Cyclic-CPRS : A Diagnosis Technique for BISTed Circuits in Nano-meter Technologies

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Chun-Yi Lee, Hung-Mao Lin, Fang-Min Wang, and James Chien-Mo Li*

Lab of Dependable Systems (LaDS)
Graduate Institute of Electronics Engineering
National Taiwan University

Outline

- **Introduction**
- Background
- Proposed Technique
- Experimental Results
- Conclusion

Introduction

- Diagnose embedded cores
  - Identify failing patterns
  - Locate failing flip-flops
- Difficulties of traditional BIST diagnosis
  - Limited observability
  - Aliasing and masking due to compressed outputs from MISR
- Greater challenges in nano-meter technologies
  - Transient errors due to signal integrity
    - IR drop, crosstalk, etc.
  - Unknowns (X's) due to random pattern applied
    - Floating tri-state nets, bus contention, high impedance, etc.

Past Research

- Early Techniques
  - Analyze MISR [Aitken 89][Savir 97]
  - Reed-Solomon code [Karpovsky 93]
  - Programmable MISR's [Wu 96]
  - ☹ Only single or few errors
  - ☹ Diagnosis fails in presence of X
- Recent techniques
  - Random Selection [Rajski 97]
  - X-compact [Mitra 02]
  - Convolution Compactor [Rajski 03]
  - Row column parities [Sinanoglu 03]
  - ☹ Diagnosis resolution degrades rapidly as X increases
  - ☹ Transient errors may lead to confusing diagnosis results

Cyclic CPRS

- Features
  - Cyclic scan chains
    - Feed back output of every scan chain to its input
    - Lock unknowns in feedback loop
  - Direct diagnosis of unknowns (X's)
    - Diagnose the unknowns in the same way as errors
- Key results
  - 100% correct even in the presence of 10% errors and X's
    - 10,000 scan cells

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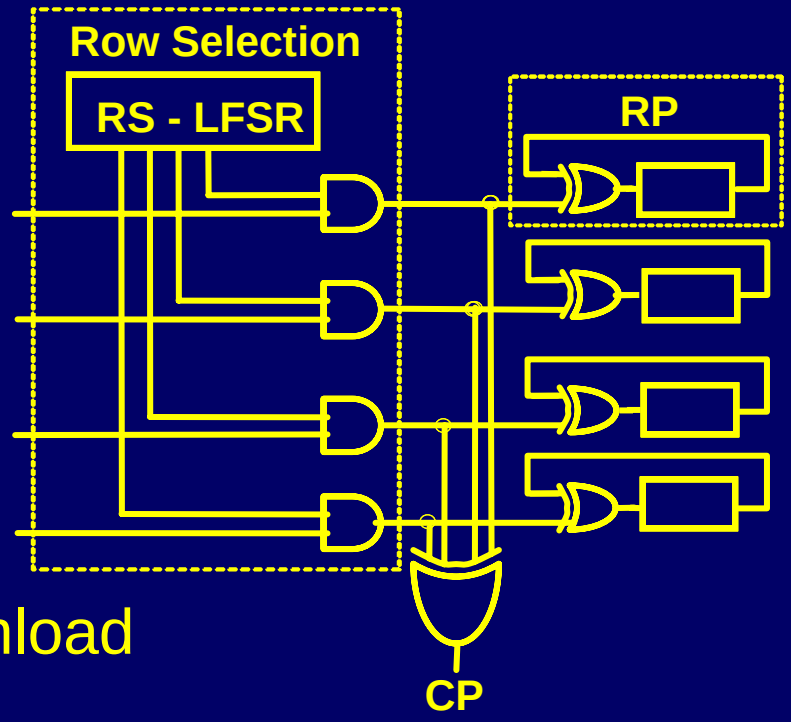
Original CPRS [Lin ITC 05]

- Combine [Rajski 97] and [Sinanoglu 03]
- Row-Selection (RS) LFSR
  - Randomly select scan chains to observe
- Column Parity (CP)
  - Parity of selected scan cells
  - Observed every scan clock
- Row Parity (RP)
  - Parity of selected scan cells
  - Accumulated in every scan chain
  - Observed at end of every scan unload



