Circuit Lines for Guiding the Generation of Random Test Sequences for Synchronous Sequential Circuits

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Motivation

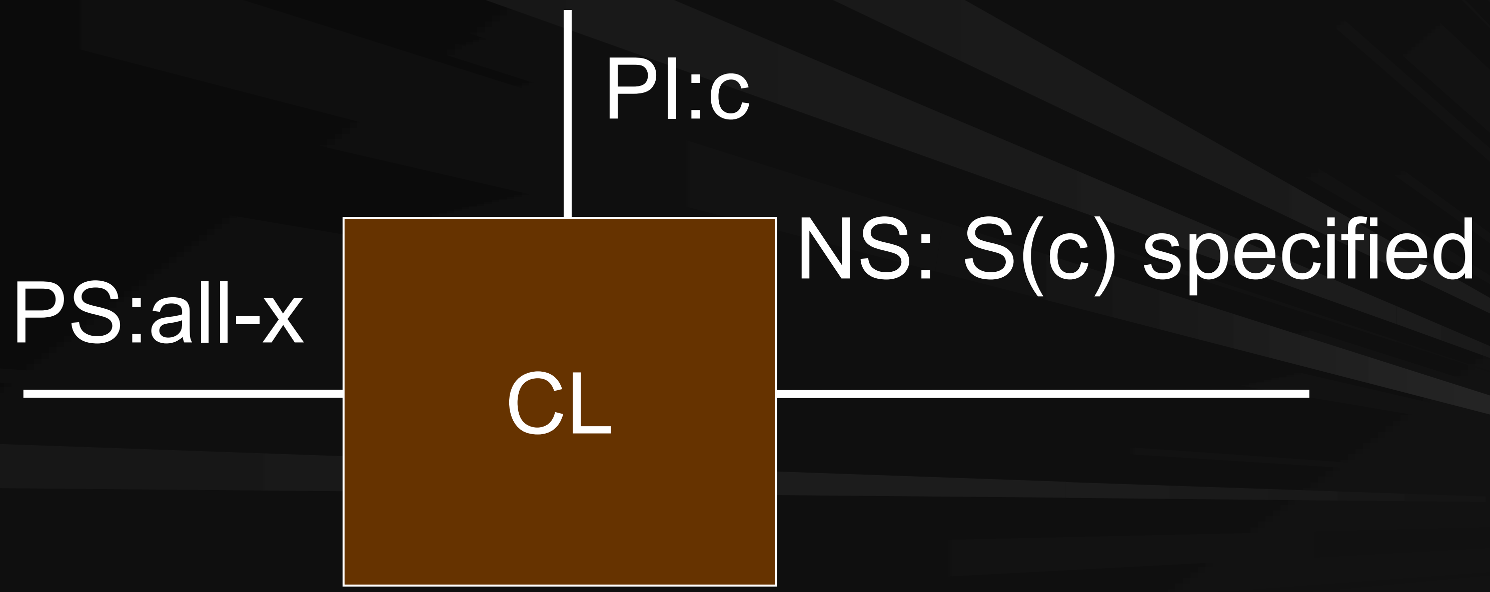
circuit	determ	random
s208	63.72	36.74
s382	91.23	12.28
s526	81.80	8.65
s1423	93.33	41.45
s5378	79.06	63.42
b09	81.19	22.62
b11	92.19	19.01
b14	88.12	44.64

Overview

- Review of repeated synchronization – a cause for the low fault coverage of random primary input sequences.
- Extension of repeated synchronization – internal lines repeatedly set to the same values.
- Internal line selection.
- Experimental results.

Repeated Synchronization
[Pomeranz & Reddy, ETS-07]

- An input cube c synchronizes a subset of state variables S(c) if



Random Input Sequences

- If c has a small number of specified values it is likely to appear often in a random primary input sequence.
- This will cause the state variables in S(c) to be synchronized repeatedly and may prevent faults from being detected.
- Solution: Identify the appearance of input cubes that synchronize state variables and replace them with different values.

Two-Phase Process

- Phase 1: Identify a set of input cubes C that synchronize some or all of the state variables.
- Phase 2: Modify a random primary input sequence T to eliminate the appearances in T of input cubes from C.
- Complexity is polynomial in the circuit size.

Identifying Input Cubes

- For i=0,1,…,M-1:
- Let v_i be a random primary input vector.
- Apply v_i to the primary inputs when the circuit is in the all-x state.
- Find the set $S(v_i)$ of state variables that become specified one time unit later.
- Unspecify bits of v_i that leave all the state variables in $S(v_i)$ specified.

