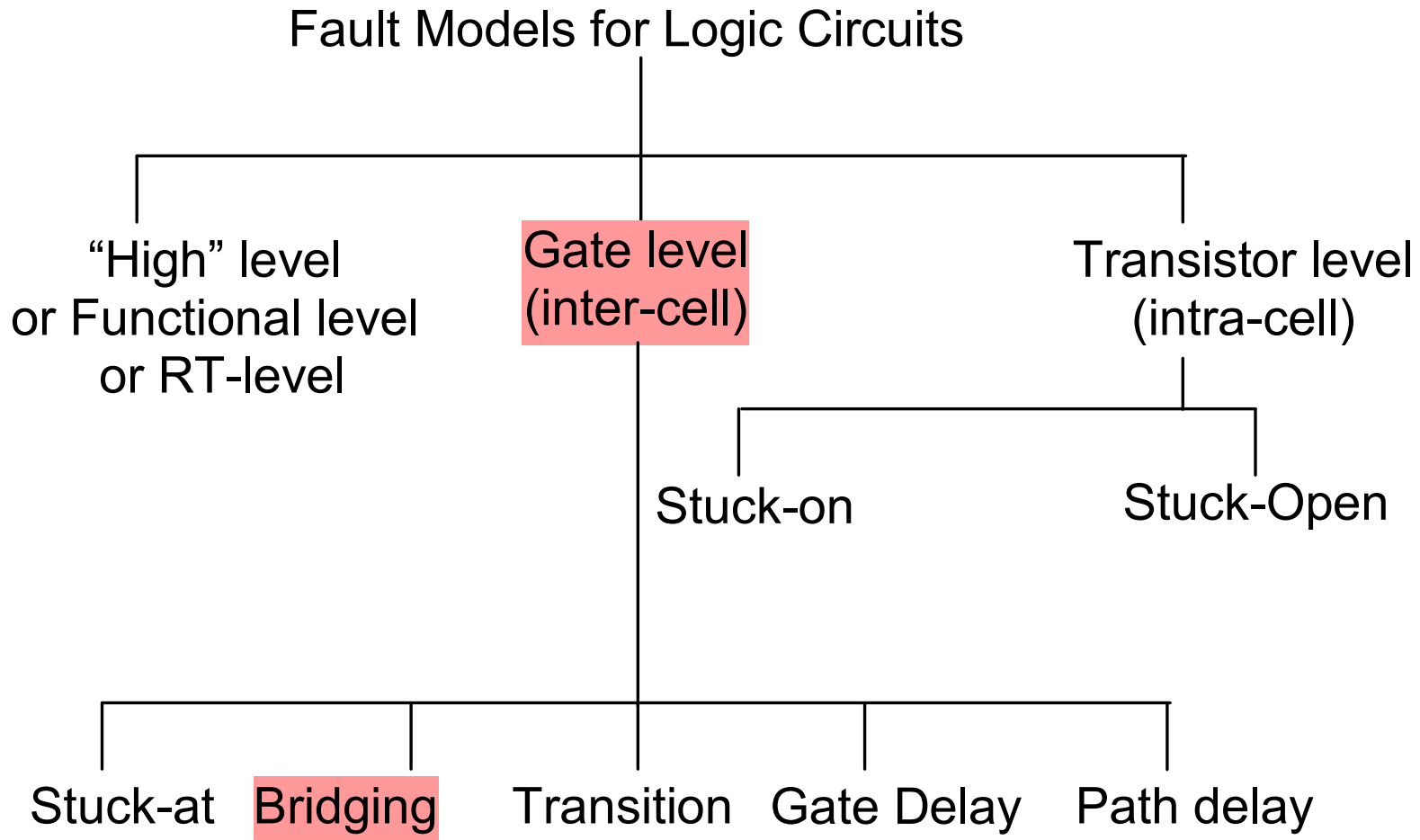


Fault Modeling

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

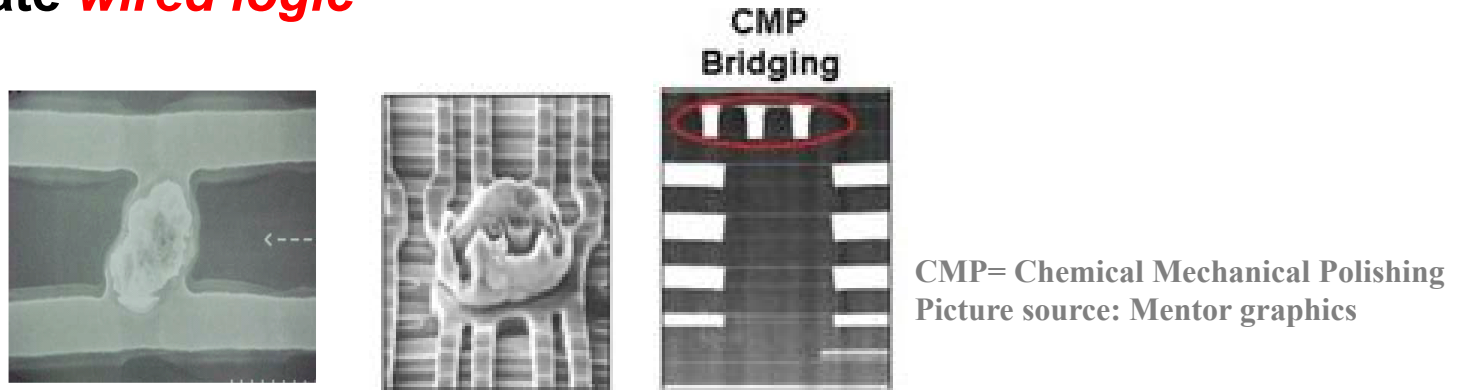


Classification of Fault Models



Bridging Faults (BF) [Williams 73][Friedman 74]

- Definition:
 - ◆ Two (or more) distinct logic signals unintended shorted together and create *wired logic*



