Results

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trojan Coverage | | | | | |
| Circuit | Golden Reference | Trojan 1 | | Trojan 2 | |
| Location 1 | Location 2 | Location 1 | Location 2 |
| C17 | 0 | 0.5 | 0.5 | 1 | 0.5 |
| C432 | 0 | 0.4285 | 0.4285 | 0.4285 | 0.4285 |
| C499 | 0 | 0.125 | 0.09375 | 0.0625 | 0.03125 |
| C880 | 0 | 0.03846 | 0.0769 | 0.2307 | 0.0769 |
| C1908 | 0 | 0.24 | 0.04 | 0.28 | 0.04 |
| C2670 | 0 | 0.0214 | 0.00714 | 0.00714 | 0.0214 |
| C3540 | 0 | 0.2272 | 0.1363 | 0.1363 | 0.04545 |
| C5315 | 0 | 0.0325 | 0.02439 | 0.04065 | 0.0325 |
| C6288 | 0 | 0.25 | 0.21875 | 0.1875 | 0.15625 |
| C7552 | 0 | 0.00925 | 0.00925 | 0.00925 | 0.00925 |

Trojan Coverage = Output Changed by unknown Circuit compared to reference circuit / Total length of the output

Let us take a benchmark circuits and add two types of Trojans in two locations, Therefore totally there are four combinations of circuits we will have in our hands. Let us consider these four circuits as unknown circuits. Now we put this Trojan into our algorithm and calculate Trojan coverage mentioned above. Now compare the Trojan coverage for the reference circuit and the unknown circuit. The output is changed for the unknown circuits because of the Trojan inserted. So we conclude that Trojan is present in the circuit. In case, if we provide the reference circuit/ Trojan free unknown circuit, the Trojan coverage will be same as the reference circuit.

Here are the Graph for the visualization:

Circuit vs Trojan coverage

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C17 | |
| Trojan 1 | Location 1 | 01100 | 0.25 | 0.5 |
| Location 2 | 10101 | 0.5 | 0.75 |
| Trojan 2 | Location 1 | 01010 | 0.25 | 0.5 |
| Location 2 | 10101 | 0.5 | 0.75 |

Trigger coverage = Number of rare nodes triggered for the pattern/ total no of rare nodes

As we can see in the table, In C17 pattern 01100 is given to the reference circuit and calculated the trigger coverage and same pattern is given to the unknown circuit and calculated the trigger coverage. The trigger coverage for Unknown/ Trojan circuit is not equal to the reference circuit.