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  - **Architecture and Diagnosis Flow**
  - Solving Errors and Unknowns
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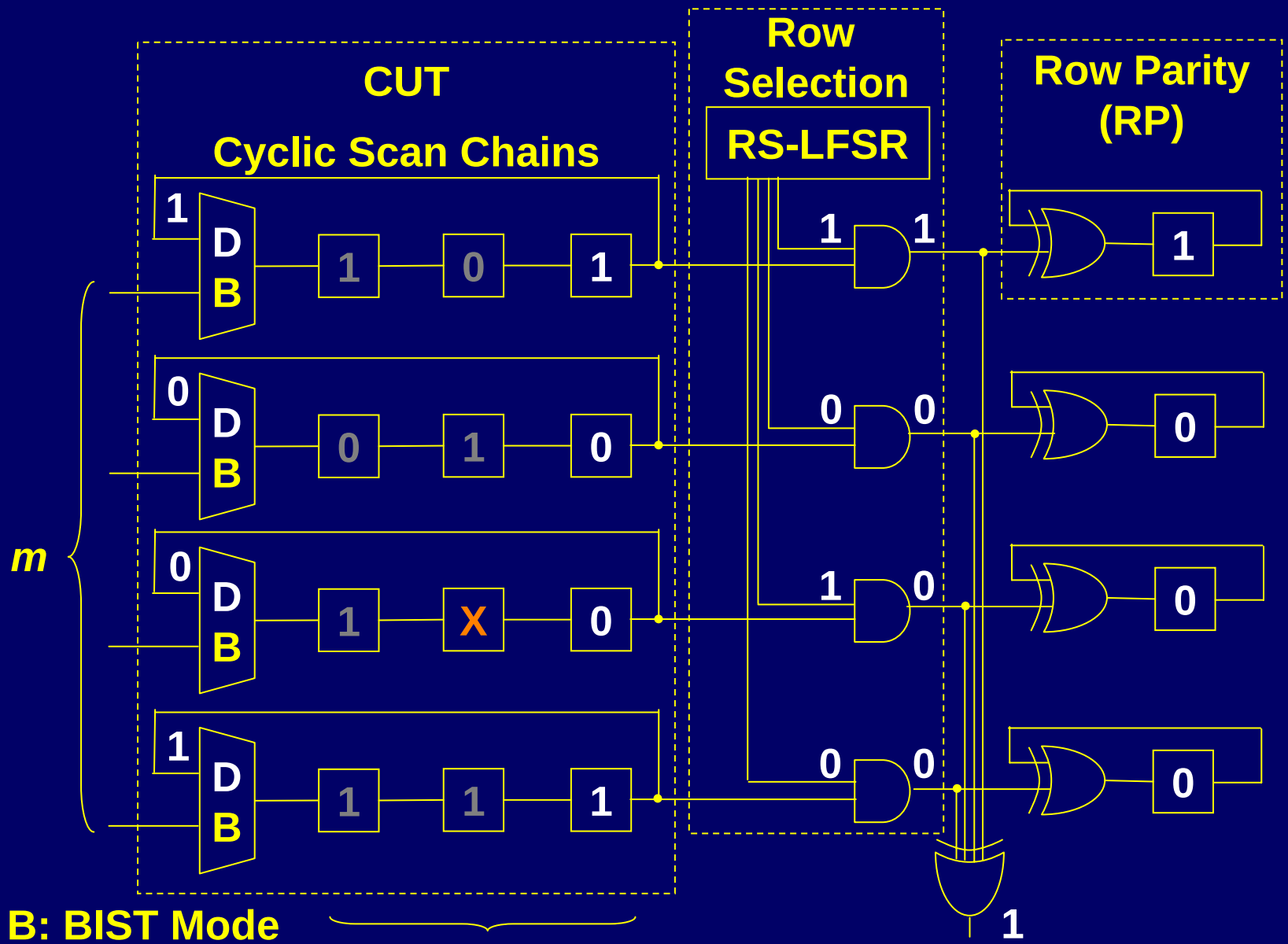
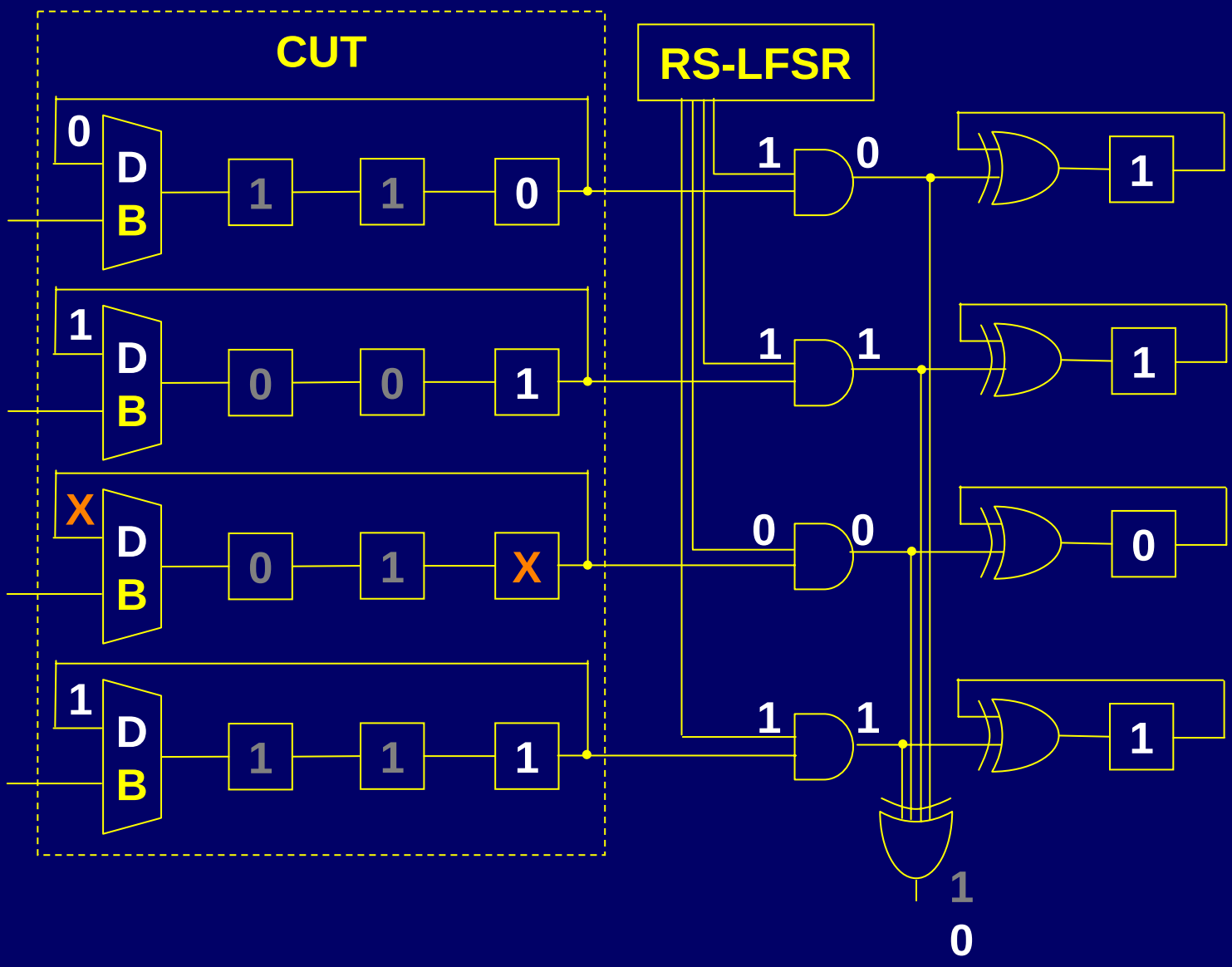
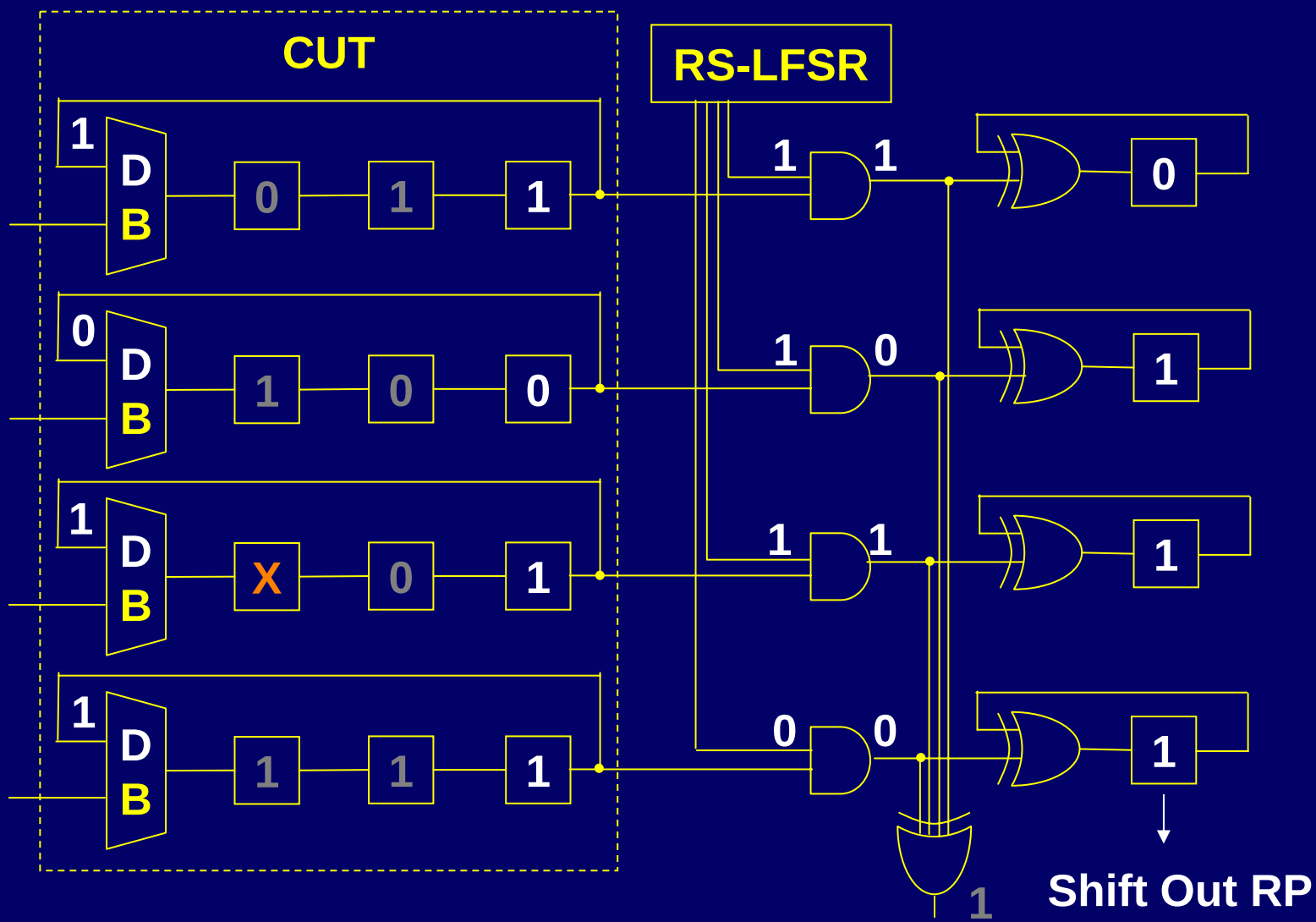
Diagnosis Data Collection (1/3)



