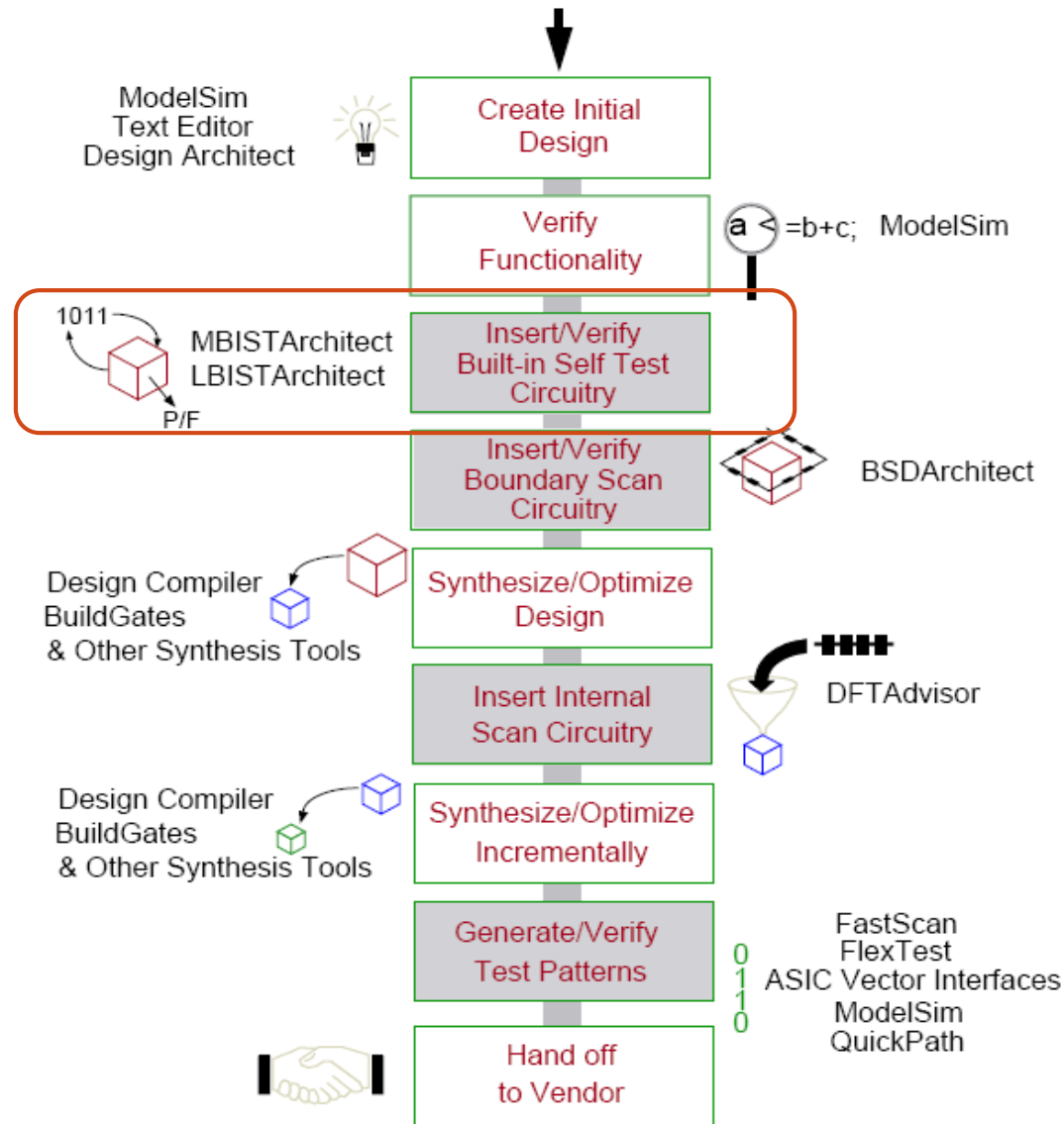


# Built-In Self Test

Smith Text: Chapter 14.7

Mentor Graphics: *LBISTArchitect Process Guide*

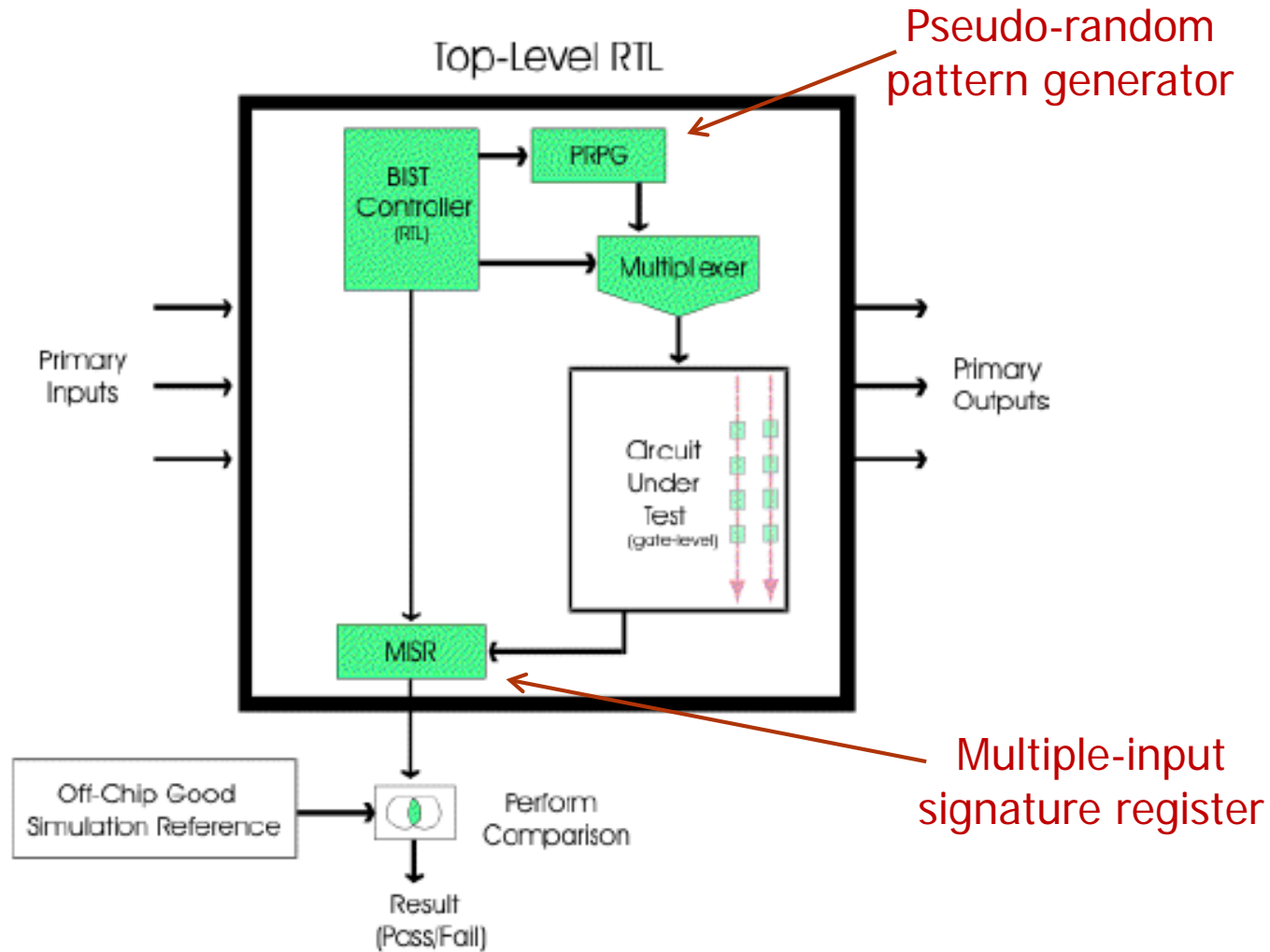
# Top-down test design flow



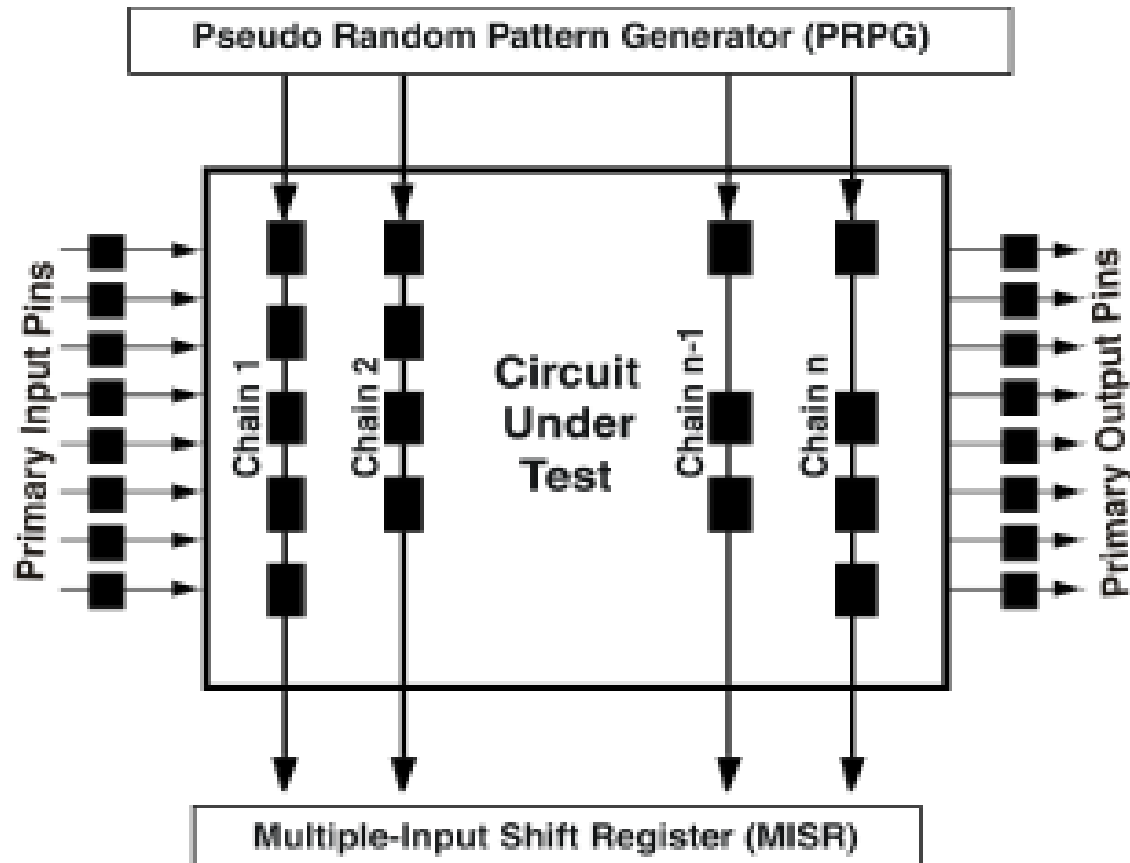
# Built-In Self-Test (BIST)

- Structured-test techniques for logic circuits to improve access to internal signals from primary inputs/outputs
- BIST procedure:
  - generate a test pattern
  - apply the pattern to “circuit under test” (CUT)
  - check the response
  - repeat for each test pattern
- Most BIST approaches use pseudo-random test vectors
- Most BIST approaches compress responses into a single “signature”

