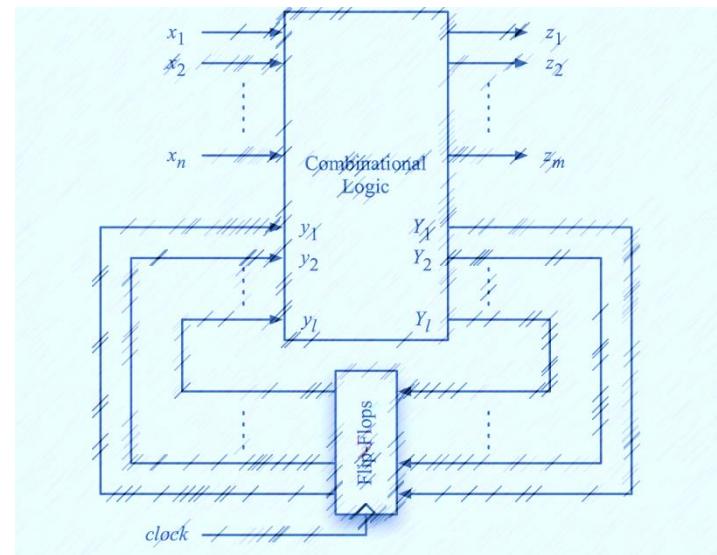


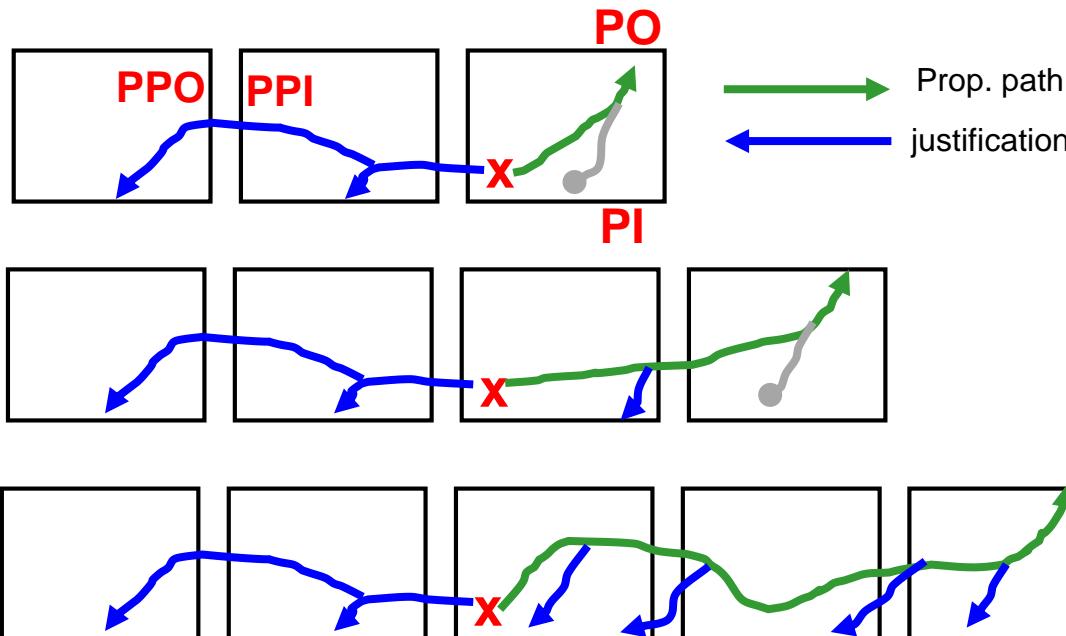
Sequential ATPG

- Introduction
- Time-frame expansion methods
 - ◆ The Extended D-algorithm [Kubo 68]
 - ◆ 9-valued D algorithm [Muth 76]
 - ◆ Backward Time Frame Processing* (not in exam)
 - EBT [Marlett 78]
 - BACK [Cheng 88]
 - ◆ Simulation-based methods*
- Issues of Sequential ATPG*
- Conclusions



Problems of Ext. D-Algorithm

- **Mixed Forward and Backward Time Frame Processing**
 - ◆ Reuse existing D-algorithm
 - both **forward** fault propagation and **backward** justification
 - ◆ How many time frames ?
 - Memory requirement **hard to predict**



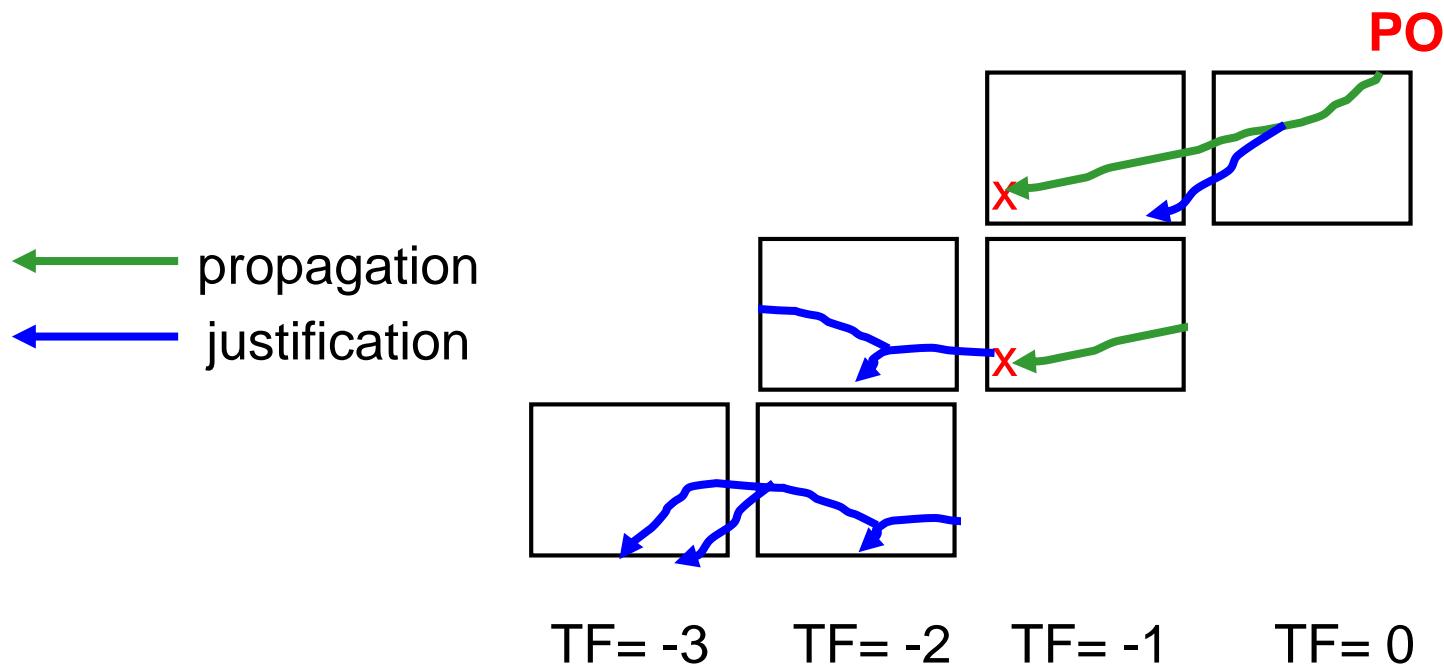
Justification fails,
Backtrack!

Justification fails,
Backtrack!

