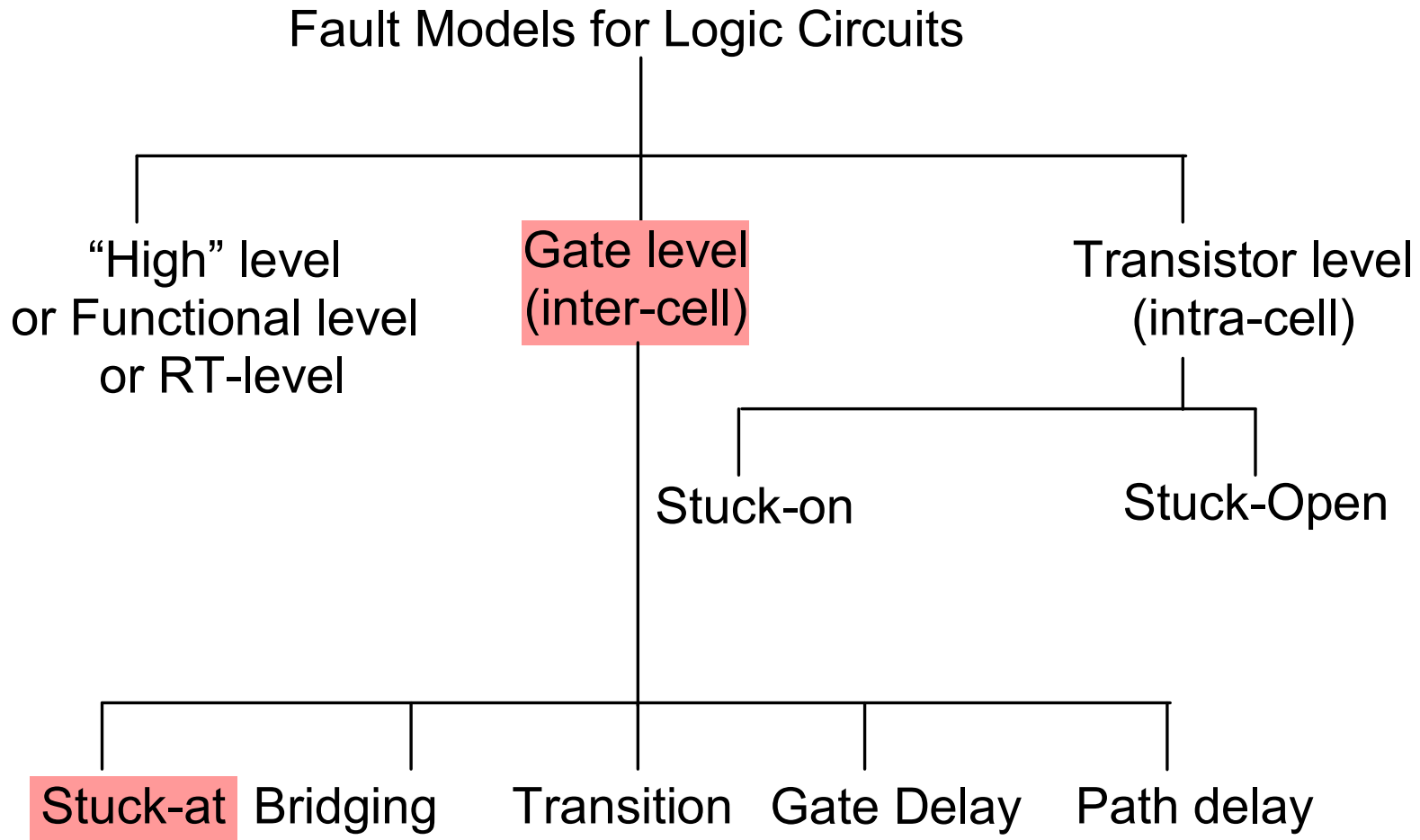


# Fault Modeling

- Introduction
- **Fault Models**
  - ◆ **Stuck-at fault (1961)**
  - ◆ Bridging fault (1973)
  - ◆ Delay fault (1974)
  - ◆ Transistor level fault
- Fault Detection
- Fault Coverage
- Conclusion