- Q: How many **two-way BF** in a circuit of n signals?
 - ◆ Arbitrary choose two signals: $C^n_2 = O(n^2)$. too many!
 - ◆ Need to identify pairs of neighbor signals **from layout**
 - * *Fault extraction*

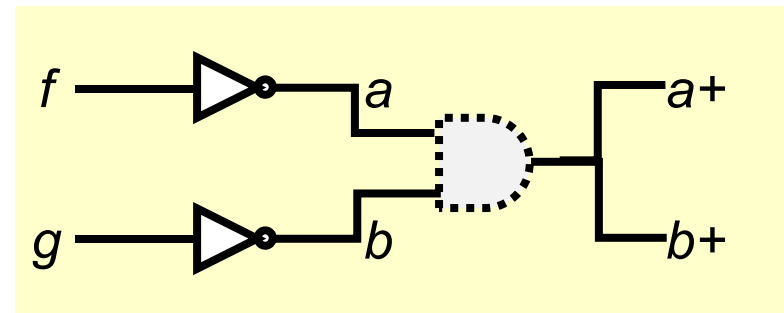
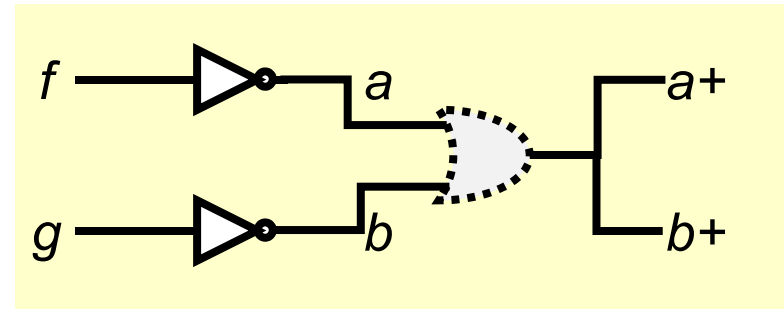
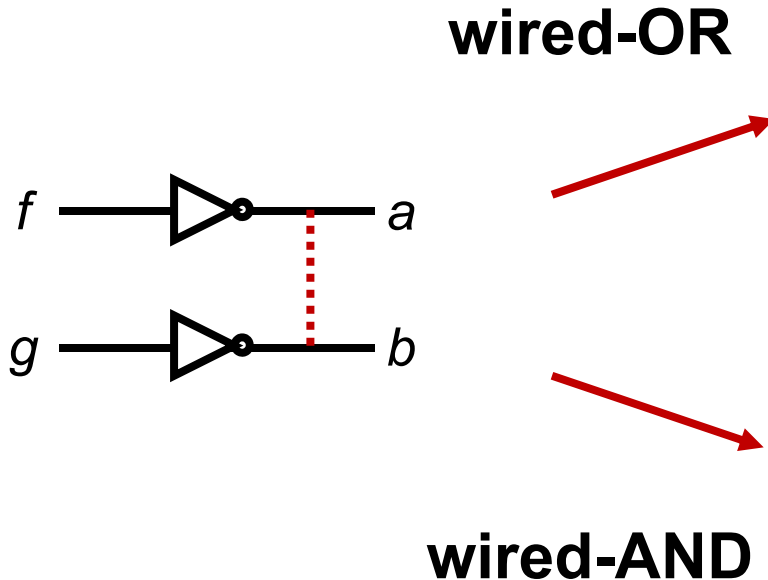
Number of Bridging Faults is $O(n^2)$