# Logic BIST architecture



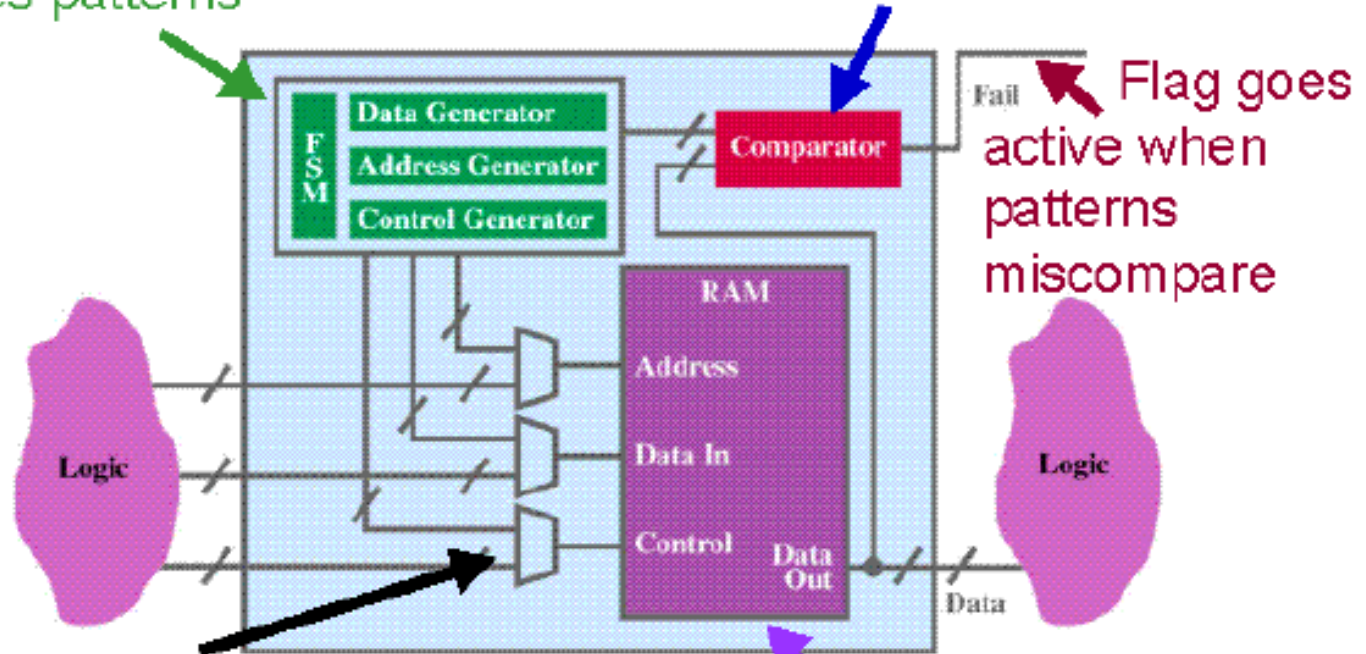
# Logic BIST general architecture



# Memory BIST architecture

BIST controller generates & applies patterns

Comparator compares patterns applied to/read from memory



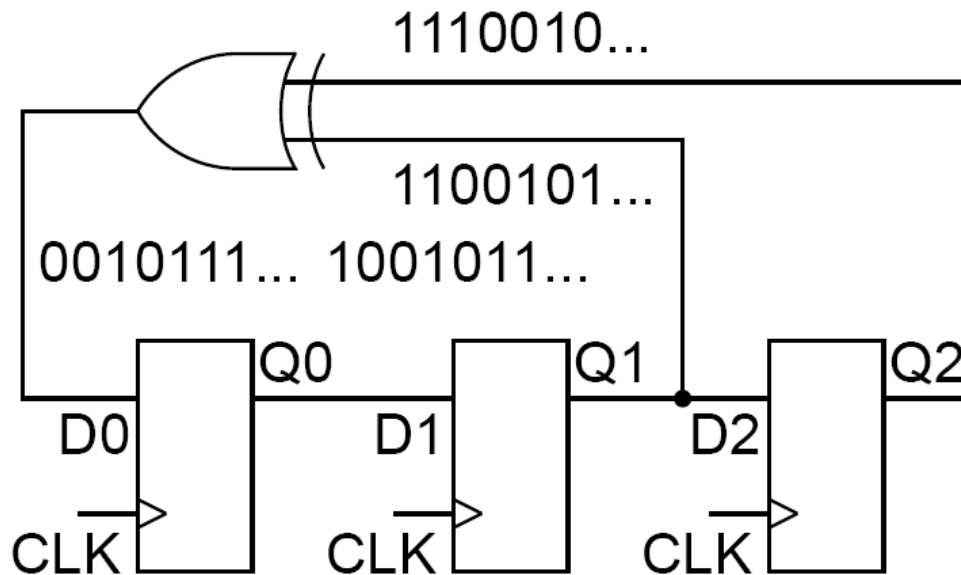
Fail Flag goes active when patterns mismatch

Multiplexers select between system and test data

Memory with BIST

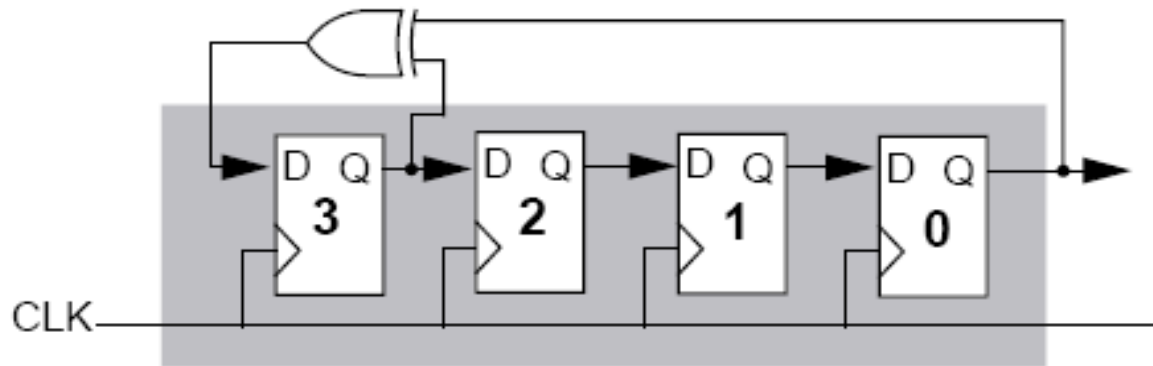
# Linear Feedback Shift Register (LFSR)

