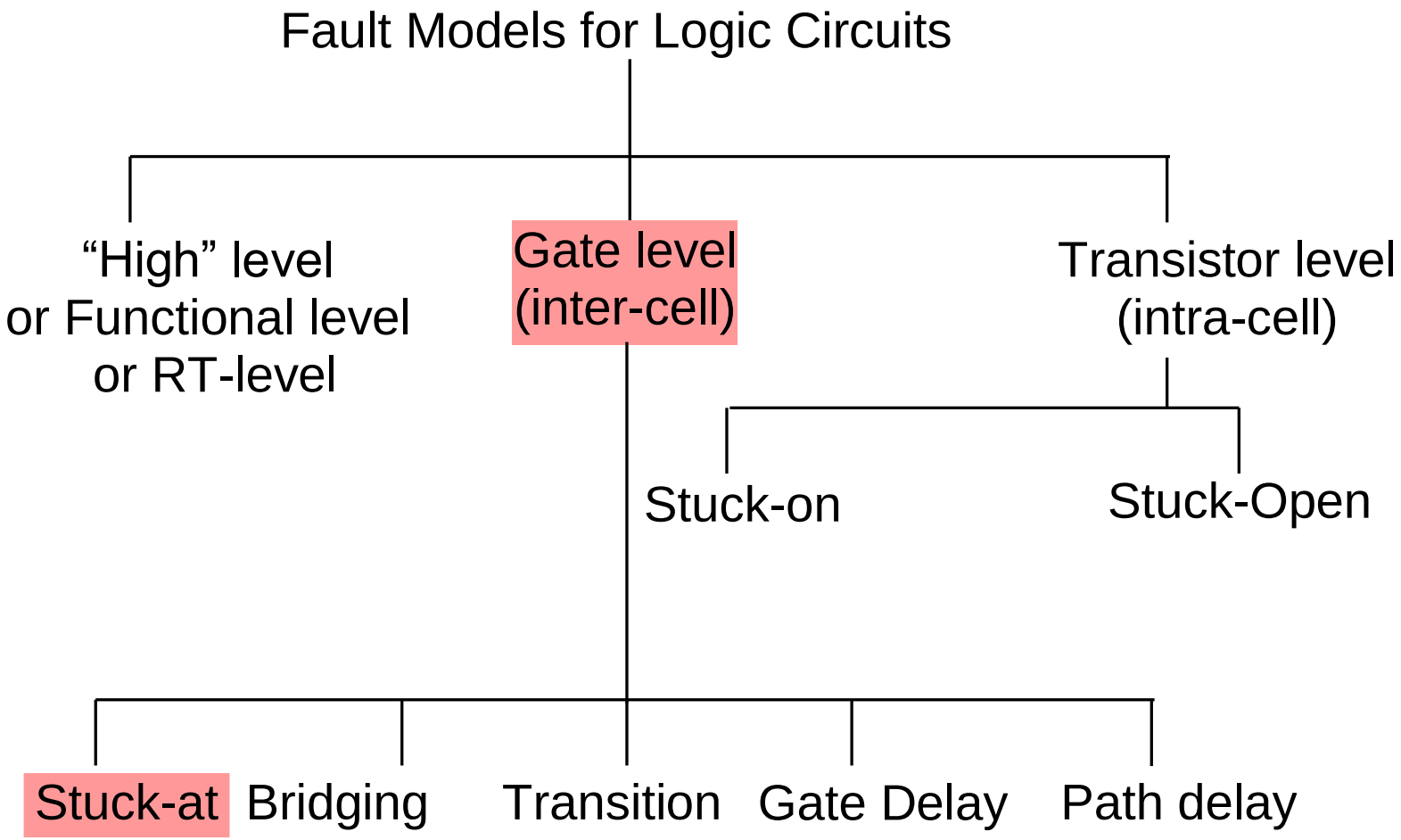
Fault Modeling

- 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



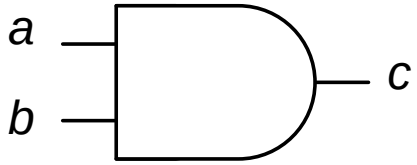
Single Stuck-at Fault Model

- *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
  - 2*n* 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	Fault-free Output	Faulty Output Value with SSF					
a b		*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**

