Evolutionary Optimization of Markov Sources for Pseudo Random Scan BIST

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1 Introduction

Recent work [1] showed that Markov sources lead to scan BIST designs of lower cost compared to earlier proposed methods in scan BIST. However the method presented in [1] utilizes tests generated using a deterministic test generator for target faults in synthesizing the Markov source to generate the tests. The requirement of a deterministic test generator may hinder the use of this procedure in industrial settings since the BIST tool must also include a deterministic ATPG tool that may add to the cost of the BIST tool.

In this paper we investigate a procedure to synthesize BIST controllers with Markov sources for test generation using Evolutionary Algorithms (EAs). This allows us to avoid using the deterministic ATPG needed in [1]. Additionally we do not employ inversion logic used in [1] thereby potentially reducing the hardware in the BIST controller. Nevertheless, the proposed method achieves close to 100% fault efficiency using far fewer tests than required by pseudo random tests.

In this work, similar to [1], we employ Markov sources based on finite state machines (FSMs) with transitions controlled by additional inputs. Hence, *transition probabilities* (TPs) of the FSM are determined by the 1-probability on a corresponding input.

2 Proposed BIST Method

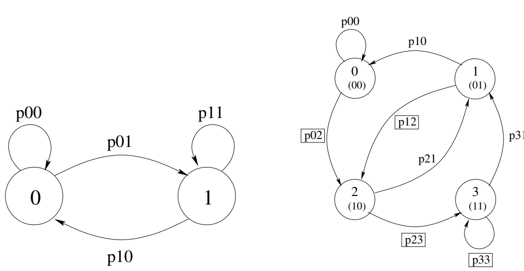

Figure 1: 2- and 4-state FSMs

In Figure 1, the FSMs for 2 and 4 state Markov sources are depicted. These correspond to the ones used in [1]. In this work, we use also the concept of phases and virtual scan chains from [1]. Different TP may be needed for different phases and chains. For phase p and virtual scan chain v, we write $p^{p,v}$ for the corresponding TP. The following algorithm outlines the testing using a 2 state FSM; it is also valid for FSMs with higher number of states except that then additional TPs are employed.

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for p = 1 ... P
  for v = 1 ... V
    Apply bit streams with 1-probabilities $p_{01}^{p,v}$,$p_{10}^{p,v}$ to FSM
    Shift the generated bits into the scan chain
  end for
  Apply the vector to the CUT; capture the response
end for

Now we present the algorithm for determining the number P of phases, the number l_p of patterns applied during phase p, and the TPs $p_{ij}^{p,v}$ for a given phase and virtual scan chain. The number of virtual scan chains, V, is an input of the algorithm.

F := All irredundant faults for the circuit
for P = 1, 2, ...
  Determine transition probabilities $(p_{ij}^{p,1}, p_{ij}^{p,2}, \ldots, p_{ij}^{p,V})$
    so that fault coverage of F is maximized (using EAs)
  $F := F - \{\text{detected faults}\}$
  if (100% coverage achieved
    or no improvement in two consecutive phases)
  then break;
end for

The TPs for a given phase are iteratively determined. EAs are used to get a set of transition probabilities maximizing fault coverage. An individual is a vector containing all transition probabilities for all virtual scan chains. The EA uses 8 known evolutionary operations, such as various crossover and mutation operations.

The best individual found is assigned to the phase, and the processing is repeated for the next phase. (The quality of an individual is defined as the fault coverage determined by fault simulation which stops after no new fault is detected during the last 2048 vectors). The detected faults are dropped. The algorithm stops if either it achieves 100% fault coverage or there are no newly detected faults during two consecutive phases.

3 Experimental Results

We applied our method to the scan versions of ISCAS 89 and ITC 99 circuits. We set the population size to 10, the number of children to 5 and the maximal number of generation without improvement to 7.

The results can be seen in Tables 1–7. The phase number is followed by the number of vectors applied to the circuit under test, the number of faults detected in this phase and the fault coverage. The number of vectors includes all vectors applied in previous phases, and the fault coverage is calculated wrt all these vectors. The number of virtual scan chains, their length and the number of irredundant faults are given in the captions of the tables. More phases mean higher

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fault coverage, but also more area overhead. More vectors will be applied, but their number is quite low and it should not be a major factor in a pseudo-random BIST environment. To the left (right) hand side of each table, results using a 2-state (4-state) FSM are given. Since the number of phases was quite high for larger circuits, we had to aggregate the results for multiple phases due to space limitations.