# Classification of Fault Models



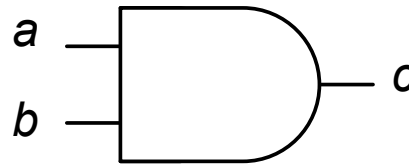
# Single Stuck-at Fault Model

- **Single Stuck-at Fault (SSF)** model [Galey 61]
  - ◆ One signal line in Boolean network of logic gates is fixed to logic 0 or 1, independent of logic values on other signal lines
- Notations: **node  $x$  stuck-at fault**
  - \*  $x/0$ ,  $x/1$ ,
  - \*  $x\ s@0$ ,  $x\ s@1$
  - \*  $x\ SA0$ ,  $x\ SA1$
- Number of faults is *linear* to circuit size
  - ◆ **2 faults (stuck-at one, stuck-at zero)** per node
  - ◆  **$2n$  SSF** in a circuit of  $n$  nodes
- Most commonly studied fault model

**SSF is Scalable for Large Circuits**

# Single Stuck-at Fault Example

- Example: SSF table of two input AND gate
  - ♦ Total **six** faults: **a/0**, **a/1**, **b/0**, **b/1**, **c/0**, **c/1**
- Test set  $ab = \{01, 11, 10\}$ 
  - ♦ **100%** SSF fault coverage, detects all SSF
- Minimum test length = **3** for 100% SSF fault coverage



Input <i>a b</i>	Fault-free Output	Faulty Output Value with SSF					
		<i>a/0</i>	<i>a/1</i>	<i>b/0</i>	<i>b/1</i>	<i>c/0</i>	<i>c/1</i>
0 0	0	0	0	0	0	0	<u>1</u>
0 1	0	0	<u>1</u>	0	0	0	<u>1</u>
1 1	1	<u>0</u>	1	<u>0</u>	1	<u>0</u>	1
1 0	0	0	0	0	<u>1</u>	0	<u>1</u>

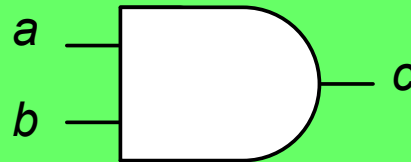
\*erroneous output values highlighted

# Quiz (Revisited)

- (Cont'd from P.3) Manger asked you to pick 2 patterns...

**Q: Based on SSF model, which patterns do you pick ?  
What is maximum fault coverage?**

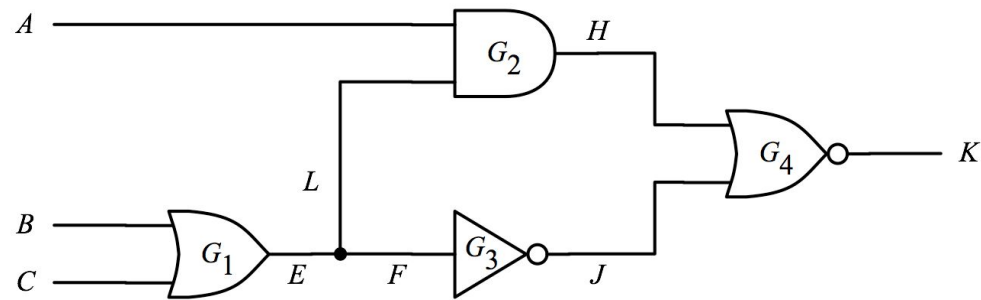
**A:**



Input <i>a b</i>	Fault-free Output	Faulty Output Value with SSF					
		<i>a/0</i>	<i>a/1</i>	<i>b/0</i>	<i>b/1</i>	<i>c/0</i>	<i>c/1</i>
0 0	0	0	0	0	0	0	<u>1</u>
0 1	0	0	<u>1</u>	0	0	0	<u>1</u>
1 1	1	<u>0</u>	1	<u>0</u>	1	<u>0</u>	1
1 0	0	0	0	0	<u>1</u>	0	<u>1</u>