From this we can conclude that no of rare nodes are getting triggered is increased or decreased due to Trojan present in the circuit. Thus the unknown circuit is Trojan infected circuit. In case of Trojan free circuit, the trigger coverage will be same as the reference circuit.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C499 | |
| Trojan 1 | Location 1 | 01111100010111011111101100011001101000101 | 0.125 | 0.25 |
| Location 2 | 11111011010111101011111100101001101110001 | 0.0625 | 0.25 |
| Trojan 2 | Location 1 | 00101100011010101111001100100001001101000 | 0.125 | 0.125 |
| Location 2 | 10110001101110001100110110111111111011011 | 0.125 | 0.125 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C432 | |
| Trojan 1 | Location 1 | 001111101101011111101111011111111011 | 0.574074074 | 0.574074074 |
| Location 2 | 111111101010111111101101011110111011 | 0.62962963 | 0.592592593 |
| Trojan 2 | Location 1 | 111101001111101111111111111011011111 | 0.444444444 | 0.462962963 |
| Location 2 | 001101111011011110101111111111111111 | 0.259259259 | 0.222222222 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C880 | |
| Trojan 1 | Location 1 | 101111111001111010011111100111011110011001001010111100101101 | 0.469135802 | 0.481481481 |
| Location 2 | 001010110111011001111110010011110111111111011101111111111111 | 0.567901235 | 0.617283951 |
| Trojan 2 | Location 1 | 110001101111111011010101110011111111110110101011001011010110 | 0.358024691 | 0.481481481 |
| Location 2 | 011110111110110100111101001111010001111011110111011001100110 | 0.407407407 | 0.456790123 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C1908 | |
| Trojan 1 | Location 1 | 010111010111111110001100111111110 | 0.440860215 | 0.455197133 |
| Location 2 | 010110100110010111011011001100111 | 0.329749104 | 0.326164875 |
| Trojan 2 | Location 1 | 111101011111111111111011111101110 | 0.41218638 | 0.372759857 |
| Location 2 | 011010110110011110101010110100110 | 0.41218638 | 0.422939068 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |
| C2670 | |
| Trojan 1 | Location 1 | 11110110111110111010111111111110111110011111101011101001111100100110011111110000110111010101100001111110111111010111110011111111011111111111000111011100000111101101111111011111101110001111111111111101011110110011111111111011111101011 | 0.362637363 | 0.318681319 |
| Location 2 | 11001111100011000001110101111011010111100000101001110111101010000011011101111111001001111110000111111010111101010101111001110010101111111111111011110011111010111111011110111111101110111110101001010110011001000111101110010011111110101 | 0.285714286 | 0.263736264 |
| Trojan 2 | Location 1 | 01101111101101111010110111110101111011011111011000011110101110011010011011110111111101111111001001011100111111111100110111111101111001111010010110101111100000101110111110101100110001110011011111110111101111101001111111011101111111111 | 0.351648352 | 0.32967033 |
| Location 2 | 01011110011110111101111101110111101111001101111101010011011010010000101111111011001101101000000011111011111011101110000111010000000111101000111011100011010111111011110111101110111111101010011011100011001101010110111111101011101111111 | 0.296703297 | 0.307692308 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Circuit | | Pattern | Golden reference | Trojan Circuit |  | Circuit | | Pattern | Golden reference | Trojan Circuit |
| C3540 | |  | C5315 | |
| Trojan 1 | Location 1 | 10110010111111110101110111111100111101101111110111 | 0.381443299 | 0.451546392 |  | Trojan 1 | Location 1 | 1110111111011101111010111011011101110101101010011111011110110001110011111011111111111111101111011111011101101101110111111001100111101111111110111111101111000100011111011010110101 | 0.48582996 | 0.44534413 |
| Location 2 | 01111101101011111101111011110101011110111101101110 | 0.479381443 | 0.469072165 |  | Location 2 | 1111101010101111100001111111011100101011111111111101111101110111111111101101101101110101101111111111111110111011111110111111100001101010111010111111101000100001101111011110011101 | 0.388663968 | 0.400809717 |
| Trojan 2 | Location 1 | 10110101101100100100100110011100101001001001100111 | 0.317010309 | 0.386597938 |  | Trojan 2 | Location 1 | 1101110111001111110111111111111110111110111111111111111110111011111111110101110011110111111111011110100111111011111111011011111011111101111111101111111111110101011111100010110101 | 0.51417004 | 0.473684211 |
| Location 2 | 00011111101110111011001111011111110011100111100000 | 0.507731959 | 0.510309278 |  | Location 2 | 1111111111101110101111101101110010111111101101110111111111111101101101011111111100011101011111111101011111011111011111101011011111111110111111110111111110111000001110111111100101 | 0.388663968 | 0.392712551 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| Circuit | | Pattern | Golden reference | Trojan Circuit |  | Circuit | | Pattern | Golden reference | Trojan Circuit |
| C6288 | |  | C7552 | |
| Trojan 1 | Location 1 | 11111001010001111100111111111110 | 0.459713297 | 0.469105289 |  | Trojan 1 | Location 1 | 111111011111101101111101101010111010000110110011111010101100111101111011111111110110010111110110111110110000111000011111101101010110101111111111101101111111011111110111111111111111101100101111011011000011101 | 0.37037037 | 0.373897707 |
| Location 2 | 01111111011011011101111010011010 | 0.434997528 | 0.439940682 |  | Location 2 | 000110111111110101110101110110101011001001010000000011000000111111010011111101100101100001111110110101001010111111010001101101000101111110101110010011111001011101011011100101011101111001010011101010010101110 | 0.333333333 | 0.328042328 |
| Trojan 2 | Location 1 | 11101010111111111011110101011111 | 0.447355413 | 0.45724172 |  | Trojan 2 | Location 1 | 000110100111011111110111111111100100110001100111010101010101111111010111111111111111100000101101001101010111011011111011011001111111111111101000010010110111100111000110111100001011111110010110111011110100101 | 0.372134039 | 0.384479718 |
| Location 2 | 10111111000001111111110111111111 | 0.435491844 | 0.423133959 |  | Location 2 | 111111101010011001000001001100100101001111011100101011101000001111101100011100111100000100010110110000000111110110101110010100101011010101001010100010000001111110101001111111010110100110110010000000111010110 | 0.312169312 | 0.310405644 |

Circuit vs pattern vs Trigger coverage:

In C499 For 2 patterns the Trigger coverage is same. Hence the patterns did not trigger the Trojans.

Circuits vs average fitness score vs no of rare nodes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Circuits** | **Threshold** | **No of rare Nodes** | **Average fitness Score** | **No of Gates** |
| C17 | 0.3 | 4 | 7.8 | 6 |
| C499 | 0.1 | 16 | 326.94 | 202 |
| C432 | 0.1 | 54 | 520.49 | 160 |
| C880 | 0.05 | 81 | 912.91 | 383 |
| C2670 | 0.01 | 91 | 3427.98 | 1269 |
| C1908 | 0.01 | 279 | 4297.48 | 880 |
| C5315 | 0.001 | 247 | 6501.49 | 2307 |
| C3540 | 0.001 | 388 | 8812.24 | 1669 |
| C7552 | 0.001 | 567 | 30358.49 | 3513 |
| C6288 | 0.001 | 2023 | 360838.74 | 2416 |

Circuits’ vs average fitness score:

Average fitness score vs no of rare nodes:

We conclude that the average fitness score of the algorithm increases when number of rare nodes increased.