Diagnosis Data Collection (2/3)

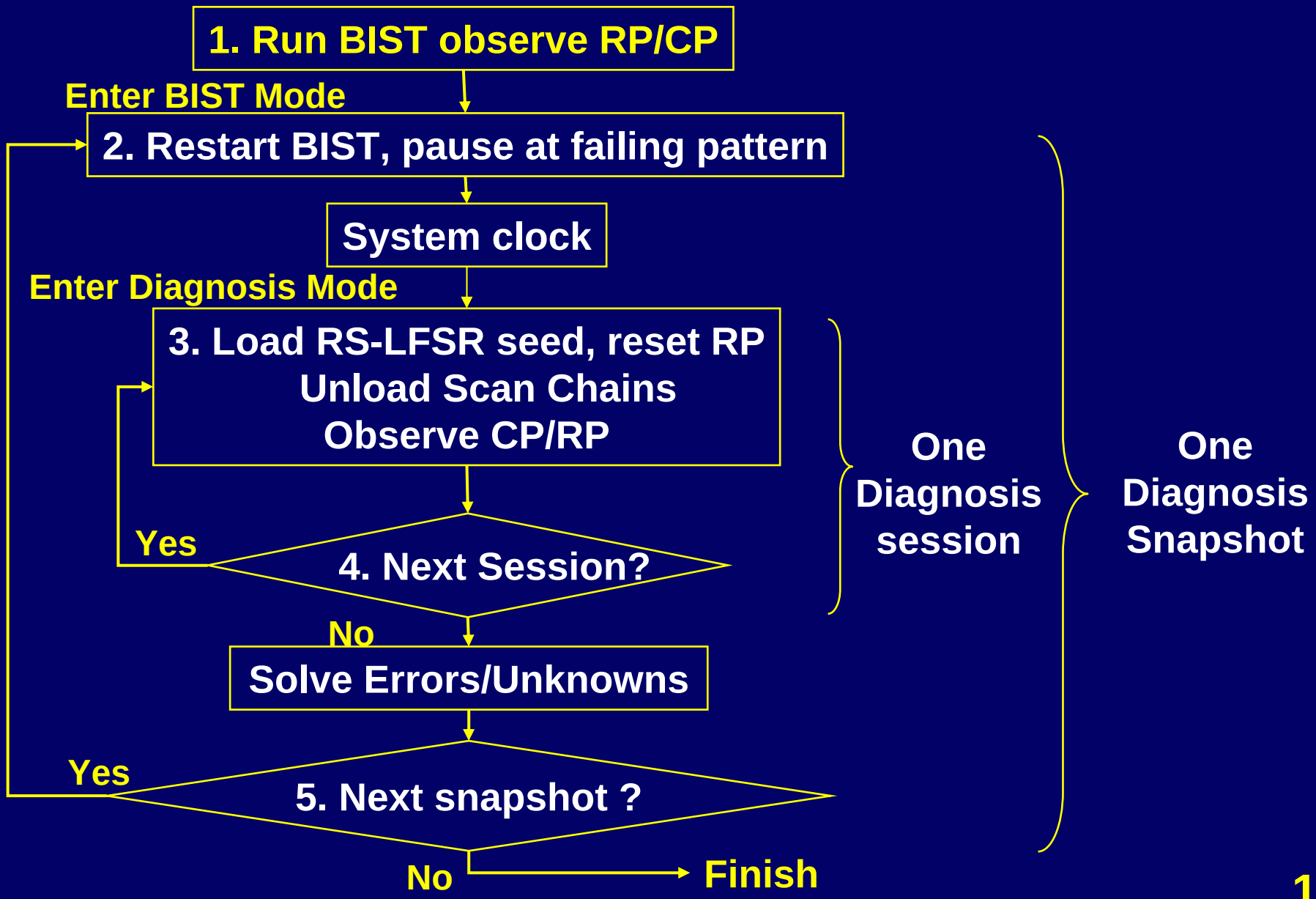


Diagnosis Data Collection (3/3)



