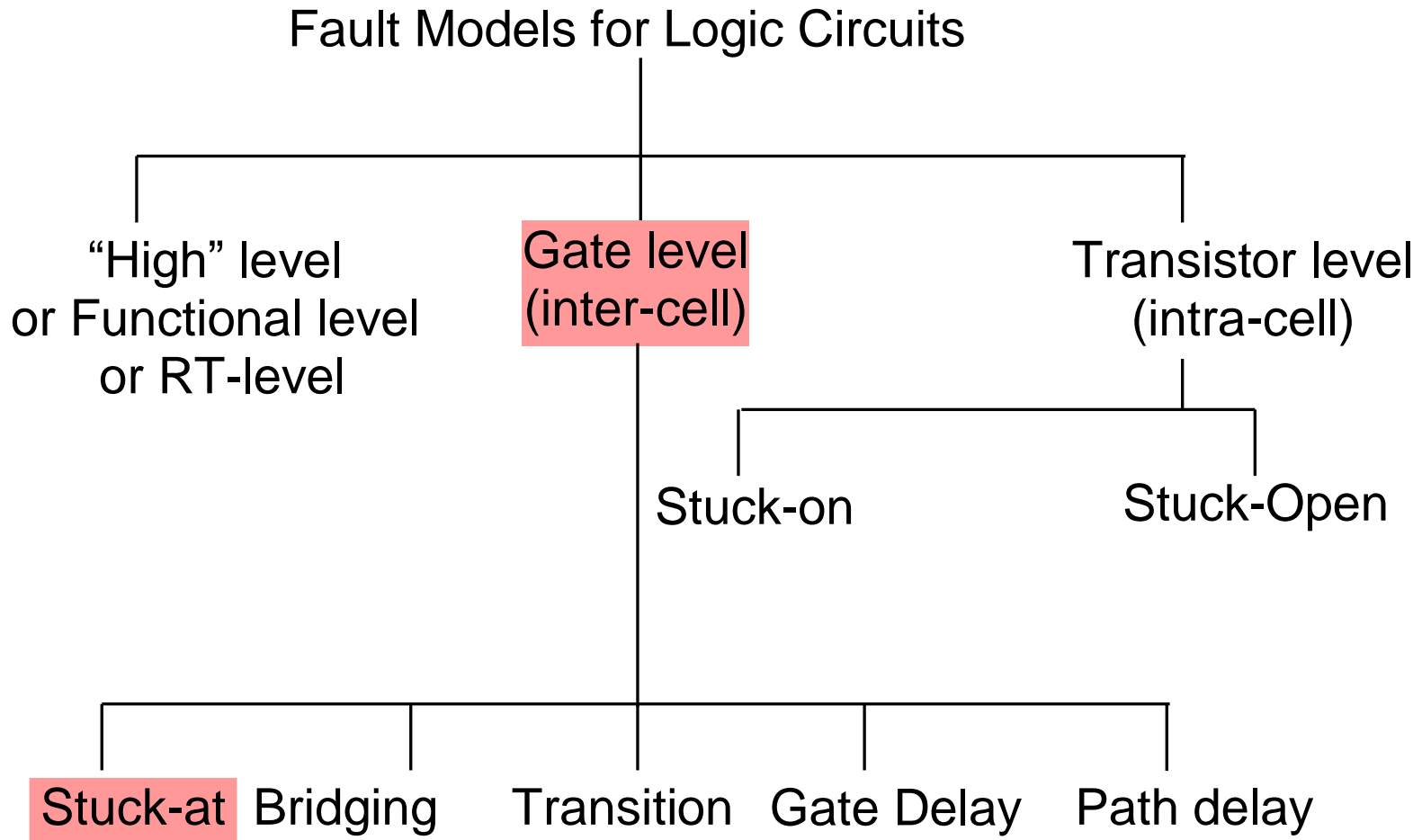# Fault Modeling

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

1

Classification of Fault Models

Fault Models for Logic Circuits

"High" level
or Functional level
or RT-level

Gate level
(inter-cell)

Transistor level
(intra-cell)