Number of gates vs runtime of algorithm:

|  |  |  |
| --- | --- | --- |
| DE algorithm runtime for circuits with 1 iteration, Theta = 0.3, Population size =10 and CR = 0.7 | |  |
| **circuits** | **time (sec)** | **No of Gates** |
| c17 | 0.0168438 | 6 |
| c17\_trojan2\_location1\_node16 | 0.01562071 | 8 |
| c17\_trojan2\_location2\_node19 | 0.03590894 | 8 |
| c17\_trojan1\_location1\_node16 | 0.03236604 | 9 |
| c17\_trojan1\_location2\_node19 | 0.01565957 | 9 |
| c432 | 0.20824051 | 160 |
| c432\_trojan2\_location1\_node386 | 0.21444082 | 162 |
| c432\_trojan2\_location2\_node404 | 0.21077442 | 162 |
| c432\_trojan1\_location1\_node386 | 0.21473575 | 163 |
| c432\_trojan1\_location2\_node404 | 0.2105751 | 163 |
| c499 | 0.2647078 | 202 |
| c499\_trojan2\_location1\_node635 | 0.25548649 | 204 |
| c499\_trojan2\_location2\_node645 | 0.26508212 | 204 |
| c499\_trojan1\_location1\_node635 | 0.26459312 | 205 |
| c499\_trojan1\_location2\_node645 | 0.26363945 | 205 |
| c880 | 0.56864977 | 383 |
| c880\_trojan2\_location1\_node773 | 0.55897856 | 385 |
| c880\_trojan2\_location2\_node815 | 0.74413371 | 385 |
| c880\_trojan1\_location1\_node773 | 0.55763102 | 386 |
| c880\_trojan1\_location2\_node815 | 0.56485629 | 386 |
| c1908 | 1.96343493 | 880 |
| c1908\_trojan2\_location1\_node2750 | 2.00688052 | 882 |
| c1908\_trojan2\_location2\_node2776 | 1.98300362 | 882 |
| c1908\_trojan1\_location1\_node2750 | 2.01367593 | 883 |
| c1908\_trojan1\_location2\_node2776 | 2.00691366 | 883 |
| c2670 | 3.5222671 | 1269 |
| c2670\_trojan2\_location1\_node3731 | 3.38691425 | 1271 |
| c2670\_trojan2\_location2\_node3806 | 3.27020335 | 1271 |
| c2670\_trojan1\_location1\_node3731 | 3.607054 | 1272 |
| c2670\_trojan1\_location2\_node3806 | 3.45253301 | 1272 |
| c3540 | 6.02235484 | 1669 |
| c3540\_trojan2\_location1\_node4847 | 5.71671891 | 1671 |
| c3540\_trojan2\_location2\_node5021 | 6.14354944 | 1671 |
| c3540\_trojan1\_location1\_node4847 | 5.7197032 | 1672 |
| c3540\_trojan1\_location2\_node5021 | 5.40652132 | 1672 |
| c5315 | 9.42479253 | 2307 |
| c5315\_trojan2\_location1\_node7935 | 9.06172562 | 2309 |
| c5315\_trojan2\_location2\_node8004 | 9.44065142 | 2309 |
| c5315\_trojan1\_location1\_node7935 | 9.5944283 | 2310 |
| c5315\_trojan1\_location2\_node8004 | 9.27974367 | 2310 |
| c6288 | 10.8688221 | 2416 |
| c6288\_trojan2\_location1\_node2020 | 11.553122 | 2418 |
| c6288\_trojan2\_location2\_node4001 | 10.948987 | 2418 |
| c6288\_trojan1\_location1\_node2020 | 10.6772475 | 2419 |
| c6288\_trojan1\_location2\_node4001 | 11.4014504 | 2419 |
| c7552 | 20.9613919 | 3513 |
| c7552\_trojan2\_location1\_node6776 | 21.3212163 | 3515 |
| c7552\_trojan2\_location2\_node9301 | 20.2043607 | 3515 |
| c7552\_trojan1\_location1\_node6776 | 20.6257343 | 3516 |
| c7552\_trojan1\_location2\_node9301 | 21.3419478 | 3516 |

We can see that the runtime of algorithm depends on number of gates in the circuit.