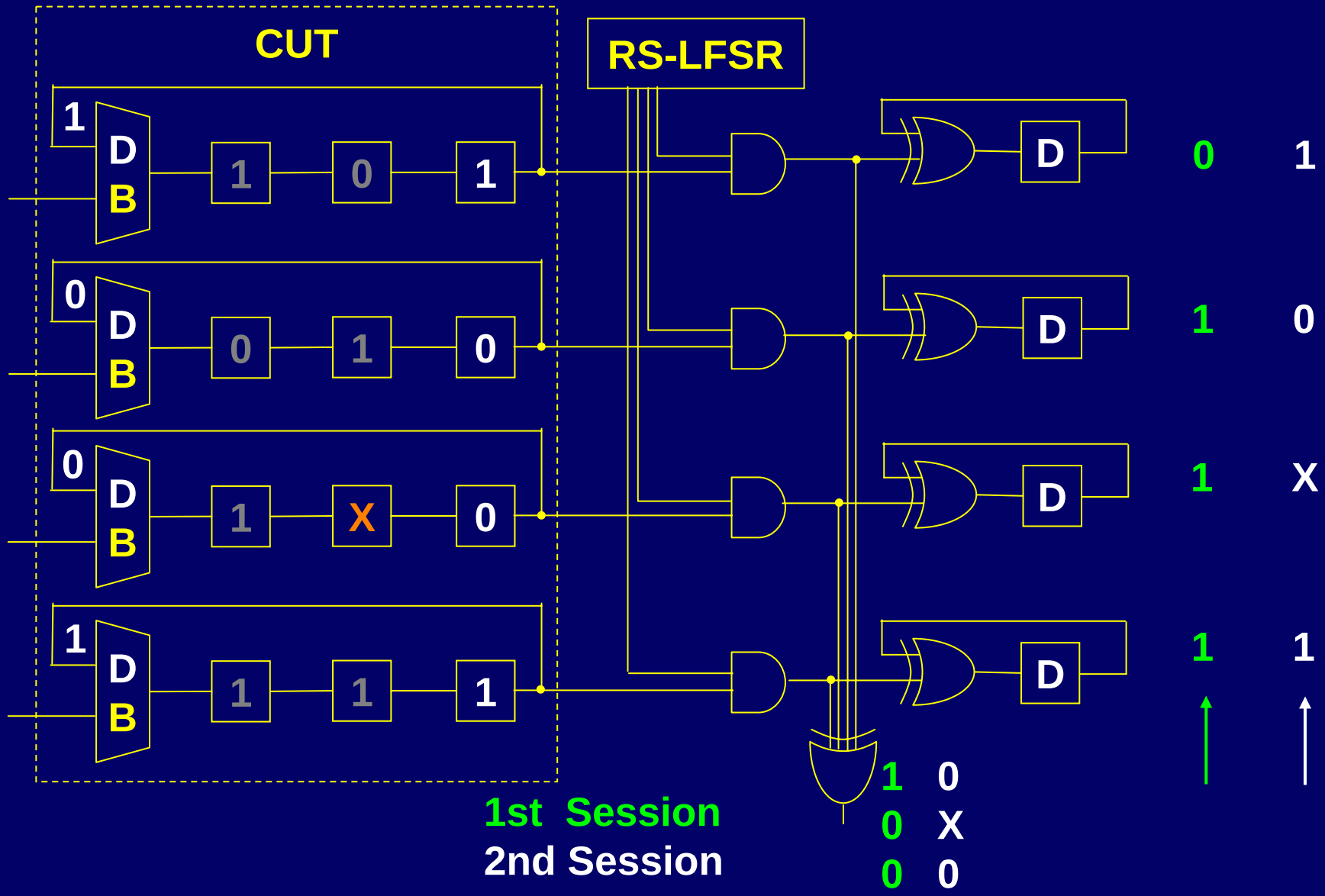
Data Compression: (*m x l*) -> (*m + l*)