Stuck-on

Stuck-Open

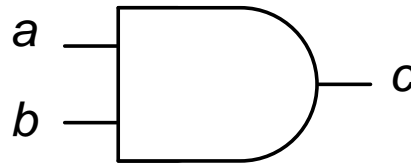Stuck-at   Bridging   Transition   Gate Delay   Path delay

2

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
  - 2*n* SSF in a circuit of *n* nodes
- Most commonly studied fault model

SSF is Scalable for Large Circuits

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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**

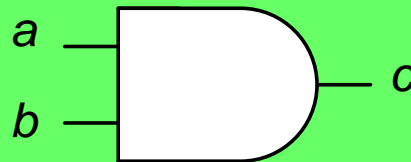| Input	Fault-free	Faulty Output Value with SSF					
a b	Output	a/0	a/1	b/0	b/1	c/0	c/1
0 0	0	0	0	0	0	0	**1**
0 1	0	0	**1**	0	0	0	**1**
1 1	1	**0**	1	**0**	1	**0**	1
1 0	0	0	0	0	**1**	0	**1**

*erroneous output values highlighted

4

Quiz (Revisited)

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

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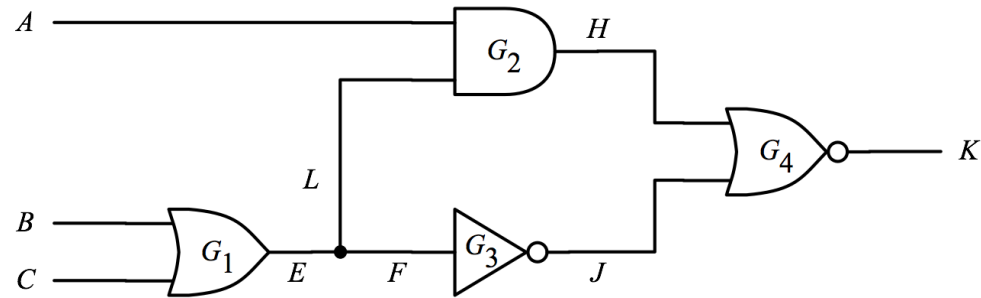   What is maximum fault coverage?**

A:

a —⊐
b —⊐ c

Input	Fault-free	Faulty Output Value with SSF					
$a\ b$	Output	$a/0$	$a/1$	$b/0$	$b/1$	$c/0$	$c/1$
0 0	0	0	0	0	0	0	**1**
0 1	0	0	**1**	0	0	0	**1**
1 1	1	**0**	1	**0**	1	**0**	1
1 0	0	0	0	0	**1**	0	**1**

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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**
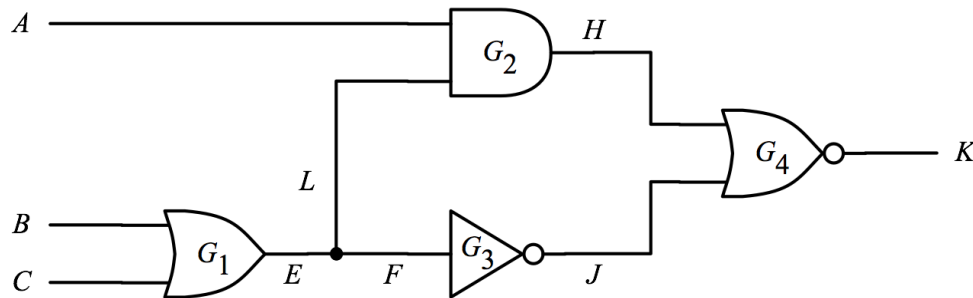 - ♦ **6 faults are not equivalent**

Stem Faults ≠ Branch Faults

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	1	1	0
0	0	1	1	0	0	1	1	1	1
0	1	0	1	0	0	1	1	1	1
0	1	1	1	0	0	1	1	1	1
1	0	0	0	0	0	0	0	1	0
1	0	1	0	0	0	1	0	0	0
1	1	0	0	0	0	1	0	0	0
1	1	1	0	0	0	1	0	0	0

6

Quiz

Q: How many single stuck-at 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 may MSF, not scalable for large circuits
  - ♦ Fortunately, SSF test set can detect many MSF