- Produce **pseudorandom binary sequences** (PRBS)
- Implement with shift register and XOR gates
- Selection of feedback points allows n-bit register to produce a PRBS of length  $2^n - 1$



LFSR produces pattern:  
111  
011  
001  
100  
010  
101  
110 (then repeats)  
(PRBS length 7)

# 4-stage LFSR with one tap point

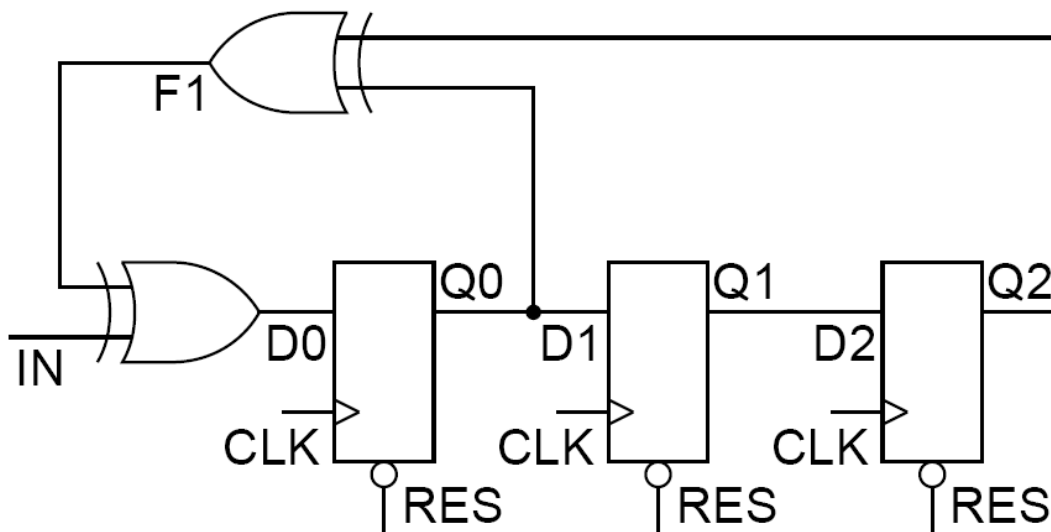


<u>State</u>	<u>Pattern</u>	<u>State</u>	<u>Pattern</u>
0	1000	8	1101
1	1100	9	0110
2	1110	10	0011
3	1111	11	1001
4	0111	12	0100
5	1011	13	0010
6	0101	14	0001
7	1010	15	1000



# Serial Input Signature Register (SISR)

- Use an LFSR to compact serial input data into an n-bit “signature”
- Good circuit has a unique signature
- For sufficiently large n, two different sequences producing the same signature is unlikely



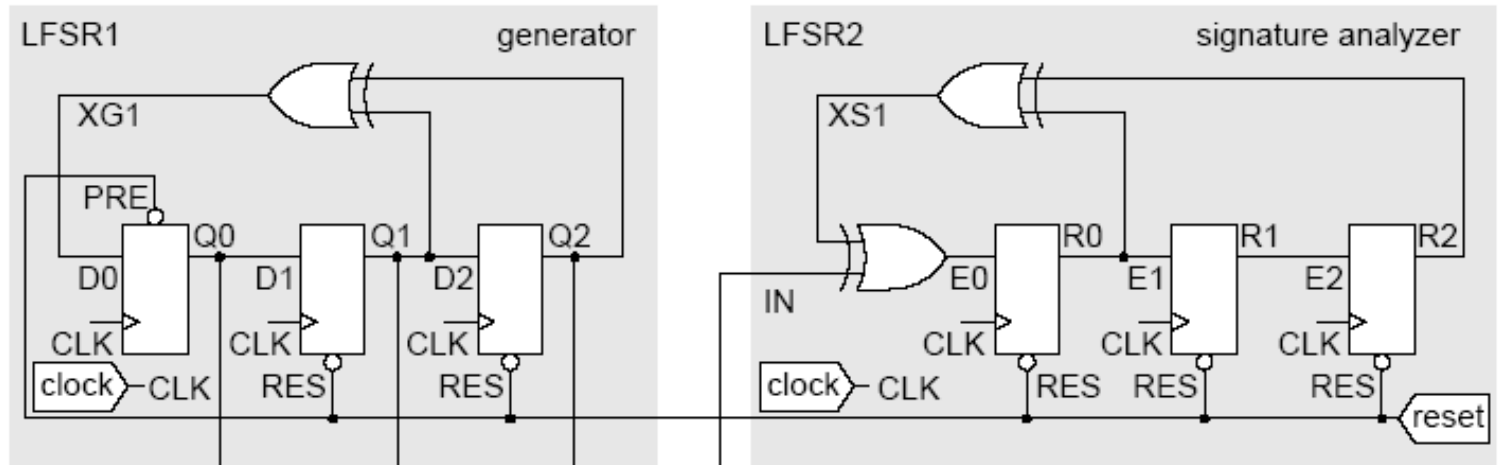
Initialize LFSR  
to '000' via RES.

Signature formed  
via shift & xor

# BIST Example (Fig. 14.25)

## Pattern generator

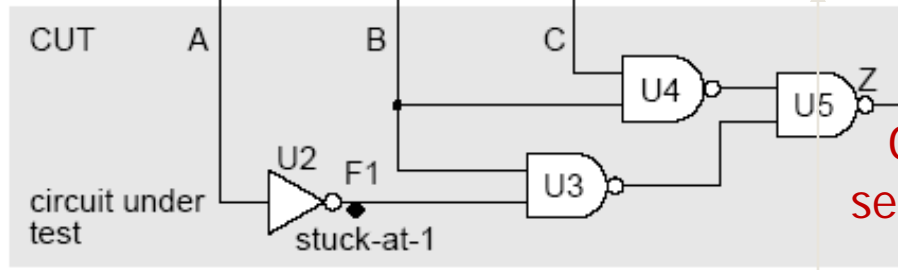
## Signature analyzer



Generated test patterns

good	1011100	0101110	0010111
bad	1011100	0101110	0010111

01001100	00111110	00011111	00001111
01011100	00111000	00011100	00001110



Output sequences



signatures:  
 good = hex 3 = 011  
 R0 = 0, R1 = 1, R2 = 1  
 bad (F1) = hex 0 = 000  
 R0 = 0, R1 = 0, R2 = 0