Test generated

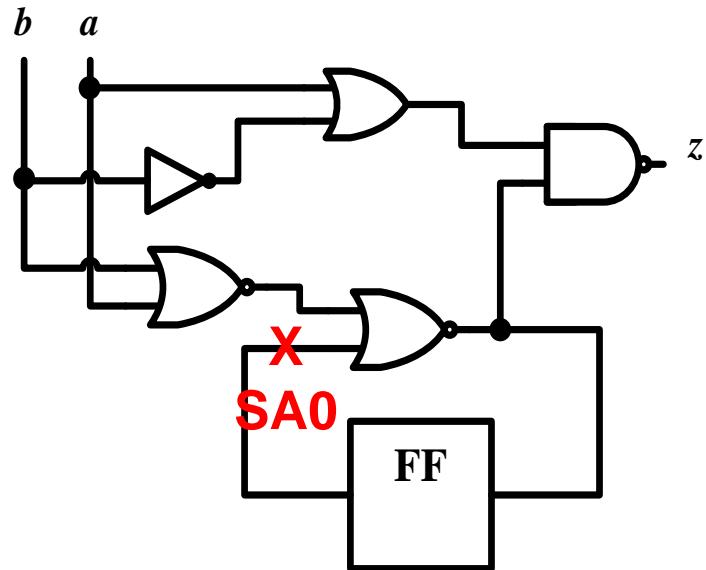
Extended Backtrace (EBT) [Marlett 78]

- **Backward Time Frame Processing Only**
 - ◆ 1. Select a **path** from fault site to PO
 - ◆ 2. **Sensitize path backwards** from the PO
 - ◆ 3. **Justify** required values **backward**
 - If justification fails, choose another path
- Advantage: only two time frames needed

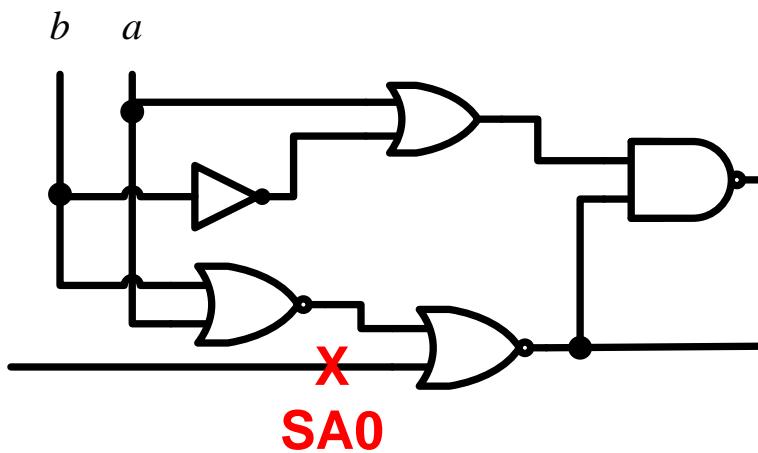


EBT Example

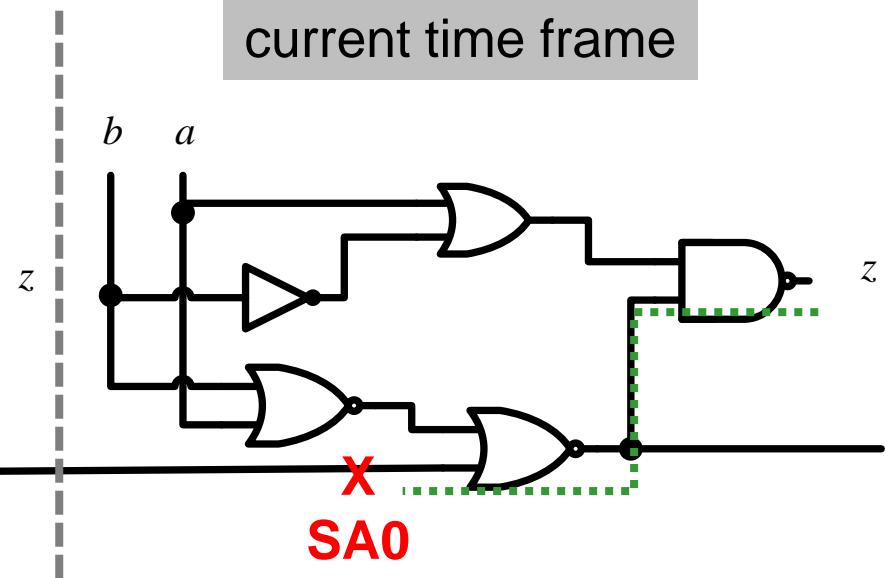
- 1. Create two time frames
- 2. Choose a path

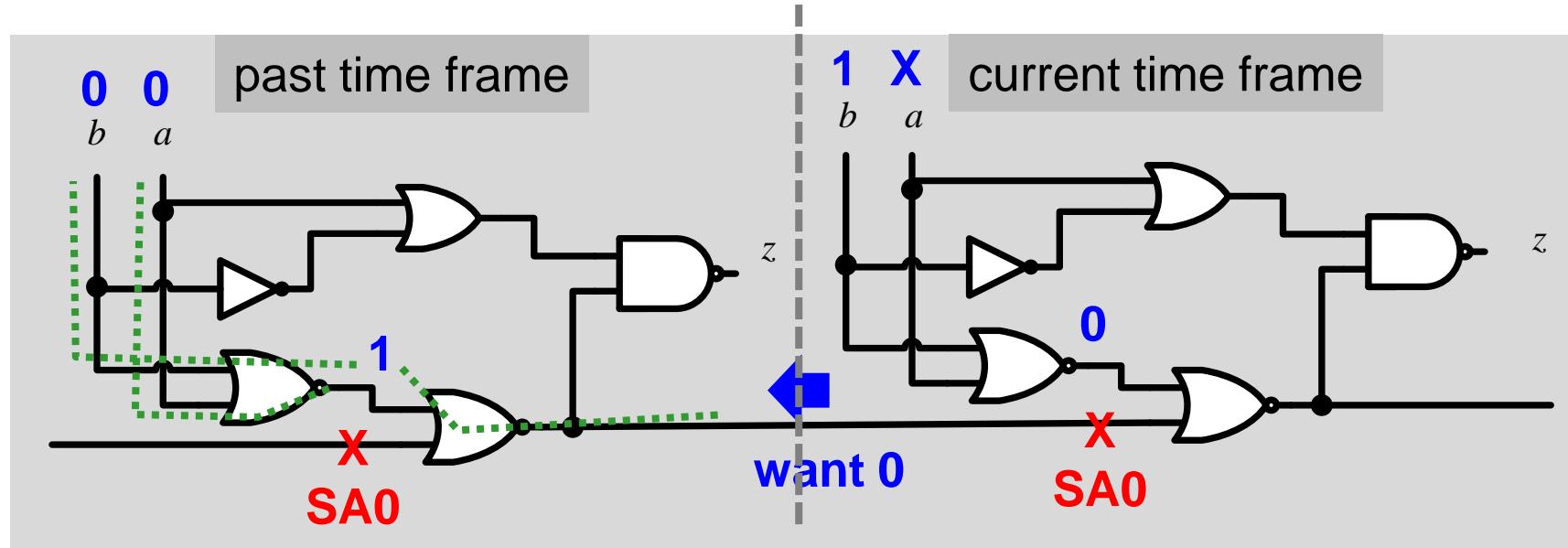
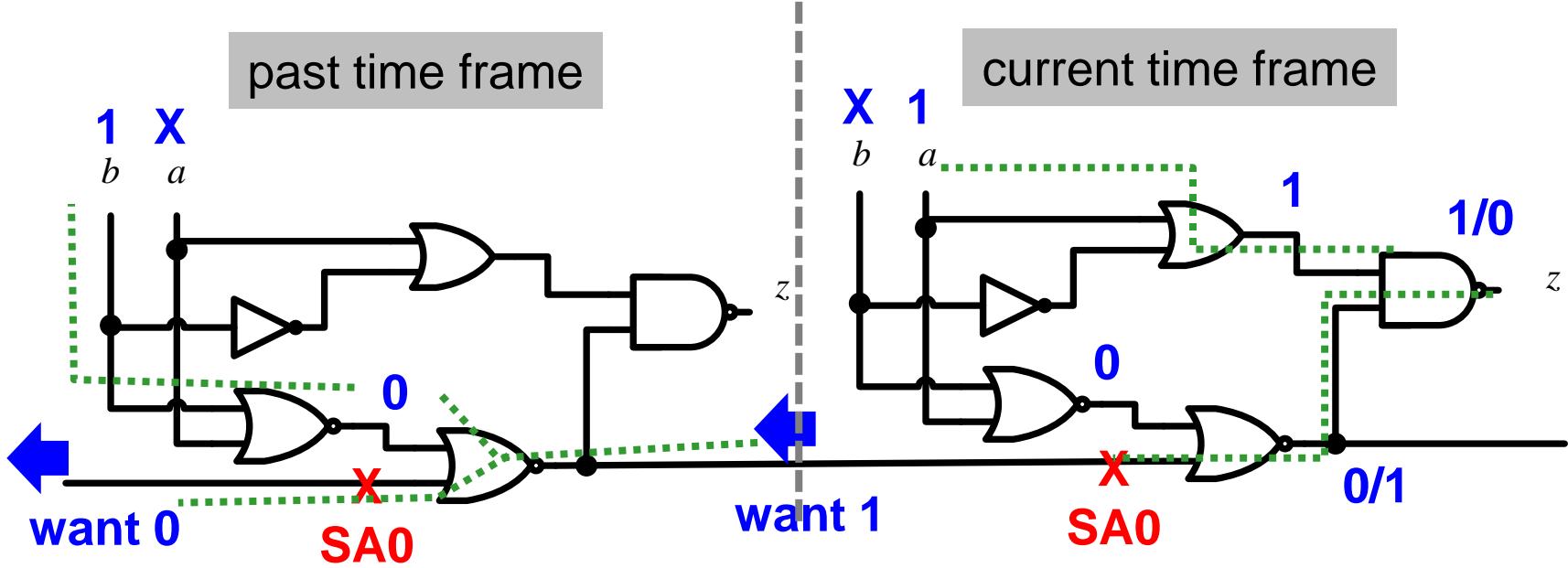