Bridging Fault Models

- Popular models for CMOS

- ♦ **Wired-OR** (1-dominant)
- ♦ **Wired-AND** (0-dominant)
- ♦ **A-dominant**

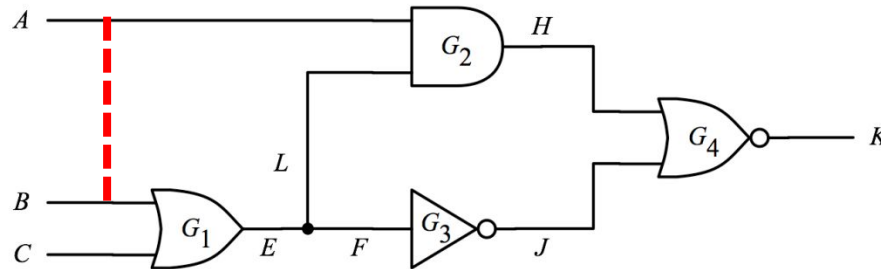
original a b	Wired-OR a ⁺ b ⁺	Wired-AND a ⁺ b ⁺	a-dominant a ⁺ b ⁺
0 0	0 0	0 0	0 0
0 1	<u>1</u> 1	0 <u>0</u>	0 <u>0</u>
1 0	1 <u>1</u>	<u>0</u> 0	1 <u>1</u>
1 1	1 1	1 1	1 1



Wired Logic Is Imaginary, not Real

Different Models Need Different Patterns

- Consider (A, B) bridging fault
 - Wired-AND, Wired-OR detected by **011**, or **010**
 - A-dominant model detected only by **010**

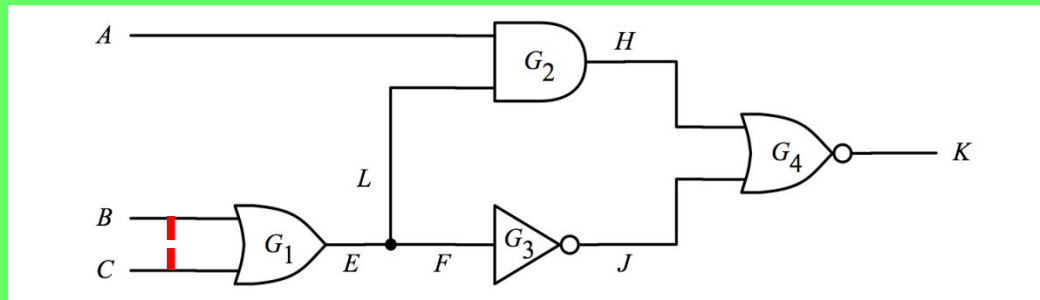


Inputs A B C	Fault-free Output	Wired- OR	Wired- AND	A- dominant
0 0 0	0	0	0	0
0 0 1	1	1	1	1
0 1 0	1	<u>0</u>	<u>0</u>	<u>0</u>
0 1 1	1	<u>0</u>	<u>0</u>	1
1 0 0	0	0	0	0
1 0 1	0	0	0	0
1 1 0	0	0	0	0
1 1 1	0	0	0	0