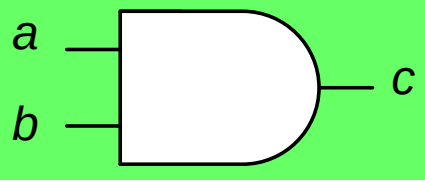
***erroneous output values highlighted**

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?

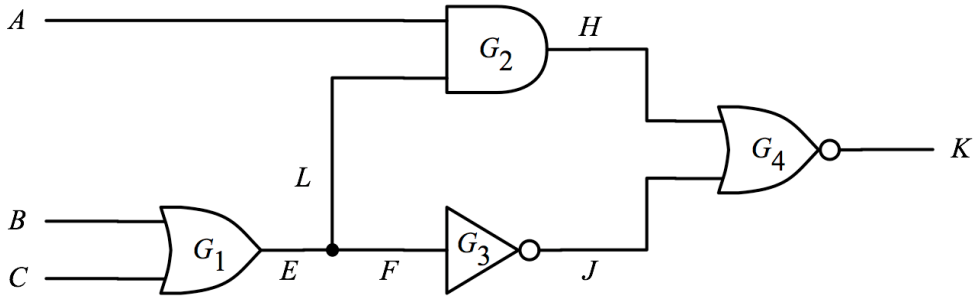
A:



Input	Fault-free Output	Faulty Output Value with SSF					
a b		*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**

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



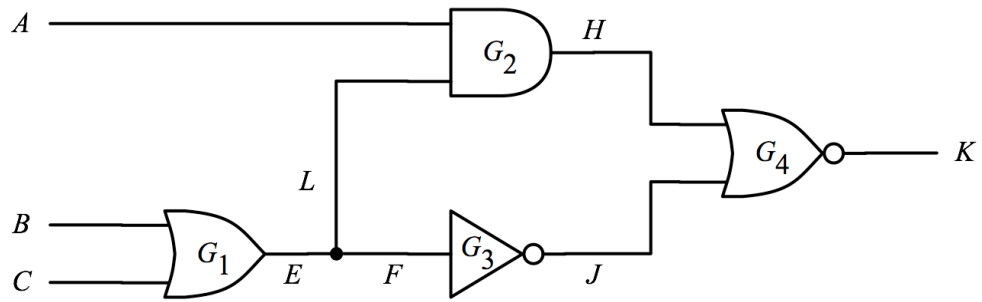
Input			Output						
A	*B*	*C*	good	*E/0*	*F/0*	*L/0*	*E/1*	*F/1*	*L/1*
0	0	0	0	0	0	0	1	1	0
0	0	1	1	0	0	1	1	1	1
0	1	0	1	0	0	1	1	1	1
0	1	1	1	0	0	1	1	1	1
1	0	0	0	0	0	0	0	1	0
1	0	1	0	0	0	1	0	0	0
1	1	0	0	0	0	1	0	0	0
1	1	1	0	0	0	1	0	0	0

Stem Faults ≠ Branch Faults

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]