past time frame



current time frame

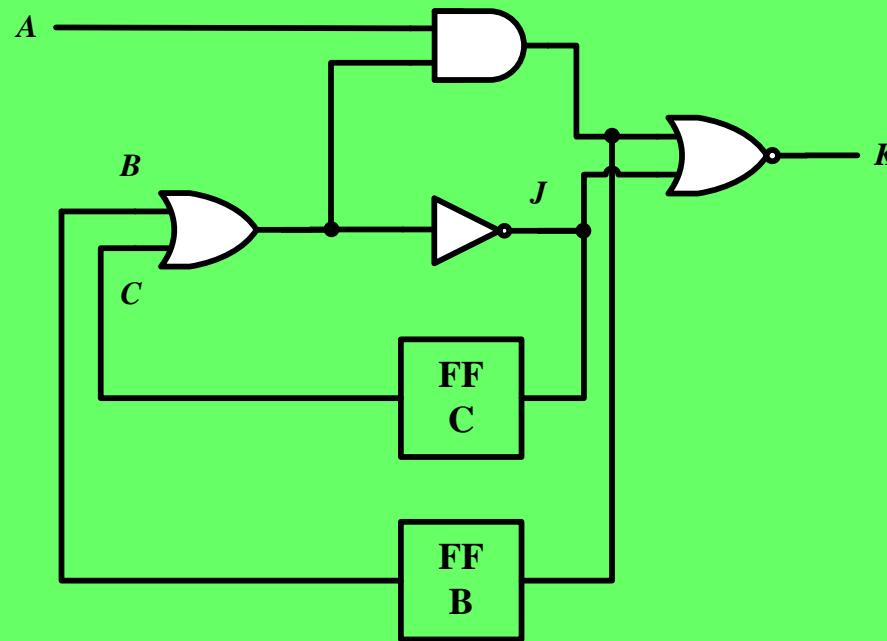




ab = 00, 1x, x1

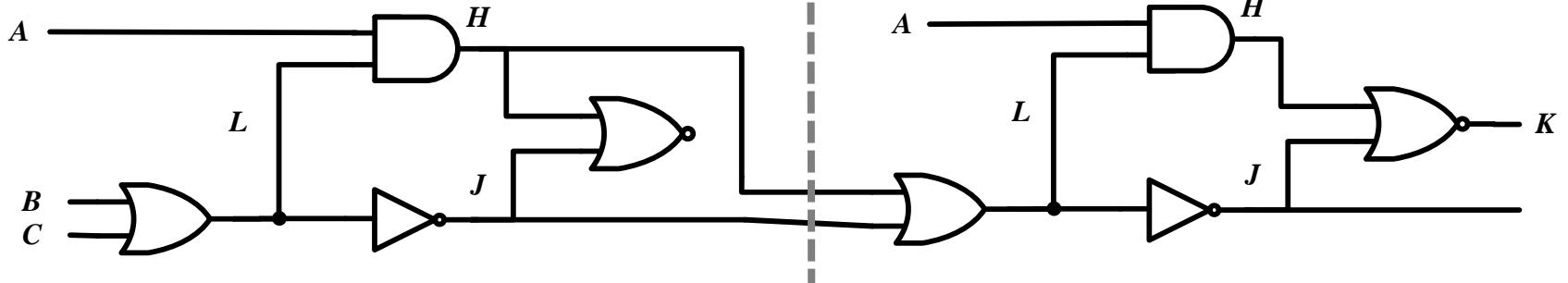
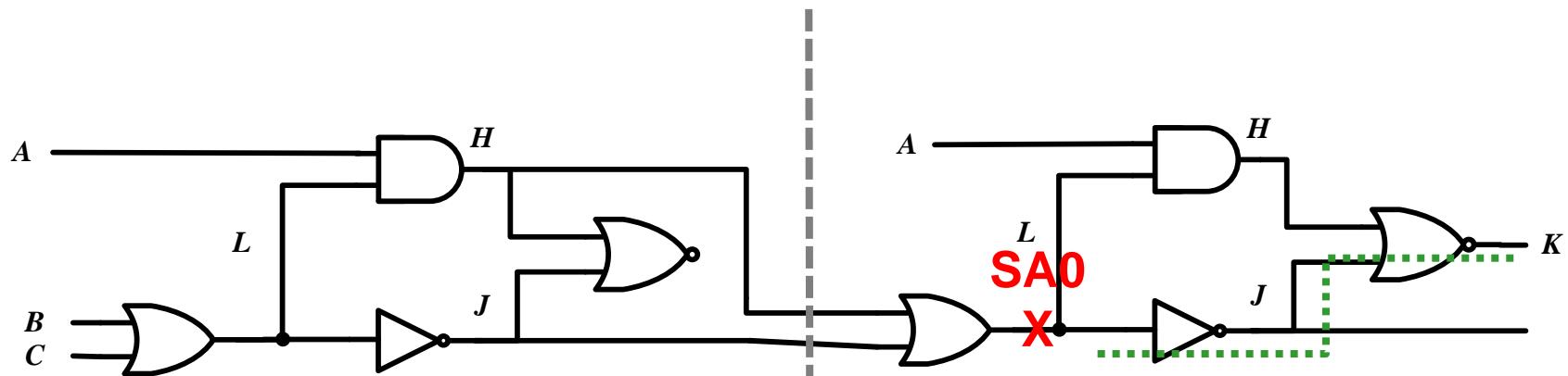
Quiz