Parameters

- If $S(c_i)$ is small, it is not important to avoid c_i. Require $S(c_i) \geq N_S$ for a constant N_S.
- If c_i has a large number of specified inputs, it is not likely to appear as part of a random input sequence. Consider primary input vectors with N_I specified values, for a constant N_I.
- Avoid an input cube with probability P<1 to allow the circuit to be synchronized.

Results (Fault Coverage)

			modified random	
circuit	determ	random	single	multiple
s208	63.72	36.74	63.26	63.72
s382	91.23	12.28	86.97	89.47
s526	81.80	8.65	70.09	78.56
s1423	93.33	41.45	78.75	89.77
s5378	79.06	63.42	73.32	76.49
b09	81.19	22.62	54.76	80.71
b11	92.19	19.01	83.93	86.04
b14	88.12	44.64	70.21	81.32

Internal Line Values

- If an internal line g assumes a value w repeatedly under a random primary input sequence, faults that require g=w' are not likely to be detected.
- Define a set of lines G that includes next-state variables as well as internal lines.
- Avoid repeated synchronization of all the lines in G.

The Internal Lines in G

- Set $n_0(g)=n_1(g)=0$ for every line g.
- For i=0,1,…,M-1:
- Let v_i be a random primary input vector.
- Apply v_i to the primary inputs when the circuit is in the all-x state.
- For every line g:
  - If g=0 increment $n_0(g)$.
  - If g=1 increment $n_1(g)$.

Interpretation of $n_0(g), n_1(g)$

- We use a limited number M of primary input vectors.
- If $n_w(g)>0$ we expect that a random sequence will be able to set g=w.
- If $n_0(g)=0$ and $n_1(g)=0$ the value of g will be specified when the state is specified.
- We consider g to be likely to be repeatedly set to w (or unlikely to be set to w') if $n_w(g)>0$ and $n_{w'}(g)=0$.

Candidate Lines for G

- If $n_0(g)>0$ and $n_1(g)=0$, $n_{01}(g)=n_0(g)$.
- If $n_1(g)>0$ and $n_0(g)=0$, $n_{01}(g)=n_1(g)$.
- Otherwise, $n_{01}(g)=0$.
- Line g may be included in G only if $n_{01}(g)>0$.
- A higher value of $n_{01}(g)$ makes it more important to include g in G.

Parameter N_{01}

- For a given value of N_{01}, G includes all the next-state variables and every line g such that $n_{01}(g) \geq N_{01}$.
- Possible values for N_{01}: $\{n_{01}(g) > 0\}$.
- In addition, M+1 will allow only next-state variables to be included in G.

Definition of Synchronization

- Given a set of lines G, an input cube c synchronizes a subset of lines S(c) contained in G if applying c to the primary inputs, when the circuit is in the all-unspecified state, results in the specification of the lines in S(c).

Results for a Single Random Primary Input Sequence

- A single random sequence of length L=1000.
- M=10000.
- NS=1, 2, ….
- P=15/16, 14/16, …, 8/16.
- All the possible values of N01.
- Find the best modified random sequence.

Results for a Single Sequence

			modified random	
circuit	determ	random	$N_{01}=M+1$	$N_{01}<M+1$
s208	63.72	36.74	63.26	[7088]63.72
s382	91.23	12.28	86.97	-
s526	81.80	8.65	70.09	[5015]75.50
s1423	93.33	41.45	78.75	[2991]83.30
s5378	79.06	63.42	73.32	-
b09	81.19	22.62	54.76	[4971]70.24
b11	92.19	19.01	83.93	[5007]86.13
b14	88.12	44.64	70.21	[1559]71.42

Best Value of N_{01}

- One of the highest values possible.
- To modify multiple random sequences:
  - The three smallest values of NS.
  - P=15/16, 14/16, …, 8/16.
  - The 10 highest values of N_{01}.
- All combinations for every sequence until 10 sequences do not improve the fault coerage.

Results for Multiple Sequences

			modified random	
circuit	determ	random	single	multiple
s208	63.72	36.74	63.72	
s382	91.23	12.28	86.97	90.98
s526	81.80	8.65	75.50	81.62
s1423	93.33	41.45	83.30	89.77
s5378	79.06	63.42	73.32	76.52
b09	81.19	22.62	70.24	81.19
b11	92.19	19.01	86.13	91.55
b14	88.12	44.64	71.42	80.56

Conclusion

- An internal line may be set repeatedly to the same value by a random primary input sequence.
- This may prevent certain faults from being detected by the sequence.
- A procedure that considers repeated setting of internal lines as well as repeated synchronization of next-state variables can improve the fault coverage significantly.