# Fanout Stems and Branches

- SSF on fanout stem **not equivalent to** SSF on fanout branches
  - ♦ Faults on stems and faults on branches are **counted separately**
- Example: **E** is fanout stem; **L, F** are fanout branches
  - ♦ 6 faults are not equivalent



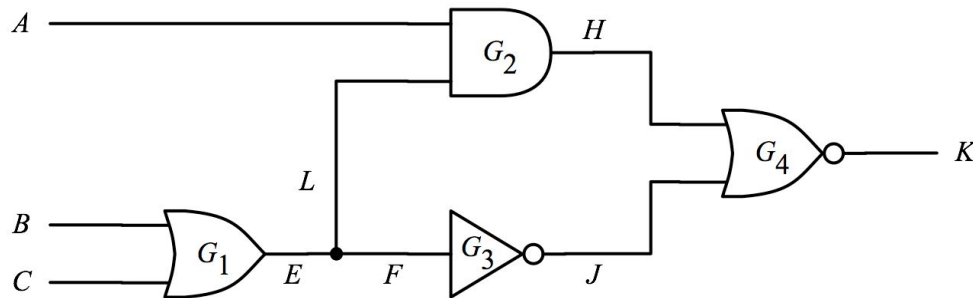
Input			Output						
A	B	C	good	E/0	F/0	L/0	E/1	F/1	L/1
0	0	0	0	0	0	0	<u>1</u>	<u>1</u>	0
0	0	1	1	<u>0</u>	<u>0</u>	1	1	1	1
0	1	0	1	<u>0</u>	<u>0</u>	1	1	1	1
0	1	1	1	<u>0</u>	<u>0</u>	1	1	1	1
1	0	0	0	0	0	0	0	<u>1</u>	0
1	0	1	0	0	0	<u>1</u>	0	0	0
1	1	0	0	0	0	<u>1</u>	0	0	0
1	1	1	0	0	0	<u>1</u>	0	0	0

**Stem Faults  $\neq$   
Branch Faults**

# Quiz

**Q: How many single stuck-at faults in this circuit?**

- A. 8 fault**
- B. 14 faults**
- C. 18 faults**



# Multiple Stuck-at Faults

- **Multiple stuck-at fault (MSF) model**
  - ♦ More than one stuck fault in a circuit
- Quiz

Q: how many multiple stuck-at faults in a circuit of  $n$  nodes?  
(do not include single stuck-at fault)

A:

- Too many MSF, not scalable for large circuits
  - ♦ Fortunately, SSF test set can detect **many** MSF