Diagnosis Data Collection Flow



Multiple Diagnosis Sessions

- Every Session has a distinct RS-LFSR Seed



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  - Architecture and Diagnosis Flow
  - **Solving Errors and Unknowns**
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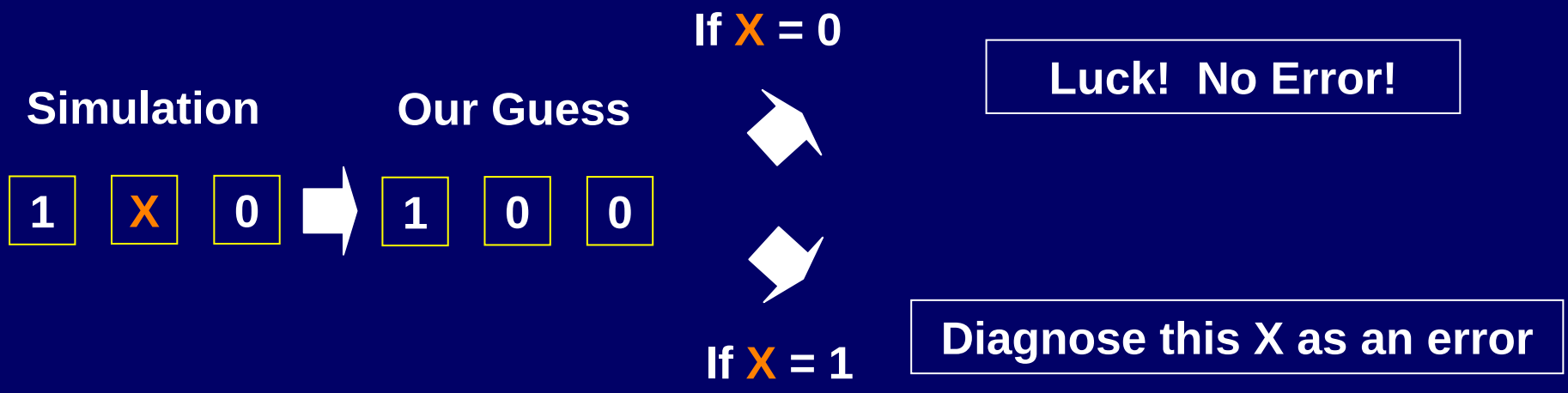
Directly Diagnosis of Unknowns

- On the silicon, every captured X can be either 1 or 0
- Cyclic scan chains keep every X unchanged
- All X's are initially assumes to be 0
  - If captured X = 0 -> Regarded it as error-free
  - If captured X = 1 -> Regarded it as an error