Circuit under test

Signatures

# Aliasing

- Good and bad circuits might produce the same signature (“aliasing”) – masking errors
- Previous example:
  - 7-bit sequence applied to signature analyzer
    - $2^7 = 128$  possible patterns
  - 3-bit signature register:  $2^3 = 8$  possible signatures
  - $128/8 = 16$  streams can produce the good signature: 1 corresponds to good circuit, 15 to faulty circuits  
(assume all bit streams equally likely)
  - $128-1 = 127$  streams correspond to bad circuits
  - $15/127 = 11.8\%$  of bad bit streams produce the good signature, and therefore will be undetected  
(Probability of missing a bad circuit = 11.8%)

# Aliasing – Error Probability

- Given test sequence length  $L$  & signature register length  $R$
- Probability of aliasing is:

- For  $L \gg R$ : 
$$p = \frac{2^{L-R} - 1}{2^L - 1}$$

- Use long sequences to minimize aliasing: 
$$p \approx 2^{-R}$$

# LFSR Theory (chap 14.7.5)

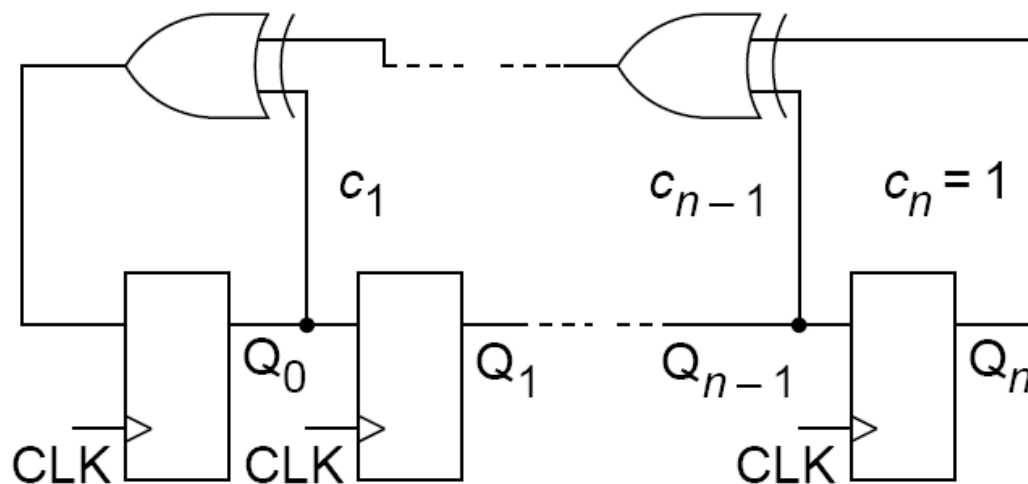
- Operation based on polynomials and Galois-field theory used in coding
- Each LFSR has a “characteristic polynomial”
  - Called a “primitive polynomial” if it generates a maximum-length PRBS
  - General form:  $P(x) = c_0 \oplus c_1x^1 \oplus \dots \oplus c_nx^n$   
 $c_k$  always 0 or 1,  $\oplus = \text{xor}$
  - Reciprocal of  $P(x)$  is also primitive:  
 $P^*(x) = x^nP(x^{-1})$
- LFSR can be constructed from  $P(x)$  or  $P^*(x)$

# Primitive polynomial examples

- $P(x) = 1 \oplus x^1 \oplus x^3$ 
  - Order:  $n = 3$
  - Coefficients:  $c_0=1, c_1=1, c_2=0, c_3=1$
  - LFSR feedback taps:  $s = 0, 1, 3$   
(non-zero coefficients)
  
- $P^*(x) = 1 \oplus x^2 \oplus x^3$

# “Type 1” LFSR schematic

$$P(x) = 1 \oplus c_1x \oplus \dots \oplus c_{n-1}x^{n-1} \oplus x^n$$



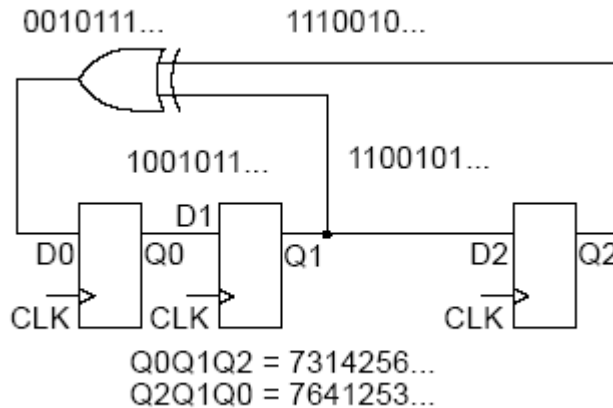
$$\text{or } P^*(x) = 1 \oplus c_{n-1}x \oplus \dots \oplus c_1x^{n-1} \oplus x^n$$

If  $c_k=1$  add feedback connection & xor gate in position k

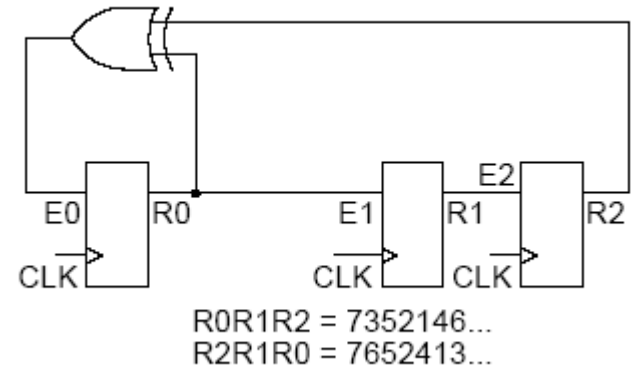
# Four LFSR structures for every primitive polynomial