**MSF Not Considered in Practice**



# Simulation Results [Hughes 86]

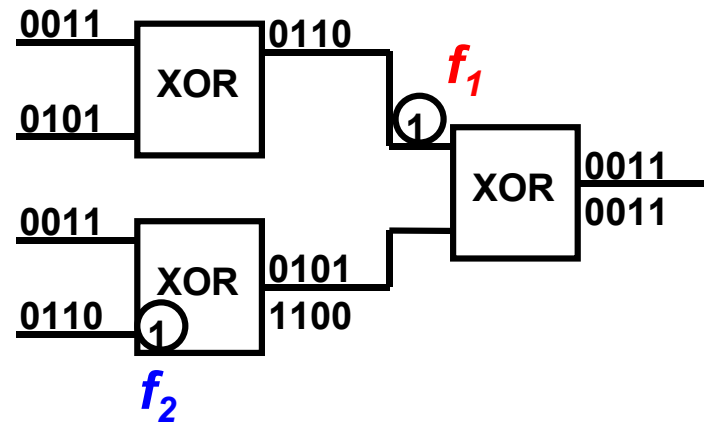
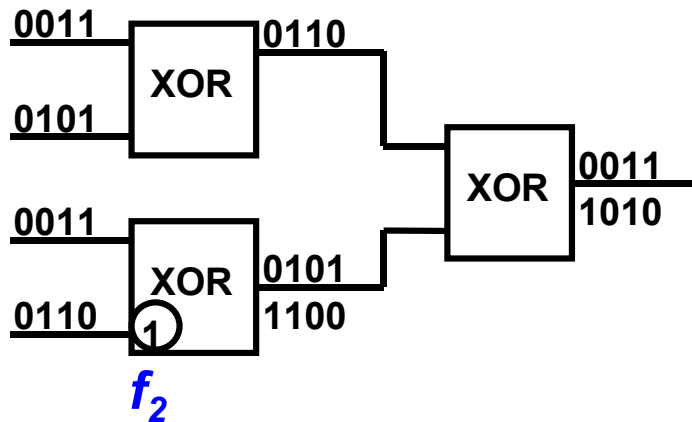
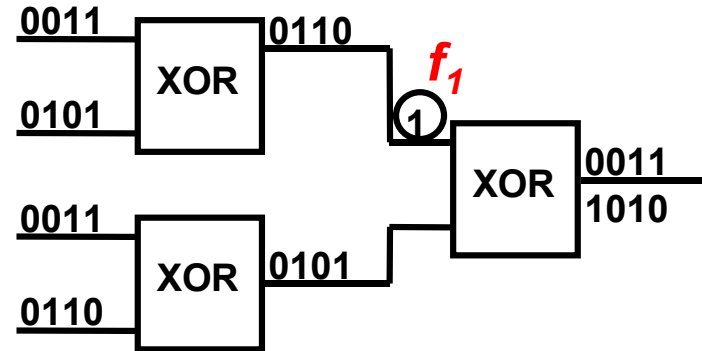
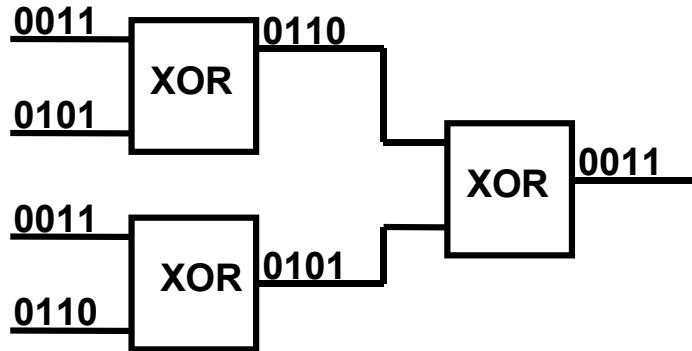
- How effective is SSF test sets for multiple stuck-at faults?
  - ♦ 14-input ALU 74LS181 circuit
  - ♦ 400 single stuck-at faults
  - ♦ 79,600 double stuck-at faults
  - ♦ 16 different test sets

Test Set	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Length	12	12	12	12	12	12	12	14	14	14	14	17	35	124	135	352
Undetected Double-stuck faults	9	8	1	9	28	13	19	4	14	11	3	30	0	0	0	0

- Observation #1: Some shorter tests are **better than** longer tests
  - ♦ Smart test generation/selection is important
- Observation #2: **Most** double SA faults are detected by SSF test sets
  - ♦ But some exceptions (see next slide)

# Why DSF NOT Detected?

- Example: double stuck-at fault not detected by 100% SSF test set



**No fault detected**

# Fault Masking

- Fault  $f_2$  **masks** fault  $f_1$  if
  - ♦ A test for  $f_1$  fails to detect  $f_1$  in the presence of  $f_2$
- When a test fails to detect a fault it is supposed to detect
  - ♦ We call it **test invalidation**
- Fault masking **rarely** happens in practice
  - ♦ Trouble more for **diagnosis** than for testing

**Fault Masking Invalidates Tests**  
**Fault Masking Makes Diagnosis Difficult**

# Fault Modeling

- Fault Models

- ◆ Stuck-at fault

- \* Number of single stuck-at faults is linear to circuit size :  $2n$
- \* Multiple stuck-at faults are exponential in number
- \* Fault masking means two faults cancel each other



# FFT

- Fault masking degrades test effectiveness
  - ♦ does fault masking degrade SSF coverage?