Matrix Representation

- Error Matrix (E)
  - Every row corresponds to a scan chain
  - Every element corresponds to a scan cell
  - 1 = error
- Selection Matrix
  - 1 = scan cell selected by RS-LFSR
- Selected Error Matrix (SEM)
  - Bit-wise AND of Error Matrix and Selection Matrix

Error Matrix

$E_{1,1}$	$E_{1,2}$	$E_{1,3}$
$E_{2,1}$	$E_{2,2}$	$E_{2,3}$
$E_{3,1}$	$E_{3,2}$	$E_{3,3}$
$E_{4,1}$	$E_{4,2}$	$E_{4,3}$

Selection Matrix

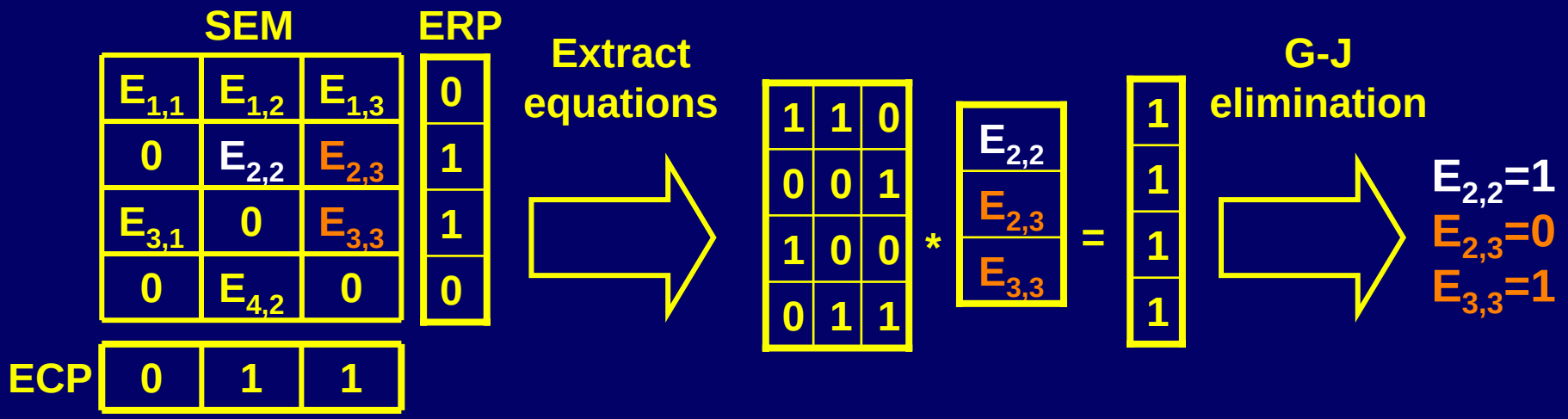
1	1	1
0	1	1
1	0	1
0	1	0

Selected Error Matrix

$E_{1,1}$	$E_{1,2}$	$E_{1,3}$
0	$E_{2,2}$	$E_{2,3}$
$E_{3,1}$	0	$E_{3,3}$
0	$E_{4,2}$	0

Solving Errors and Unknowns

- Error Row Parity (ERP)
  - Difference of gold RP and observed RP
- Error Column Parity (ECP)
  - Difference of gold CP and observed CP
- Eg. 1 errors: $E_{2,2}$=1; 2 unknowns:
  - $E_{2,3}$ (Captured 0), $E_{3,3}$ (Captured 1)



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Experimental Results

- Error Matrix: 10 x 100. 15 Errors, Scattered X (uniformly distributed)
- Cyclic-CPRS needs less diagnosis sessions