Quiz

Q1: Fill in table with (B,C) bridging fault.

Q2: Which test pattern detects wired-OR fault?



Inputs A B C	Fault-free Output	Wired- OR	Wired- AND	B- dominant
0 0 0	0	0	0	0
0 0 1	1			
0 1 0	1			
0 1 1	1			
1 0 0	0			
1 0 1	0			
1 1 0	0			
1 1 1	0			

SSF Test Sets Not Good Enough

- How effective is SSF test sets for bridging faults? [Millman 88]
 - ◆ 74LS181 ALU, 100% fault coverage SSF test sets
 - * Total **7,981** testable bridging faults

Test set	Bry2	Bry6	Goel	Hugh	Krish	McC4	Micz2
Test Length	14	12	35	135	12	124	17
# of missed BF	111	138	15	2	171	13	85
missed BF %	1.39	1.73	0.19	0.03	2.14	0.16	1.07

Some BF not Detected by SSF Test Sets

Feedback Bridging Faults

- **Type1: creates memory**

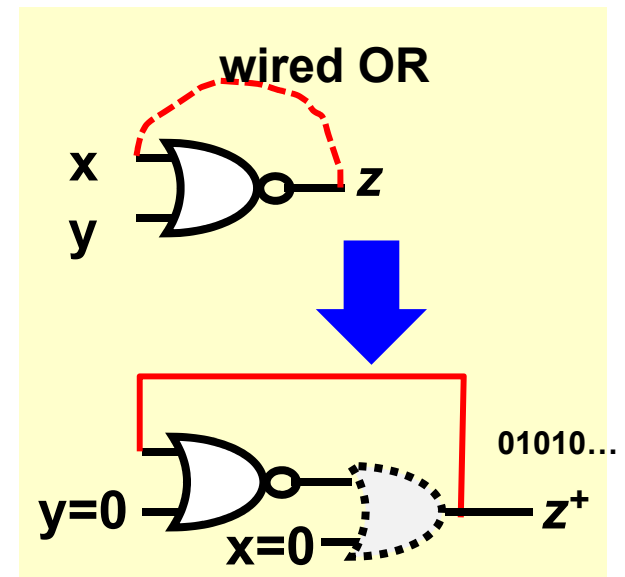
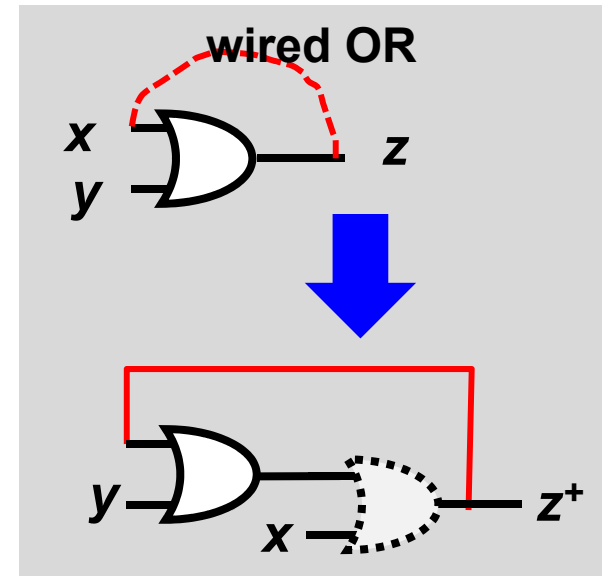
- ◆ Detected by *test sequence* **01→00**