Q: Please redraw this into two time frames

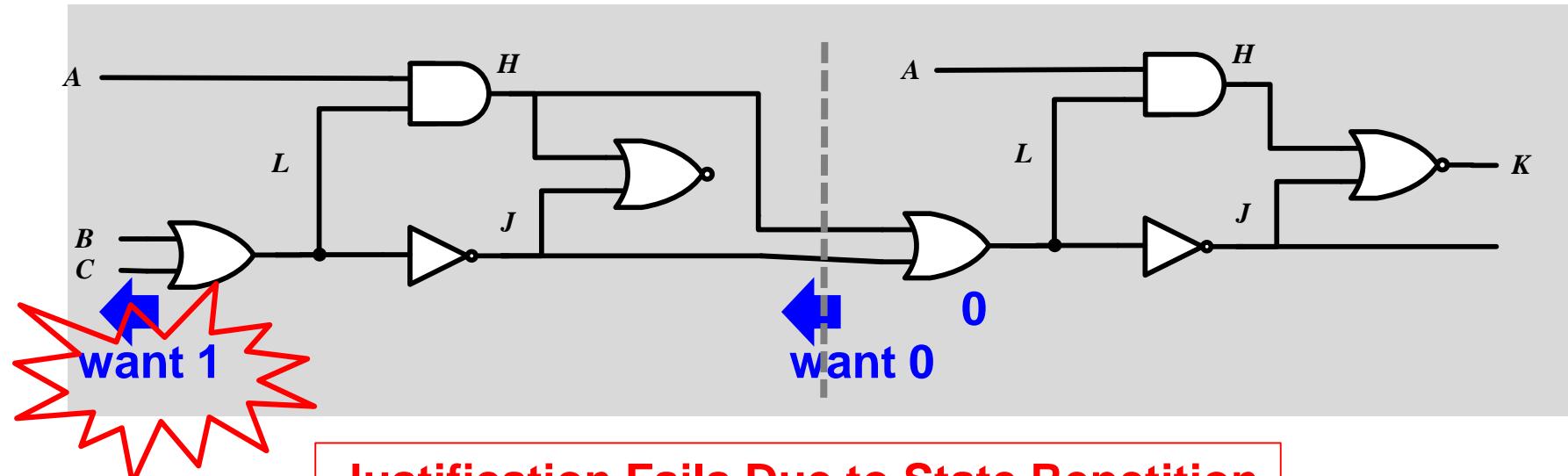
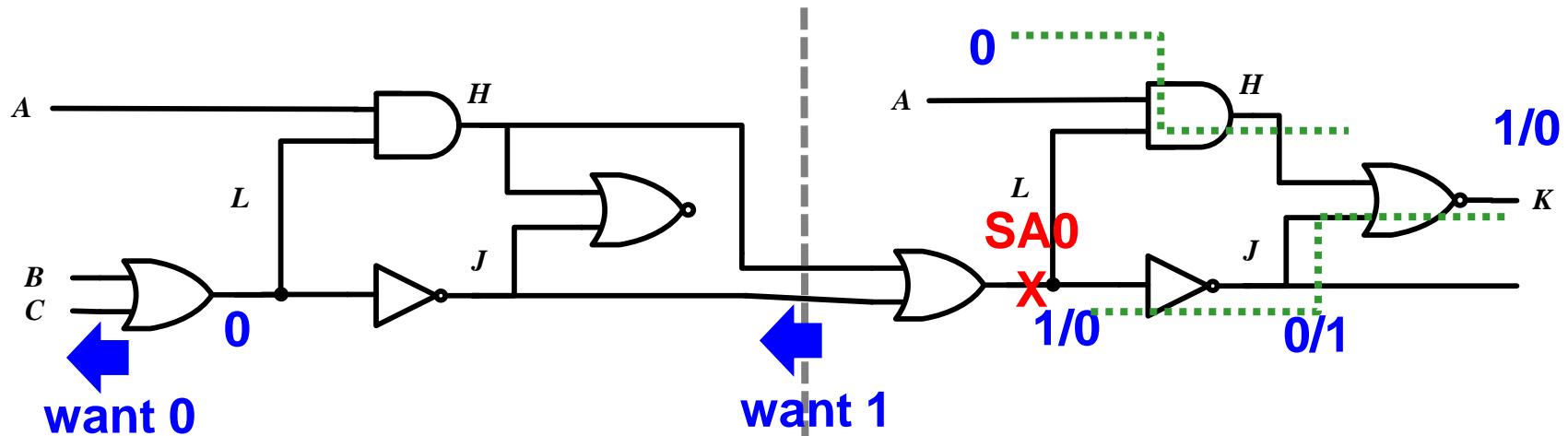


Quiz (cont'd)

Q: Use EBT to generate test patterns for SA0 fault



State Repetition



Justification Fails Due to State Repetition

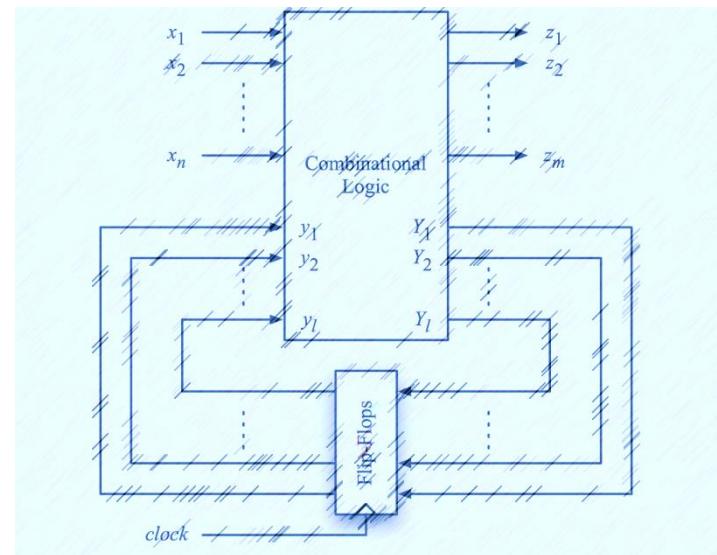
Comparison

	Advantages	Disadvantages	Example
Mixed F/B Time Frame	😊 Reuse existing D algorithm	😢 Too many time frames	Extended D
Backward TF Only	😊 Fixed time frames 😊 State repetition recognized	😢 Too many paths! How to choose path?	EBT

Need Help to Make Smart Decision

Sequential ATPG

- Introduction
- Time-frame expansion methods
 - ◆ The Extended D-algorithm [Kubo 68]
 - ◆ 9-valued D algorithm [Muth 76]
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 - ◆ Simulation-based methods*
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- Conclusions



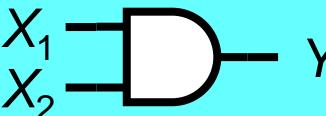
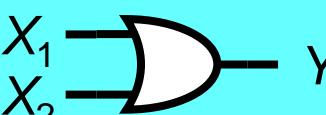
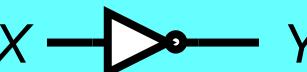
BACK Algorithm [Cheng 88]

- BACK selects a **PO** for fault detection,
 - ◆ Do not explicitly select a *path*
- PO selection based on a testability measures
 - ◆ *Drivability*
- Sensitized path will be created implicitly when drivability calculation

BACK Chooses PO Instead of Path

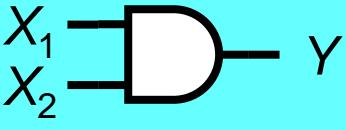
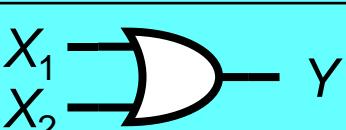
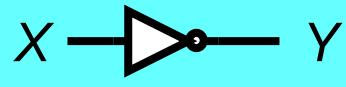
Review: SCOAP (CH 6)

- $CC^0(N)$, $CC^1(N)$
 - ◆ Minimum number of combinational PI assignments and logic levels required to control a 0 or a 1 on node N
 - ◆ Estimates effort to control signal to zero or one
 - Smaller number, easier to control

	$CC^0(Y)$	$CC^1(Y)$
	$\min[CC^0(X_1), CC^0(X_2)] + 1$	$CC^1(X_1) + CC^1(X_2) + 1$
	$CC^0(X_1) + CC^0(X_2) + 1$	$\min[CC^1(X_1), CC^1(X_2)] + 1$
	$CC^1(X) + 1$	$CC^0(X) + 1$
Primary inputs	1	1