# of Diagnosis Sessions	X	Original CPRS			Cyclic-CPRS		
		Correct	Wrong	Amb.	Correct	Wrong	Amb.
2	10x	954.8	13.7	31.5	874.1	12.2	113.7
	50x	939.3	11.3	49.4	702.2	31.5	266.3
	100x	924.6	7.9	67.5	551.8	53.7	394.4
4	10x	941.1	16.3	42.7	817.8	4.7	177.5
	50x	947.0	14.6	38.4	569.2	10.9	419.9
	100x	902.6	5.6	91.9	375.8	19.2	605.0
8	10x	977.7	21.2	1.0	987.8	11.5	0.8
	50x	964.9	19.7	15.4	615.8	11.8	372.4
	100x	901.2	6.7	92.1	434.6	17.8	547.6
12	10x	985.9	13.4	0.8	998.6	1.3	0.1
	50X	973.8	22.5	3.7	999.8	0.2	0.0
	100X	929.9	13.2	56.8	999.4	0.6	0.0
16	10x	987.5	11.7	0.8	1000.0	0.0	0.0
	50x	974.5	23.6	1.9	1000.0	0.0	0.0
	100x	942.5	16.0	41.4	1000.0	0.0	0.0
32	10x	988.8	10.2	0.9	1000.0	0.0	0.0
	50x	973.2	25.1	1.7	1000.0	0.0	0.0
	100x	965.2	20.5	14.2	1000.0	0.0	0.0
256	10x	989.2	9.8	1.0	1000.0	0.0	0.0
	50x	972.6	23.6	3.8	1000.0	0.0	0.0
	100x	974.3	23.1	2.6	1000.0	0.0	0.0

Experimental Results (Con't)

- Error Matrix: 10 x 100. 15 Errors. X clustered in two scan chains
- Cyclic-CPRS needs less diagnosis sessions

# of Diagnosis Sessions	X	Original CPRS			Cyclic-CPRS		
		Correct	Wrong	Amb.	Correct	Wrong	Amb.
2	10x	945.1	10.8	44.1	885.8	12.8	101.4
	50x	952.1	12.2	35.8	725.4	32.5	242.1
	100x	960.1	13.8	26.1	581.9	57.7	360.4
4	10x	933.1	14.4	52.5	839.0	5.9	155.1
	50x	937.7	14.8	47.5	629.7	15.8	354.5
	100x	945.4	15.8	38.7	428.5	24.8	546.7
8	10x	977.7	21.7	0.6	991.2	8.2	0.6
	50x	973.7	26.2	0.1	847.8	15.4	136.9
	100x	967.2	32.3	0.5	675.9	28.1	296.0
12	10x	986.9	12.9	0.2	1000.0	0.0	0.0
	50X	980.2	19.8	0.0	999.9	0.1	0.0
	100X	973.2	26.6	0.1	990.4	9.0	0.6
16	10x	987.9	11.9	0.2	1000.0	0.0	0.0
	50x	983.4	16.6	0.0	1000.0	0.0	0.0
	100x	978.2	21.8	0.0	1000.0	0.0	0.0
32	10x	988.9	10.7	0.4	1000.0	0.0	0.0
	50x	987.1	12.9	0.0	1000.0	0.0	0.0
	100x	985.7	14.3	0.0	1000.0	0.0	0.0
256	10x	990.0	9.2	0.9	1000.0	0.0	0.0
	50x	987.6	12.4	0.0	1000.0	0.0	0.0
	100x	987.8	12.2	0.0	1000.0	0.0	0.0

Comparison

- Comparison of Correctly Diagnosed Bits
- Performed on 100 x 100 scan cells (100 scan chains)

Technique	Error	0.10%X	0.50%X	1.00%X	5.00%X	10.00%X
X-compact [Mitra 02]	1	92.0 %	15.7 %	0.06 %	NA	NA
CC-3 [Rajski 03]	1	97.1 %	18.7 %	0.08 %	NA	NA
CC-7 [Rajski 03]	1	97.7 %	52.4 %	14.3 %	NA	NA
Cyclic-CPRS	1	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Cyclic-CPRS	15	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

Diagnosis Data Compression

- Diagnosis Data required for Direct Dumping
  - $m \times l$
- Diagnosis Date required for Cyclic-CPRS
  - $s \times (m + l)$
- Eg. 15 Errors, 10% Unknowns

Technique	m	l	s	Data Needed	Compression Ratio
Direct Dumping	10	100	1	1,000 bits	1
Cyclic-CPRS	10	100	16	1,760 bits	176.0%
Direct Dumping	100	100	1	10,000 bits	1
Cyclic-CPRS	100	100	16	3.200 bits	32.0%
Direct Dumping	100	1,000	1	100,000 bits	1
Cyclic-CPRS	100	1,000	16	17,600 bits	17.6 %

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Conclusion

- **Cyclic-CPRS BIST Diagnosis**
  - Cyclic Scan Chain
    - Retain the transient errors and unknowns
  - Direct Diagnosis
    - Face the unknowns as if they are errors
  - 100% correct even when 10% scan cells are errors and X's
- Suitable for embedded cores in nano-technologies

Thank You!