Inputs x y	Fault-free Output	Faulty Output
0 0	0	<u>unchanged</u>
0 1	1	1
1 0	1	1
1 1	1	1

- **Type2: creates oscillation**

- ◆ “hard” detected by **10**, or **11**
 - ◆ “potentially” detected by **00**

Inputs x y	Fault-free Output	Faulty Output
0 0	1	oscillation
0 1	0	0
1 0	0	<u>1</u>
1 1	0	<u>1</u>

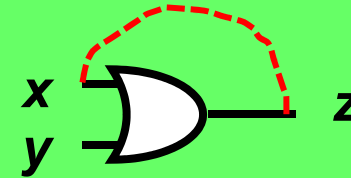


Quiz

Q1: Fill in table with a Wired-AND feedback BF (x, z)

A:

Inputs $x\ y$	Fault-free Output	Faulty Output
0 0	0	
0 1	1	
1 0	1	
1 1	1	

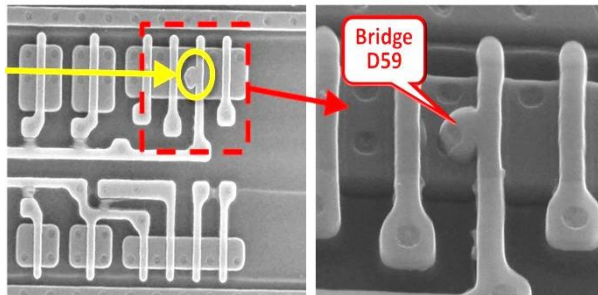


Q2: Find a test to detect this feedback BF

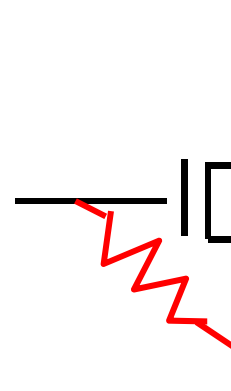
A:

What are NOT Bridging Fault?

- ① BF does NOT consider shorts to **power** and **ground**
- ② BF does NOT consider **defect resistance value**
- ③ BF does NOT consider **Intra-cell** (intra-gate) defects
 - ◆ BF is **gate-level**, NOT **transistor-level** fault model



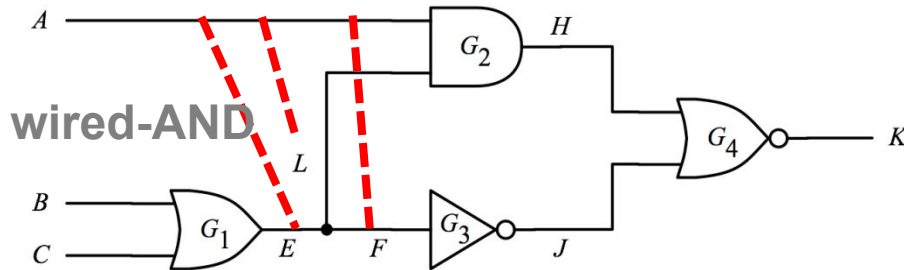
Intra-gate bridging defect
[Mentor graphics]



- ④ BF does NOT distinguish between **fanout stem** and **branches**
 - ⑤ BF is **NOT transient** fault
- (4, 5 see next slides)

Fanout Stem and Branches

- SSF on fanout stem and branches are **different** (see 3.2)
- BF on fanout stem and branches **are the same**
- Example: wired-AND model
 - ♦ $(A,E) = (A,L) = (A,F)$
 - ♦ Why? FFT