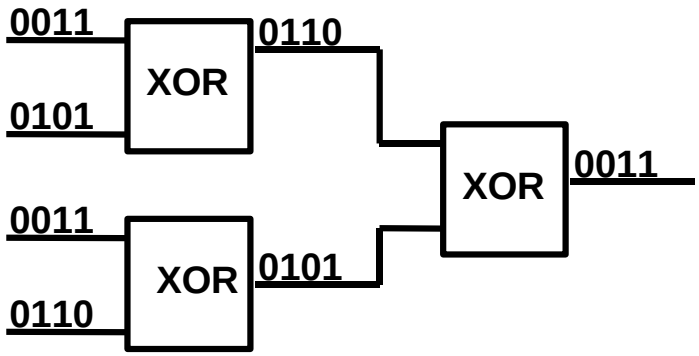
- How effective is SSF test sets for multiple stuck-at faults?
  - 14-input ALU 74LS181 circuit
  - 400 single stuck-at faults
  - 79,600 double stuck-at faults
  - 16 different test sets

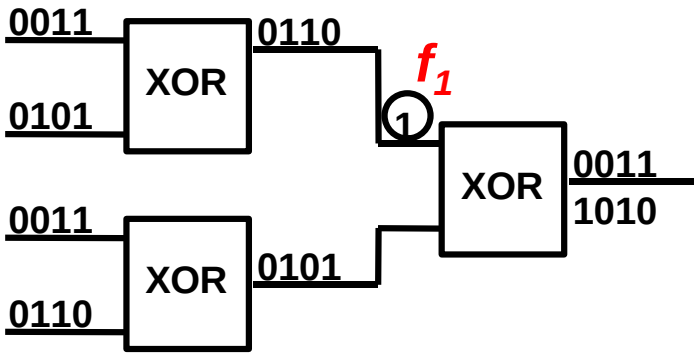
Test Set	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Length	12	12	12	12	12	12	12	14	14	14	14	17	35	124	135	352
Undetected Double-stuck faults	9	8	1	9	28	13	19	4	14	11	3	30	0	0	0	0

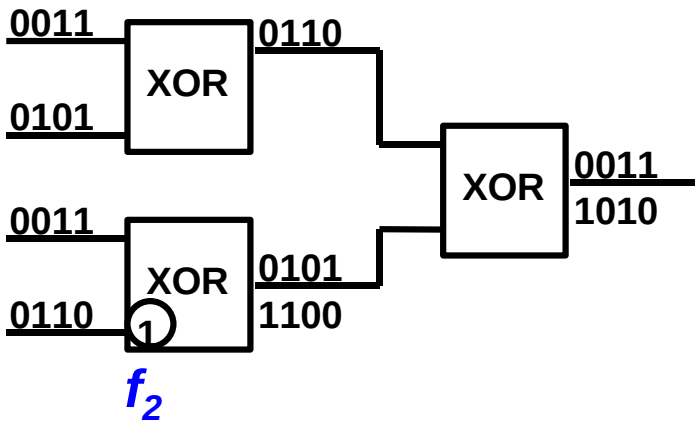
- Observation #1: Some shorter tests are better than longer tests
  - Smart test generation/selection is important
- Observation #2: Most double SA faults are detected by SSF test sets
  - But some exceptions (see next slide)

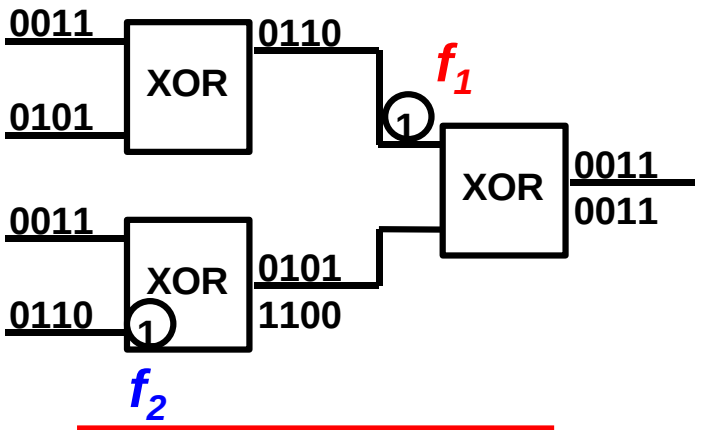
Why DSF NOT Detected?

- **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?**