attempt to propagate D through G_8.

Objective (1, G_6)

Backtrace to set $x_4 = 0$

Implication produces $G_3 = 1$ $G_7 = 0$ $G_8 = 1$
failed in propagating error

Example - 4



BACKTRACK to most recent assignment $x_4 = 1$

Implication results in $G_3 = 0, G_6 = D, G_8 = \overline{D}$

Generated test 1111