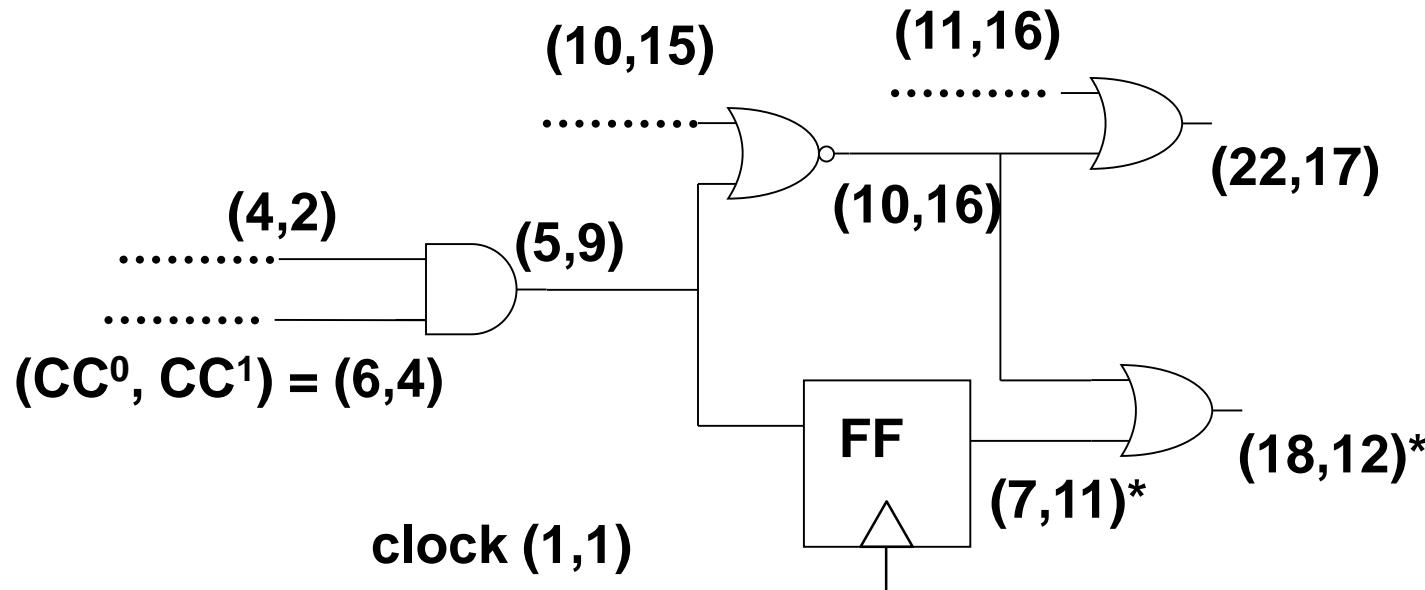
Drivability: $d^{0/1}$, $d^{1/0}$

- Estimates **effort** to propagate a **D or D'** from fault site to Y
 - $d^{0/1}(Y) = \text{drivability of } D' \text{ to node } Y$
 - $d^{1/0}(Y) = \text{drivability of } D \text{ to node } Y$

	$d^{0/1}(Y)$	$d^{1/0}(Y)$
	$\min \{CC^1(X_1) + d^{0/1}(X_2),$ $d^{0/1}(X_1) + CC^1(X_2),$ $d^{0/1}(X_1) + d^{0/1}(X_2)\} + 1$	$\min \{CC^1(X_1) + d^{1/0}(X_2),$ $d^{1/0}(X_1) + CC^1(X_2),$ $d^{1/0}(X_1) + d^{1/0}(X_2)\} + 1$
	$\min \{CC^0(X_1) + d^{0/1}(X_2),$ $d^{0/1}(X_1) + CC^0(X_2),$ $d^{0/1}(X_1) + d^{0/1}(X_2)\} + 1$	$\min \{CC^0(X_1) + d^{1/0}(X_2),$ $d^{1/0}(X_1) + CC^0(X_2),$ $d^{1/0}(X_1) + d^{1/0}(X_2)\} + 1$
	$d^{1/0}(X) + 1$	$d^{0/1}(X) + 1$
$Y = \text{FF out}$ $X = \text{FF in}$	$d^{0/1}(X) + K \text{ (constant)}$	$d^{1/0}(X) + K \text{ (constant)}$

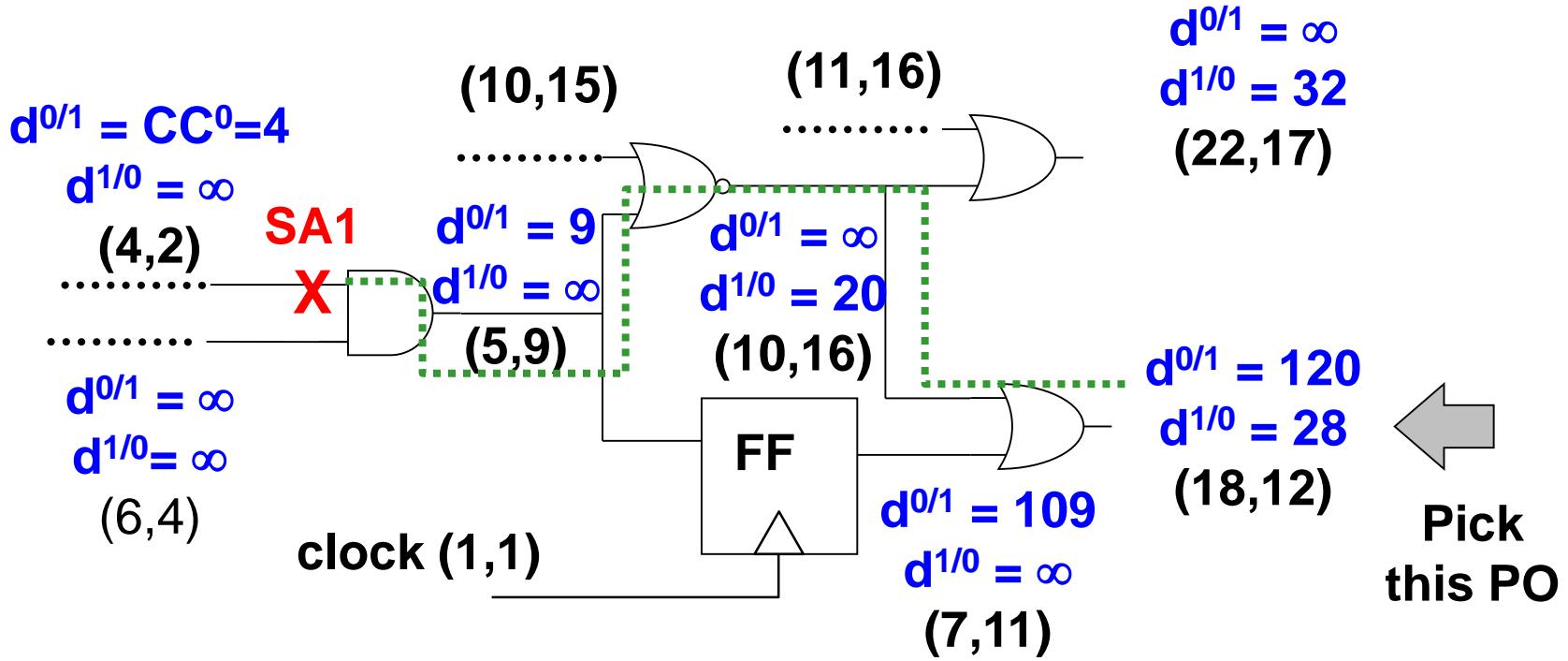
Example 1/2: SCOAP (BA Fig. 8.7)

- Fault-free circuit



* different from textbook

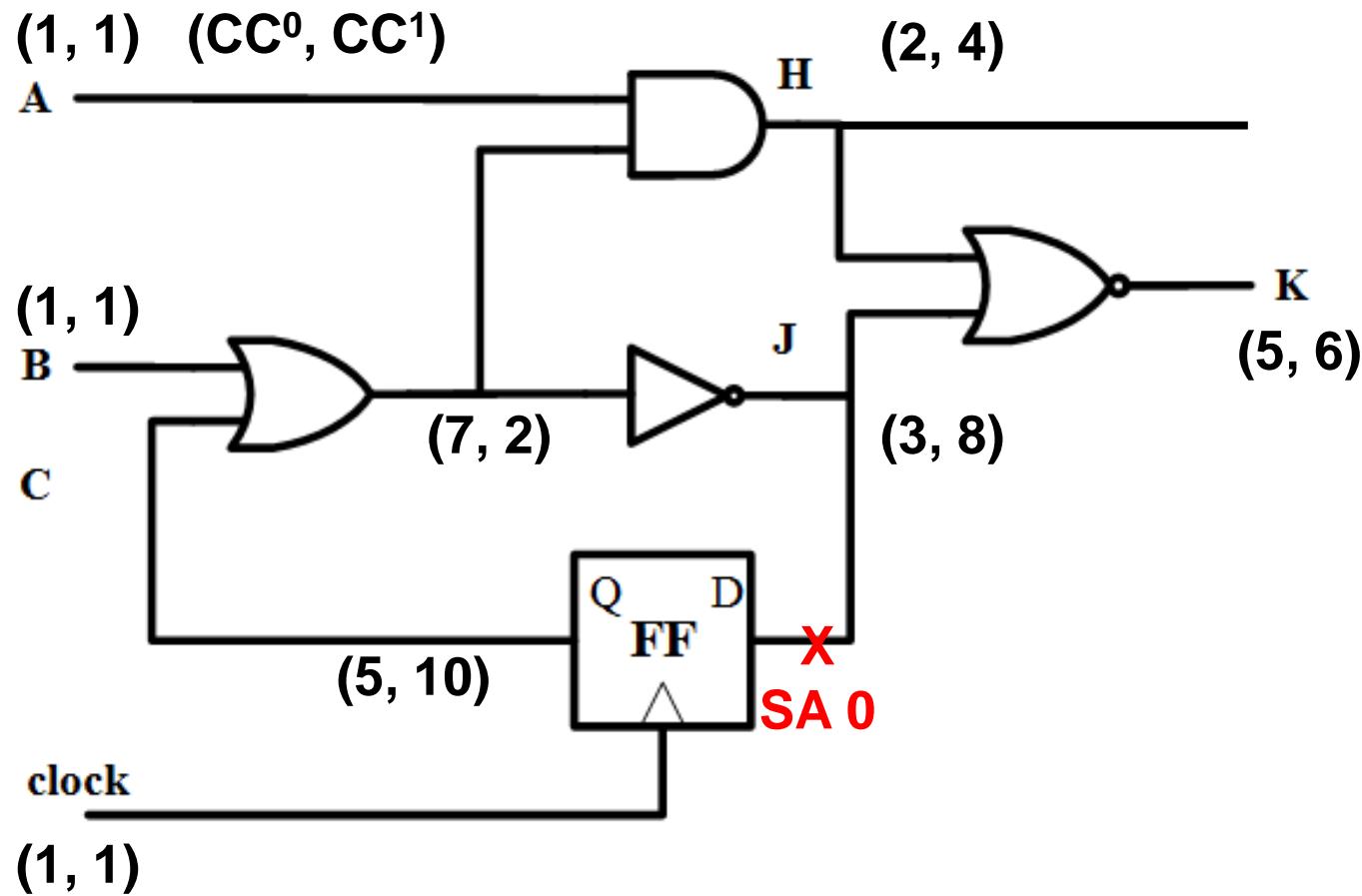
Example 2/2: Drivability (BA Fig. 8.7)