## Type 1

- external XOR
- easy to build from existing registers
- Q outputs delayed by 1 clock (test seq's are correlated)



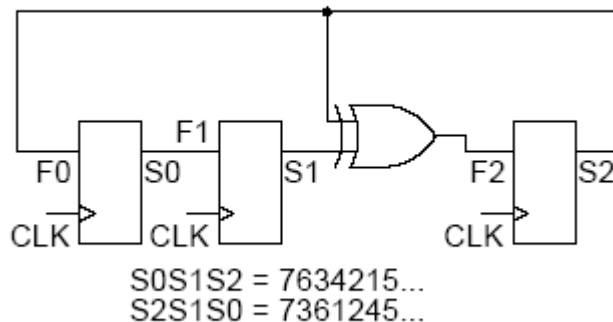
Type 1,  $P^*(x)$  (a)



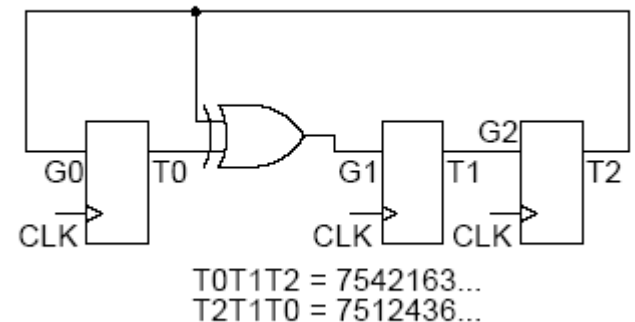
Type 1,  $P(x)$  (b)

## Type 2

- internal XOR
- fewer series XORs (faster)
- outputs not correlated
- usually used for BIST



Type 2,  $P(x)$  (c)



Type 2,  $P^*(x)$  (d)

$$P(x) = 1 \oplus x \oplus x^3$$

$$P^*(x) = 1 \oplus x^2 \oplus x^3$$



# Common LFSR Configurations

**Table 2-1. Common LFSR Configuration**

<b>LFSR Length</b>	<b>Primitive Polynomial</b>	<b>Tap Points (“in”/Type2)</b>	<b>Tap Points (“out”/Type1)</b>
8-bits	$x^8+x^4+x^3+x^2+1$	6, 5, 4	4, 3, 2
16-bits	$x^{16}+x^5+x^4+x^3+1$	13, 12, 11	5, 4, 3
24-bits	$x^{24}+x^7+x^2+x+1$	23, 22, 17	7, 2, 1
32-bits	$x^{32}+x^{22}+x^2+x+1$	31, 30, 10	22, 2, 1

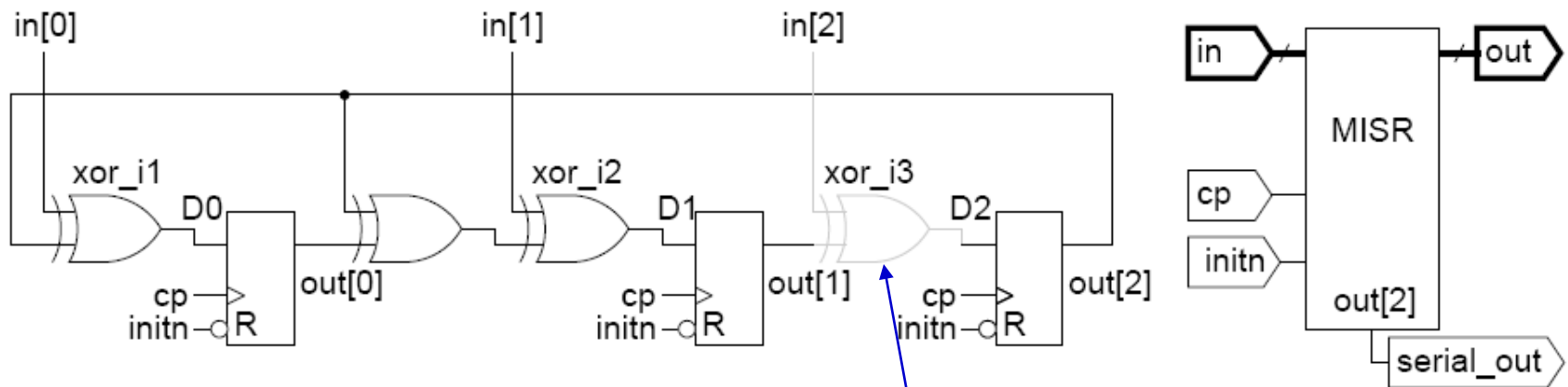
Source: Mentor Graphics “LBISTArchitect Process Guide”

Also see Figure 14.27 and Table 14.11 in the Smith Text

# Multiple-Input Signature Register (MISR)

- Reduce test logic by using multiple bit streams to create a signature
- BILBO (built-in logic block observer) – uses MISR as *both* PRBS generator and signature register