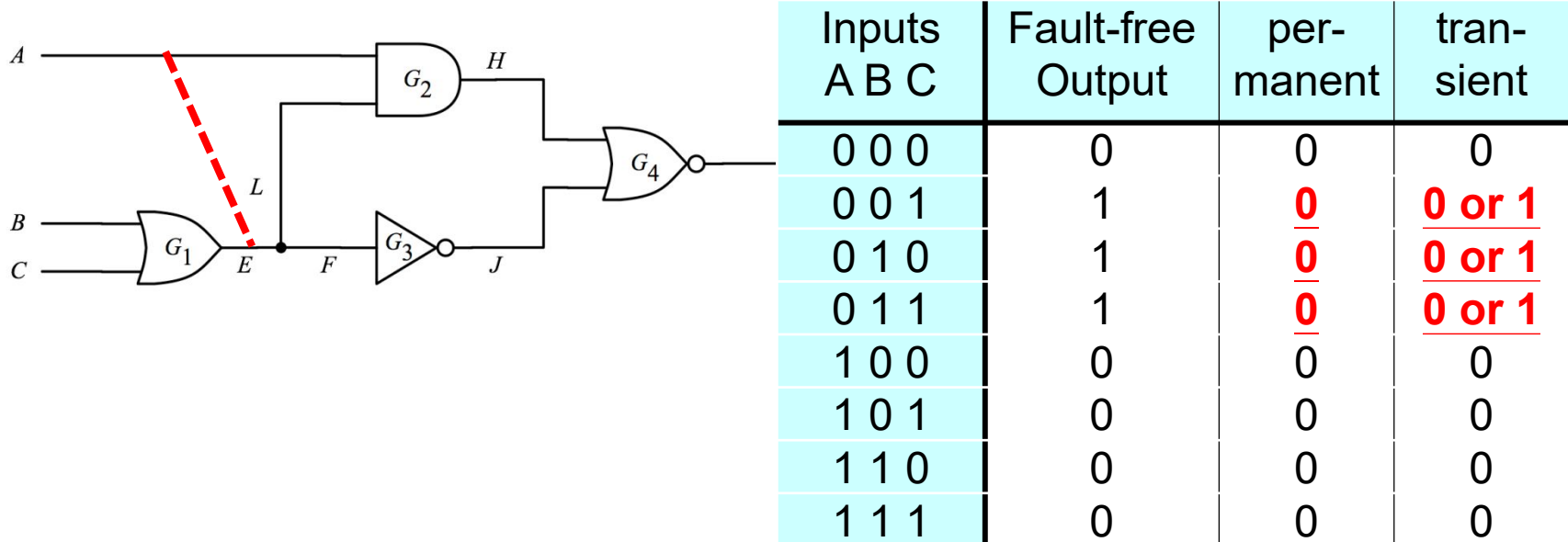


Inputs A B C	Fault-free Output	BF (A,E)	BF (A,L)	BF (A,F)
0 0 0	0	0	0	0
0 0 1	1	<u>0</u>	<u>0</u>	<u>0</u>
0 1 0	1	<u>0</u>	<u>0</u>	<u>0</u>
0 1 1	1	<u>0</u>	<u>0</u>	<u>0</u>
1 0 0	0	0	0	0
1 0 1	0	0	0	0
1 1 0	0	0	0	0
1 1 1	0	0	0	0

BF on Stem and Branches Are Same

Permanent Faults vs. Transient Faults

- **Permanent faults:** faults always present
 - ♦ caused by defects
 - ♦ e.g. bridging faults caused by particle defects
- **Transient faults:** faults not always present
 - ♦ induced by **environmental (EMI)** or **internal (IR drop...)** disturbance
 - ♦ e.g. crosstalk faults caused by coupling effect



Summary

- Bridging fault models for CMOS
 - ♦ **Wired-OR, wired-AND, A-dominant**
- Number of bridging faults is $O(n^2)$. too many!
 - ♦ Needs **fault extraction** from layout
- SSF test set may not good enough to detect all BF
 - ♦ **Feedback BF** may cause **memory** or **oscillation**
- BF model does NOT distinguish **fanout stem and branches**
- BF is **permanent fault** ; crosstalk fault is **transient fault**



FFT

- BF does *NOT* distinguish fanout stem and branches
 - ♦ $(A,E) = (A,L) = (A,F)$
- FFT: BF is unlike SSF, why?
 - ♦ $E \text{ SA1} \neq F \text{ SA1} \neq L \text{ SA1}$ (see 3.2)