- $K=100$
- When D impossible, $d^{1/0} = \infty$

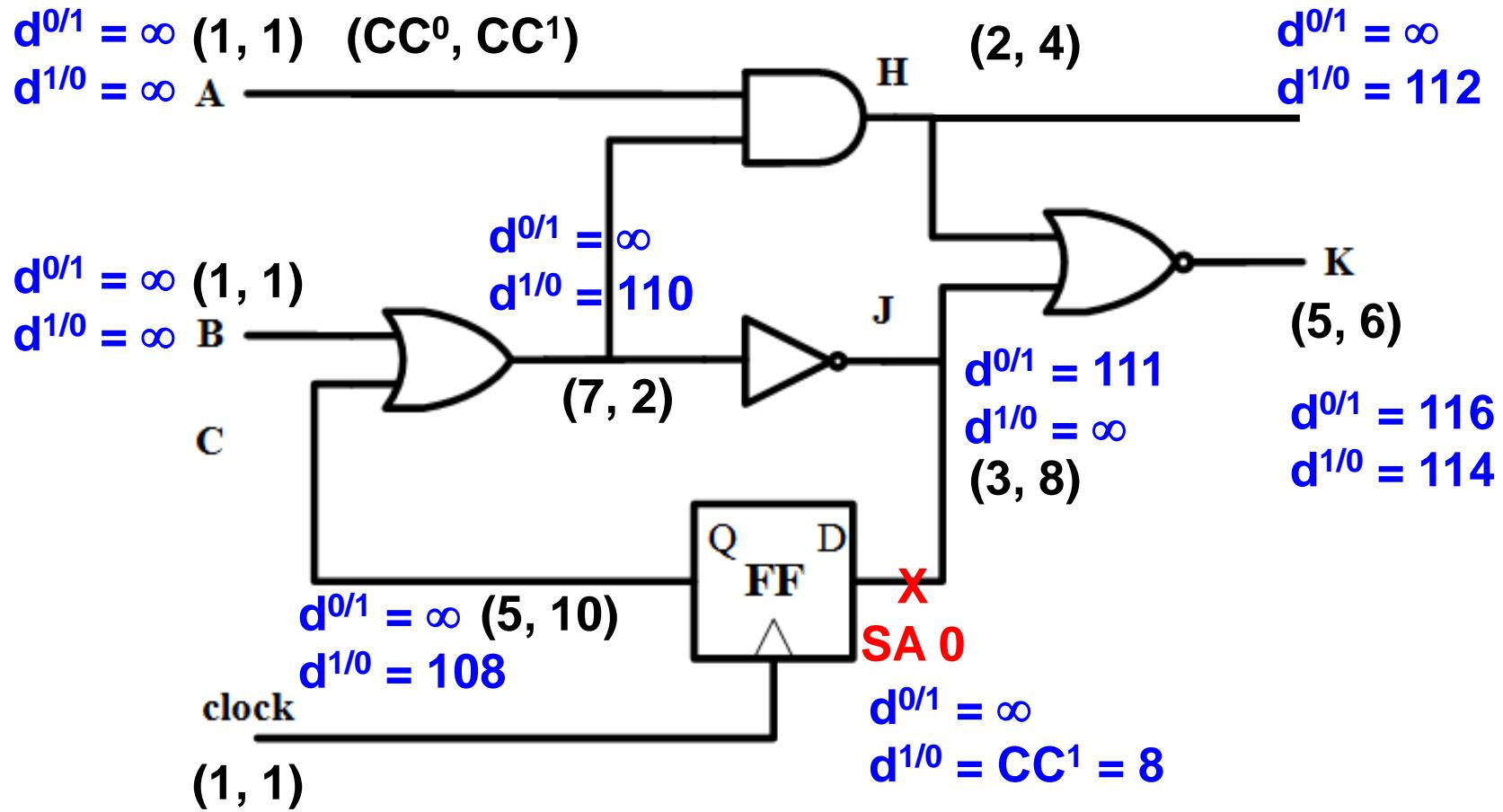
Quiz

Q: Based on SCOAP, please calculate drivability of SA0 fault.
(Assume K=100)



Quiz

Q: Based on SCOAP, please calculate drivability of SA0 fault.
 (Assume K=100)