Example: MISR from Type 2 LFSR with  $P^*(x) = 1 \oplus x^2 \oplus x^3$

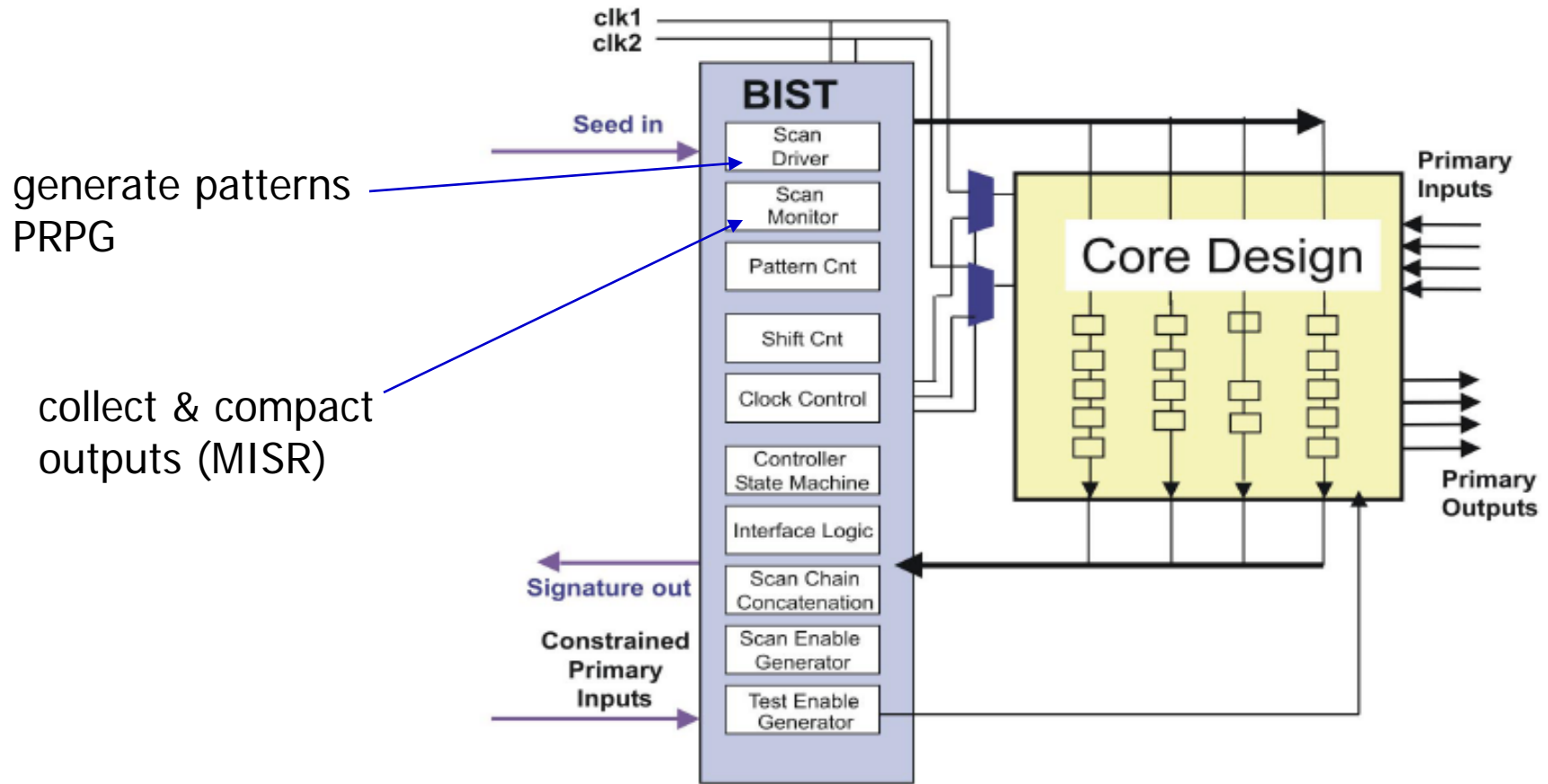


omit xor\_i3 if only 2 outputs to test

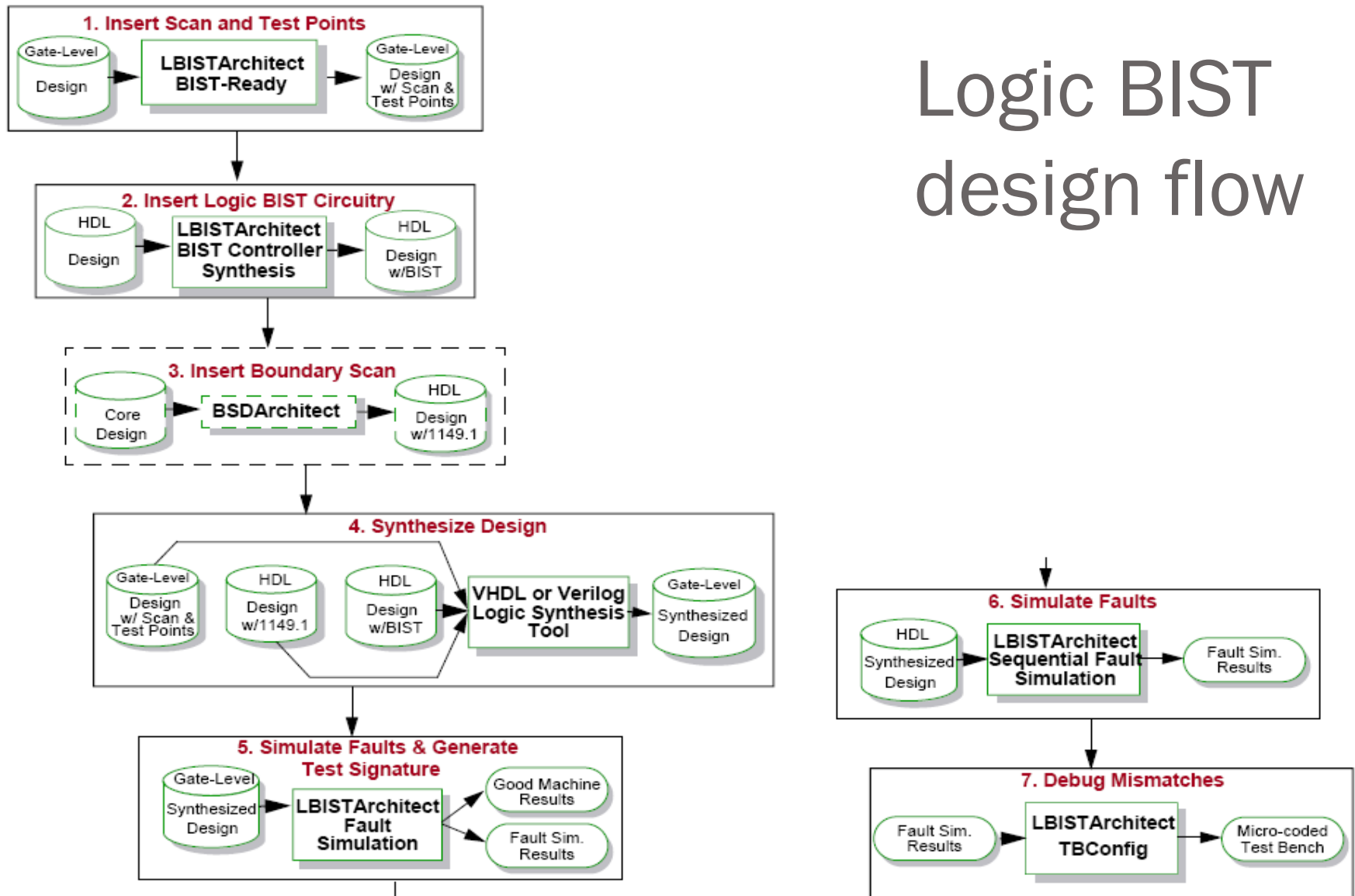
# Mentor Graphics Tools

- LBISTArchitect
  - logic BIST design & insertion
  - Reference: “LBISTArchitect Process Guide”
- MBISTArchitect
  - memory BIST design & insertion
  - Reference: “MBISTArchitect Process Guide”

# Architecture produced by LBISTArchitect

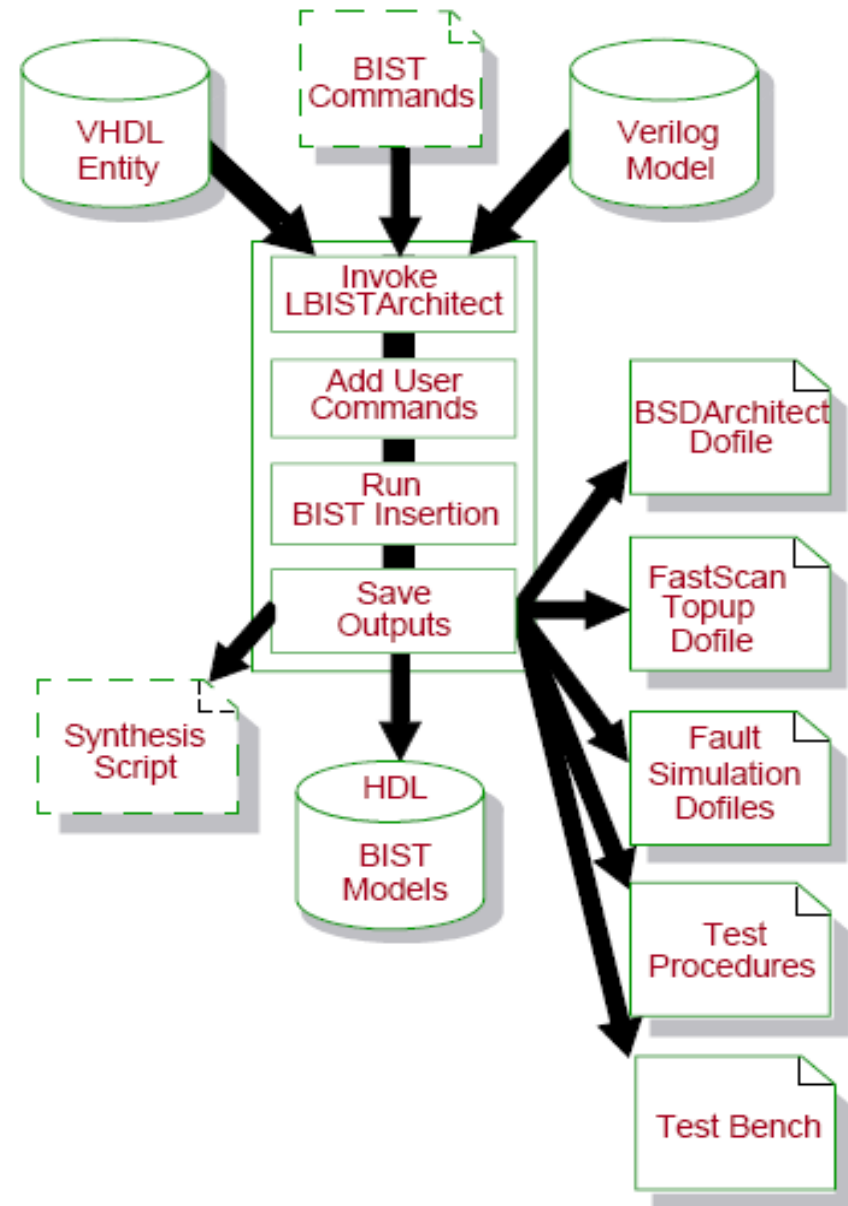


# Logic BIST design flow



Source: Mentor Graphics "LBISTArchitect Process Guide"

# Logic BIST insertion flow



# Logic BIST design phases

- BIST-Ready:
  - check design for testability
  - insert scan circuits & test points
- BIST Controller Generation:
  - produce synthesizable RTL model (VHDL, Verilog)
  - includes scan driver/PRPG, scan monitor/MISR
- Boundary Scan Insertion (optional)
  - BSDarchitect can tie 1149.1 to logic BIST
  - inserts boundary scan ckts & TAP controller

# LOGIC BIST design phases (2)

- Fault simulation & signature generation
  - determine fault coverage of BIST patterns
  - generate signature of “good circuit”
- Sequential fault simulation (optional)
  - determine fault coverage of BIST hardware
- BIST verification (optional)
  - generate test bench for full simulation
- Manufacturing diagnostics (optional)
  - generate info to assist in fault diagnosis



# BIST-ready phase: test point insertion

- Add control test points to gain access to inputs of difficult-to-test gates
- Add observe test points to gain access to outputs of difficult-to-test gates
- MTPI: Multiphase Test Point Insertion
  - break test into phases (ex. 256 patterns each)
  - activate only test points used in a phase
  - add points to improve detection of faults not detected in previous test phases

# MTPI Example

**Table 2-2. Four-Phase Test Point Control Activity**

Phase	Patterns	Activity
0	1—256	No active TP controls
1	257—512	1st TP control active
2	513—768	2nd TP control active
3	769—1024	3rd TP control active