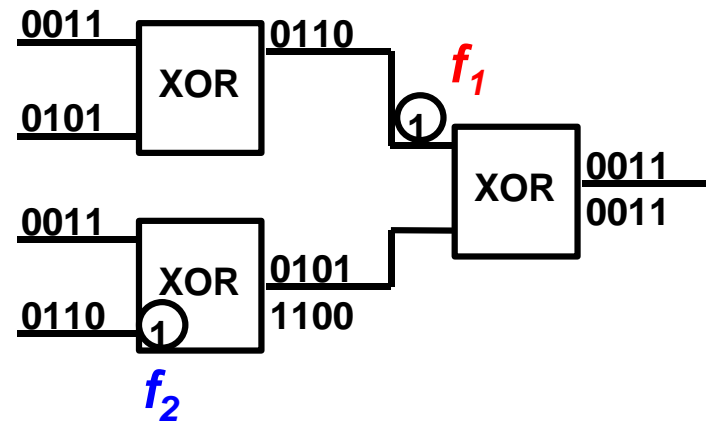## MSF Not Considered in Practice
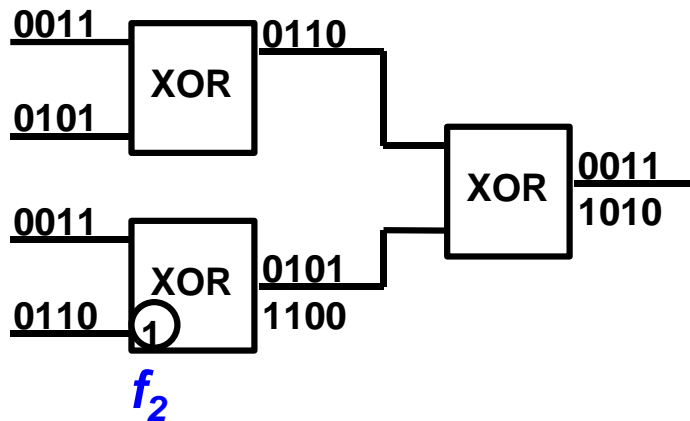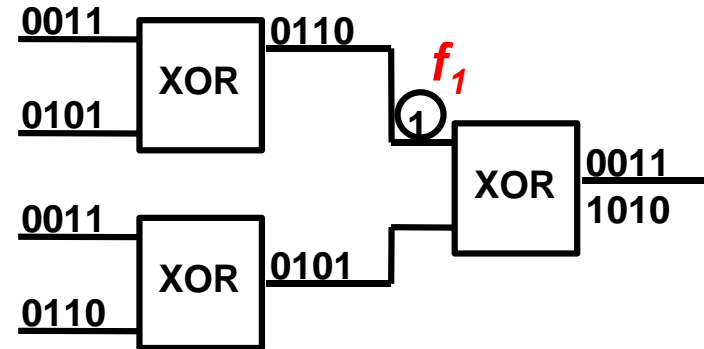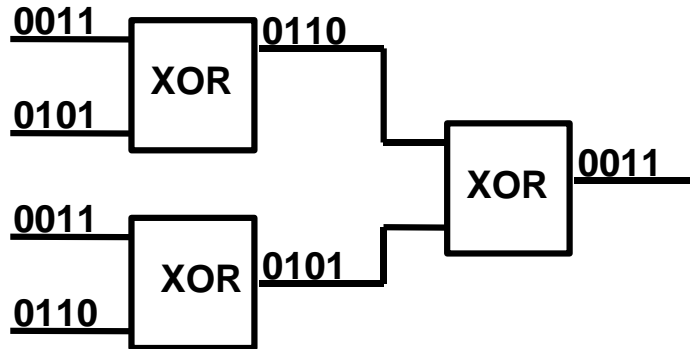
Simulation Results [Hughes 86]

- **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)**

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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**

<div style="border:1px solid red; color:red; text-align:center; font-weight:bold">

Fault Masking Invalidates Tests
Fault Masking Makes Diagnosis Difficult

</div>

11

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?**