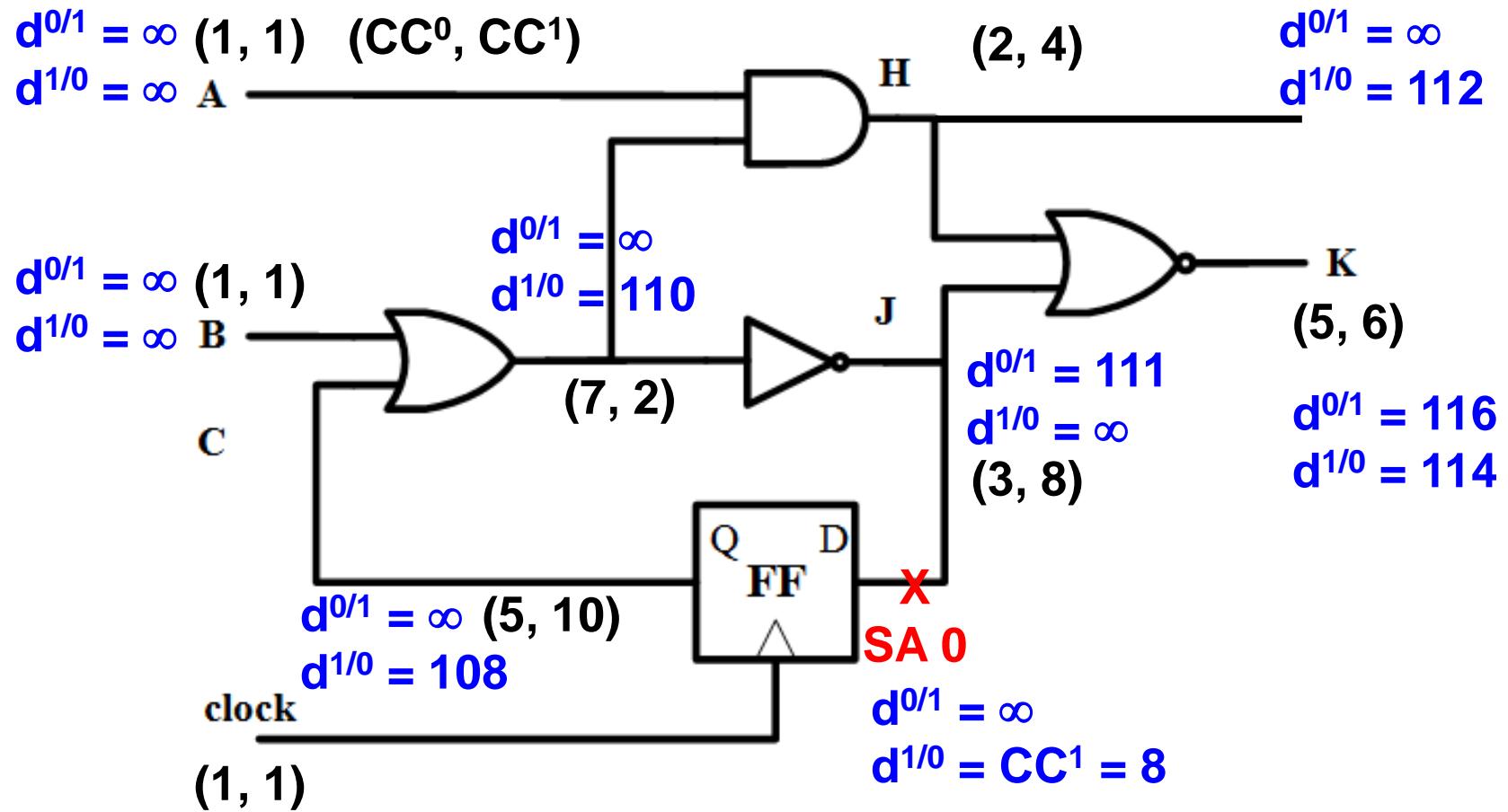
Summary

- **Backward time frame processing** has advantages:
 - ◆ Fixed time frame
 - ◆ State repetition recognized
- EBT selects **one path** at a time
- BACK proposes **drivability** to select best PO

	Advantages	Disadvantages	Example
Mixed F/B Time Frame	😊 Reuse existing alg.	😢 Too many time frames	Extended D
Backward TF Only	😊 Fixed time frames 😊 State repetition recognized	😢 Too many paths!	EBT BACK
Forward TF Only	😊 No need to justify	😢 Hard to decide time frames	FASTEST (PODEM-like)

FFT1

- Do we need feedback to iteratively calculate Drivability?



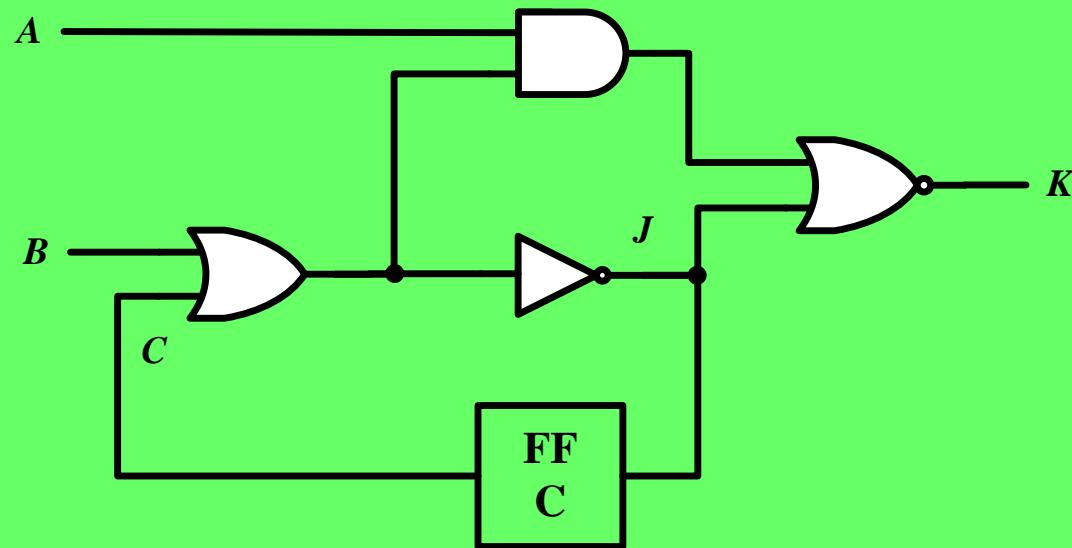
FFT2

- Q: For forward time frame processing, can we fix time frames, like EBT?

	Advantages	Disadvantages	Example
Mixed F/B Time Frame	😊 Reuse existing alg.	😢 Too many time frames	Extended D
Backward TF Only	😊 Fixed time frames 😊 State repetition recognized	😢 Too many paths!	EBT BACK
Forward TF Only	😊 No need to justify	😢 Hard to decide time frames	PODEM-like

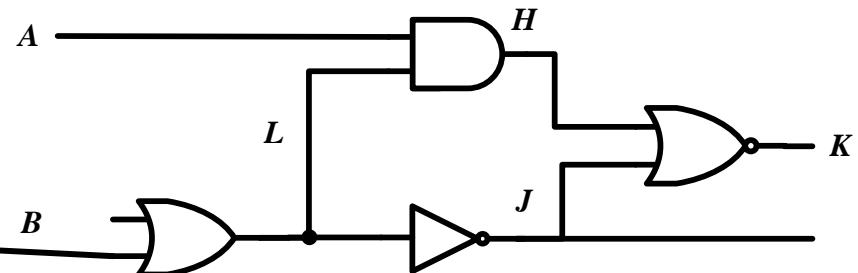
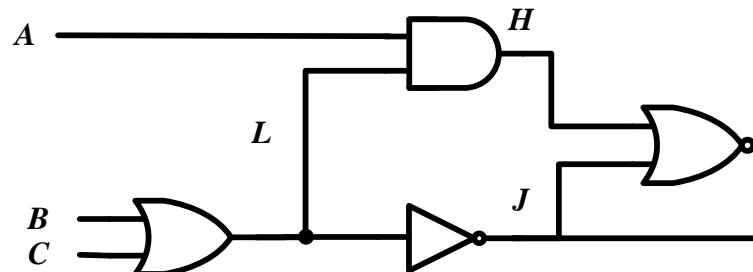
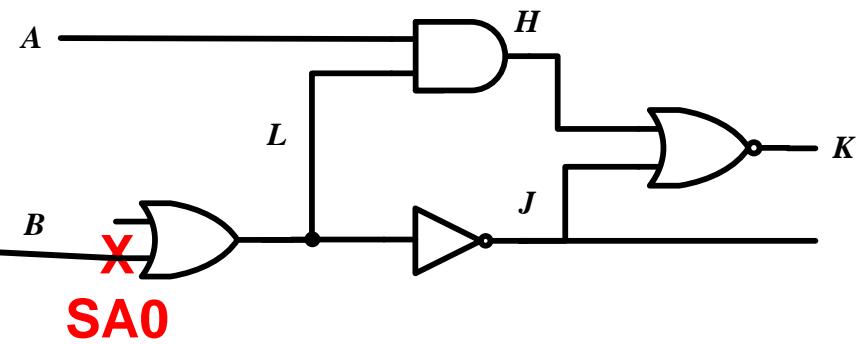
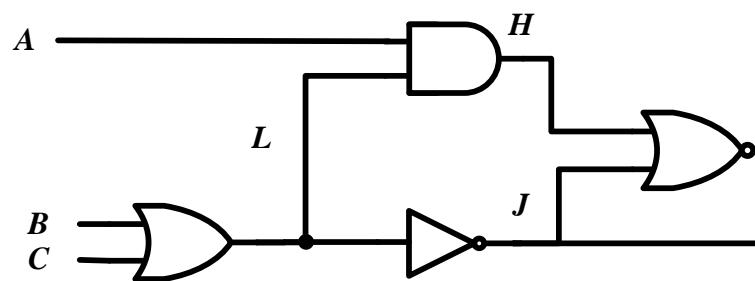
Quiz

Q: Please redraw this into two time frames



Quiz (cont'd)

Q: Use EBT to generate test patterns for SA0 fault



Drivability

- **Drivability** estimates effort of propagating a **D or D'** from fault site to that signal
 - ◆ Similar to **SCOAP**
- Review of SCOAP