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In this table the SCOAP parameters are compared to the Reference circuit and Trojan detect circuit at the Trojan inserted Node.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Trojan 1 | | | | | | | | | | | | | | | |
| circuit | | Trojan inserted Node | | Without Trojan | | | | | | With Trojan | | | | | |
|  | |  | | CC0 | | CC1 | | CO | | CC0 | | CC1 | | CO | |
| C17 | | 16 | | 4 | | 2 | | 3 | | 4 | | 2 | | 11 | |
| C17 | | 19 | | 4 | | 2 | | 3 | | 4 | | 2 | | 11 | |
| C432 | | 386 | | 8 | | 2 | | 19 | | 8 | | 2 | | 27 | |
| C432 | | 404 | | 8 | | 2 | | 19 | | 8 | | 2 | | 27 | |
| C499 | | 635 | | 27 | | 216 | | 29 | | 27 | | 216 | | 276 | |
| C499 | | 645 | | 27 | | 216 | | 29 | | 27 | | 216 | | 276 | |
| C880 | | 773 | | 15 | | 9 | | 37 | | 15 | | 9 | | 59 | |
| C880 | | 815 | | 28 | | 10 | | 35 | | 28 | | 10 | | 59 | |
| C1908 | | 2750 | | 90 | | 65 | | 113 | | 90 | | 65 | | 247 | |
| C1908 | | 2776 | | 3 | | 93 | | 26 | | 3 | | 93 | | 126 | |
| C2670 | | 3731 | | 38 | | 61 | | 0 | | 38 | | 61 | | 103 | |
| C2670 | | 3806 | | 22 | | 80 | | 736 | | 22 | | 80 | | 852 | |
| C3540 | | 4847 | | 59 | | 60 | | 10 | | 59 | | 60 | | 133 | |
| C3540 | | 5021 | | 34 | | 19 | | 136 | | 34 | | 19 | | 178 | |
| C5315 | | 7935 | | 25 | | 40 | | 44 | | 25 | | 40 | | 113 | |
| C5315 | | 8004 | | 25 | | 40 | | 22 | | 25 | | 40 | | 91 | |
| C6288 | | 2020 | | 24 | | 25 | | 1380 | | 24 | | 25 | | 1434 | |
| C6288 | | 4001 | | 4 | | 11 | | 1732 | | 4 | | 11 | | 1812 | |
| C7552 | | 6776 | | 4 | | 50 | | 196 | | 4 | | 50 | | 263 | |
| C7552 | | 9301 | | 50 | | 12 | | 318 | | 50 | | 12 | | 346 | |
| Trojan 2 | | | | | | | | | | | | | | |
| circuit | Trojan inserted Node | | Without Trojan | | | | | | With Trojan | | | | | |
|  |  | | CC0 | | CC1 | | CO | | CC0 | | CC1 | | CO | |
| C17 | 16 | | 4 | | 2 | | 3 | | 4 | | 2 | | 6 | |
| C17 | 19 | | 4 | | 2 | | 3 | | 4 | | 2 | | 6 | |
| C432 | 386 | | 8 | | 2 | | 19 | | 8 | | 2 | | 22 | |
| C432 | 404 | | 8 | | 2 | | 19 | | 8 | | 2 | | 22 | |
| C499 | 635 | | 27 | | 216 | | 29 | | 27 | | 216 | | 58 | |
| C499 | 645 | | 27 | | 216 | | 29 | | 27 | | 216 | | 57 | |
| C880 | 773 | | 15 | | 9 | | 37 | | 15 | | 9 | | 45 | |
| C880 | 815 | | 28 | | 10 | | 35 | | 28 | | 10 | | 46 | |
| C1908 | 2750 | | 90 | | 65 | | 113 | | 90 | | 65 | | 131 | |
| C1908 | 2776 | | 3 | | 93 | | 26 | | 3 | | 93 | | 30 | |
| C2670 | 3731 | | 38 | | 61 | | 0 | | 38 | | 61 | | 32 | |
| C2670 | 3806 | | 22 | | 80 | | 736 | | 22 | | 80 | | 770 | |
| C3540 | 4847 | | 59 | | 60 | | 10 | | 59 | | 60 | | 18 | |
| C3540 | 5021 | | 34 | | 19 | | 136 | | 34 | | 19 | | 143 | |
| C5315 | 7935 | | 25 | | 40 | | 44 | | 25 | | 40 | | 70 | |
| C5315 | 8004 | | 25 | | 40 | | 22 | | 25 | | 40 | | 48 | |
| C6288 | 2020 | | 24 | | 25 | | 1380 | | 24 | | 25 | | 1396 | |
| C6288 | 4001 | | 4 | | 11 | | 1732 | | 4 | | 11 | | 1764 | |
| C7552 | 6776 | | 4 | | 50 | | 196 | | 4 | | 50 | | 217 | |
| C7552 | 9301 | | 50 | | 12 | | 318 | | 50 | | 12 | | 331 | |

The CO i.e. Observability of the node is increased when compared to the Reference circuit due to Trojan insertion.