For all ISCAS benchmarks, we obtain tests detecting at least 99% of irredundant faults. Furthermore, the number of phases can be chosen flexibly, according to the individual fault coverage constraints and available area. The results reported in [1] typically include fewer phases; however, additional *inversion logic* is used in [1] but not in this work, so the hardware overhead is expected to be comparable.

4 References

[1] N.Z. Basturkmen, S.M. Reddy, and I. Pomeranz. Pseudo random patterns using markov sources for scan BIST. Proc. *ITC*, pp. 1013–1021, 2002.

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	72848	6379	98.517	1	57533	6334	97.822
2	79530	71	99.614	2	64744	95	99.290
3	87750	16	99.861	3	16406	30	99.753
4	87750	0	99.861	4	79102	11	99.923
5	89387	3	99.907	6	79884	3	99.969

Table 1: s9234 (6 virtual scan chains, 6475 detectable faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	40677	9459	97.879	1	67667	9478	98.075
2	56365	180	99.741	2	77548	158	99.710
3	57334	21	99.959	3	84706	19	99.907
4	58218	2	99.979	5	88728	9	100.000

Table 2: s13207 (15 virt. scan chains, 9664 detectable faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	37767	11144	98.306	1	41092	10995	96.992
2	63654	146	99.594	2	60063	243	99.135
3	69775	6	99.647	3	69210	38	99.471
4	70101	2	99.665	4	71833	8	99.541
5	72820	2	99.682	5	75140	6	99.594
10	78046	7	99.744	10	83245	12	99.700
15	84367	5	99.788	15	90182	8	99.771
17	85669	1	99.797	31	101211	13	99.885

Table 3: s15850 (13 virt. scan chains, 11336 detect. faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	82055	34226	98.359	1	115771	34457	99.023
2	121283	351	99.368	2	140379	271	99.802
3	139395	116	99.701	3	147271	37	99.908
4	144186	25	99.773	4	154875	12	99.943
5	147909	11	99.805	5	156913	9	99.968
16	161764	51	99.951	9	158174	3	99.977

Table 4: s38584 (23 virt. scan chains, 34797 detect. faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	12342	35110	100.000	1	13159	35110	100.000

Table 5: s35932 (14 virt. scan chains, 35932 detect. faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	81984	29595	95.422	1	67659	29676	95.683
2	121735	566	97.246	2	91934	385	96.924
3	150453	176	97.814	3	112159	223	97.643
4	163418	61	98.011	4	126711	89	97.930
5	172593	51	98.175	5	130704	26	98.014
6	182024	31	98.275	6	142662	50	98.175
10	203304	140	98.726	10	169389	165	98.707
15	216218	54	98.901	15	182366	63	98.910
20	227603	32	99.004	20	192622	31	99.010
25	236794	41	99.136	25	206773	43	99.149
30	251194	29	99.229	30	215533	37	99.268
35	264175	19	99.291	35	229127	24	99.345
40	272191	8	99.316	40	233877	15	99.394
50	280663	27	99.404	45	243713	13	99.436
57	289430	13	99.445	47	246940	6	99.455

Table 6: s38417 (26 virt. scan chains, 31015 detect. faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	35139	11781	93.970	1	48719	11654	92.957
2	78417	337	96.658	2	90570	370	95.908
3	93275	70	97.216	3	113314	144	97.057
4	101441	30	97.456	4	124578	56	97.503
5	108905	32	97.711	5	134009	30	97.743
10	151310	120	98.668	6	135774	1	97.751
15	161832	13	98.772	10	140349	19	97.902
30	180019	26	98.979	20	177959	108	98.764
38	192034	19	99.131	30	189111	24	98.955

Table 7: b14 (6 virt. scan chains, 12537 detectable faults)

2 states:				4 states:			
Ph	# of vectors	New det. faults	Cumul. coverage	Ph	# of vectors	New det. faults	Cumul. coverage
1	79647	21815	94.765	1	89669	22275	96.764
2	136984	676	97.702	2	109221	178	97.537
3	144468	81	98.054	3	120227	58	97.789
4	154703	92	98.454	4	127938	39	97.958
5	156092	10	98.497	5	130823	85	98.328
6	159218	8	98.532	6	133269	15	98.393
10	169395	28	98.653	10	143209	63	98.666
15	201366	99	99.083	15	155069	42	98.849
20	218721	49	99.296	20	161269	31	98.983
25	225125	20	99.383	30	179915	40	99.157
30	230567	9	99.422	40	192952	17	99.288
33	235468	9	99.461	51	206023	29	99.409

Table 8: b15 (8 virt. scan chains, 23020 detectable faults)