	$CC^0(Y)$	$CC^1(Y)$
$Y = X_1 \text{ AND } X_2$	$\min[CC^0(X_1), CC^0(X_2)] + 1$	$CC^1(X_1) + CC^1(X_2) + 1$
$Y = X_1 \text{ OR } X_2$	$CC^0(X_1) + CC^0(X_2) + 1$	$\min[CC^1(X_1), CC^1(X_2)] + 1$
$Y = X'$	$CC^1(X) + 1$	$CC^0(X) + 1$
Primary inputs	1	1

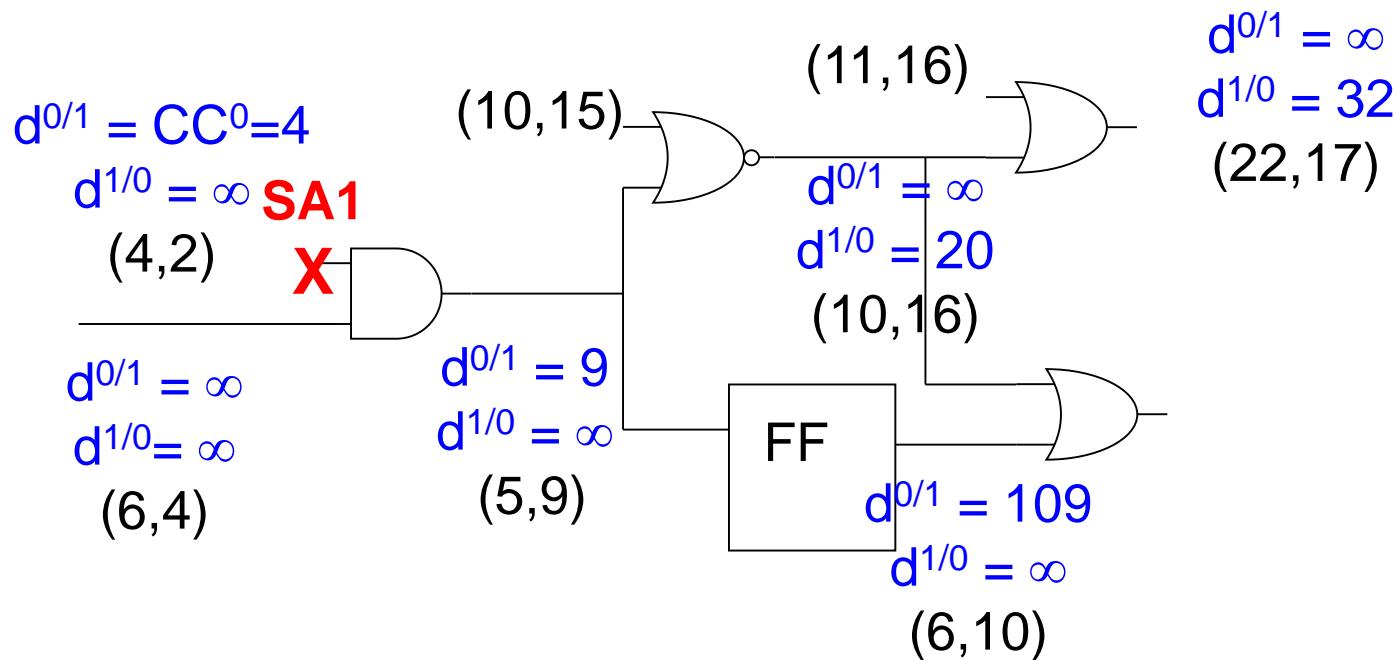
Drivability is like SCOAP for a Specific Fault

Drivability: $d(0/1)$ & $d(1/0)$

- $d^{0/1}(Y) = \text{drivability of } D'$
 - ◆ Effort to bring node Y to D' when the fault presents
- $d^{1/0}(Y) = \text{drivability of } D$

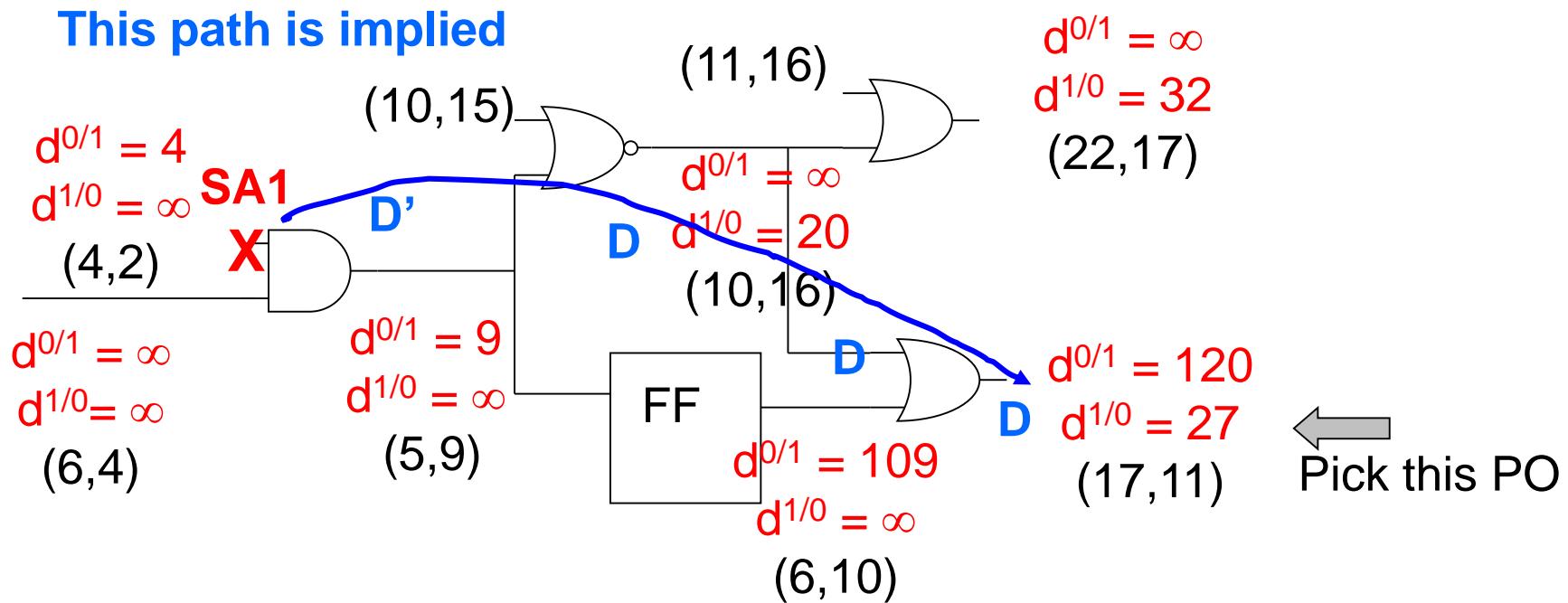
	$d^{0/1}(Y)$	$d^{1/0}(Y)$
$Y = X_1 \text{ AND } X_2$	$\min \{CC^1(X_1) + d^{0/1}(X_2),$ $d^{0/1}(X_1) + CC^1(X_2),$ $d^{0/1}(X_1) + d^{0/1}(X_2)\} + 1$	$\min \{CC^1(X_1) + d^{1/0}(X_2),$ $d^{1/0}(X_1) + CC^1(X_2),$ $d^{1/0}(X_1) + d^{1/0}(X_2)\} + 1$
$Y = X_1 \text{ OR } X_2$	$\min \{CC^0(X_1) + d^{0/1}(X_2),$ $d^{0/1}(X_1) + CC^0(X_2),$ $d^{0/1}(X_1) + d^{0/1}(X_2)\} + 1$	$\min \{CC^0(X_1) + d^{1/0}(X_2),$ $d^{1/0}(X_1) + CC^0(X_2),$ $d^{1/0}(X_1) + d^{1/0}(X_2)\} + 1$
$Y = X'$	$d^{1/0}(X) + 1$	$d^{0/1}(X) + 1$
$Y = \text{FF out}$ $X = \text{FF in}$	$d^{0/1}(X) + K \text{ (constant)}$	$d^{1/0}(X) + K \text{ (constant)}$

Drivability Example 1/2 (BA Fig. 8.7)



- $K=100$
- When D impossible, $d^{1/0} = \infty$

Drivability Example 2/2 (BA Fig. 8.7)



- To justify a D or D' at gate output, select gate input with smallest drivability as D or D' input