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EECS DEPARTMENT

MERO: A Statistical Approach for Hardware Trojan Detection

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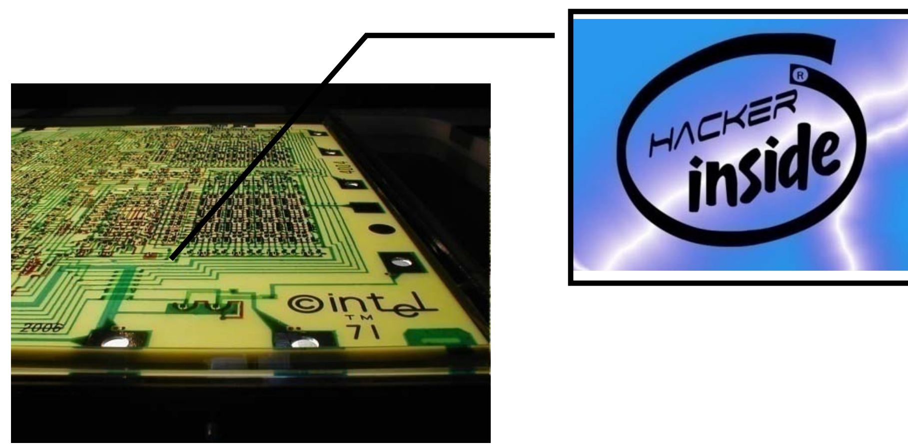
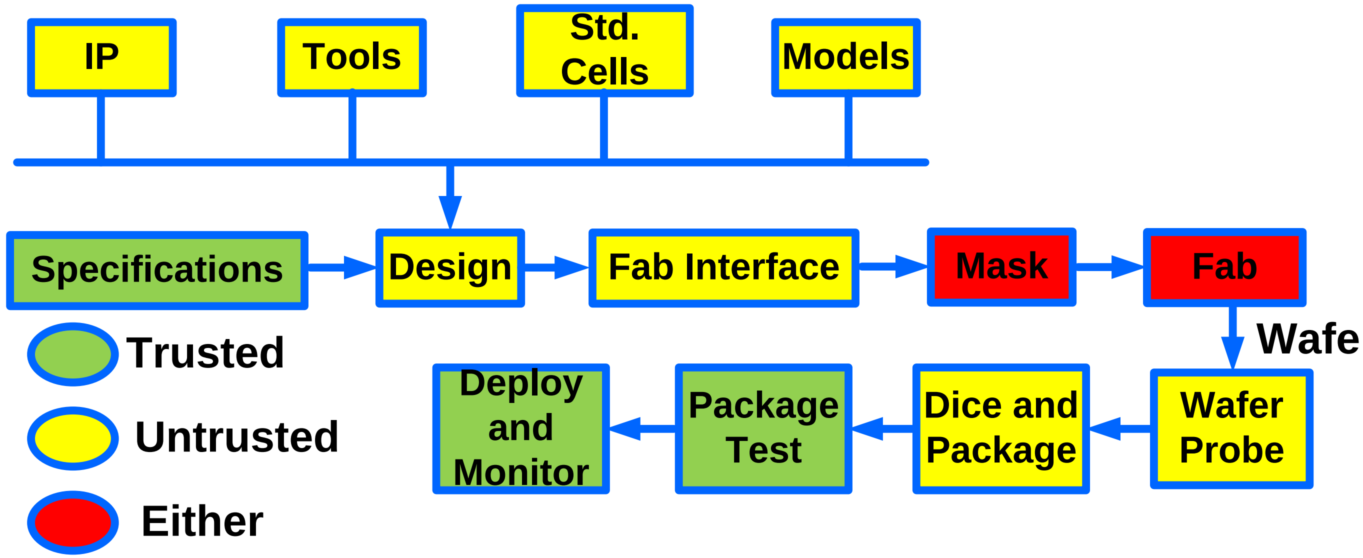
CHES-2009

Outline

- **Introduction**
- **Background and Motivation**
  - **Existing approaches of Trojan detection**
  - **Motivation for a statistical approach**
- **Proposed Technique**
  - **Overview**
  - ***MERO: Multiple Excitation of Rare Occurrence***
  - **Automation**
- **Results**
- **Conclusion**



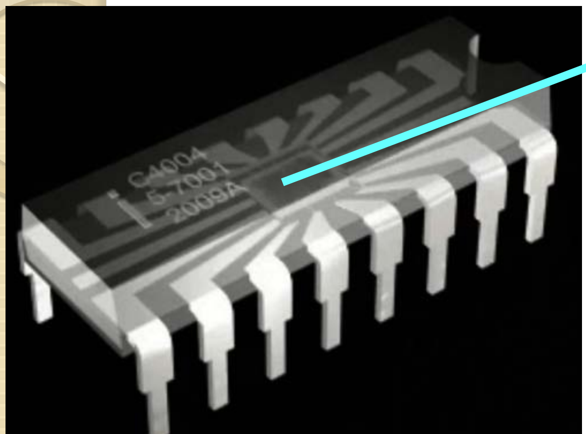
Modern IC Design & Manufacturing

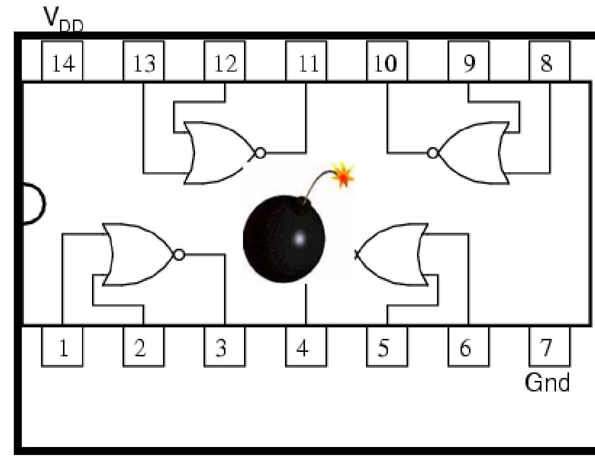


- **Economics of IC Design and Manufacturing:**
  - ***Intellectual Property*** **(IP) based designs**
  - ***Fabless*** **manufacturing model (trend on the rise)**
  - **Outsourcing of manufacturing to offshore *fabs***
  - **Loss of control over design and manufacture**
  - **Potentially untrusted parties getting involved**

http://www.darpa.mil/MTO/solicitations/baa07-24/index.html

What are Hardware Trojans?

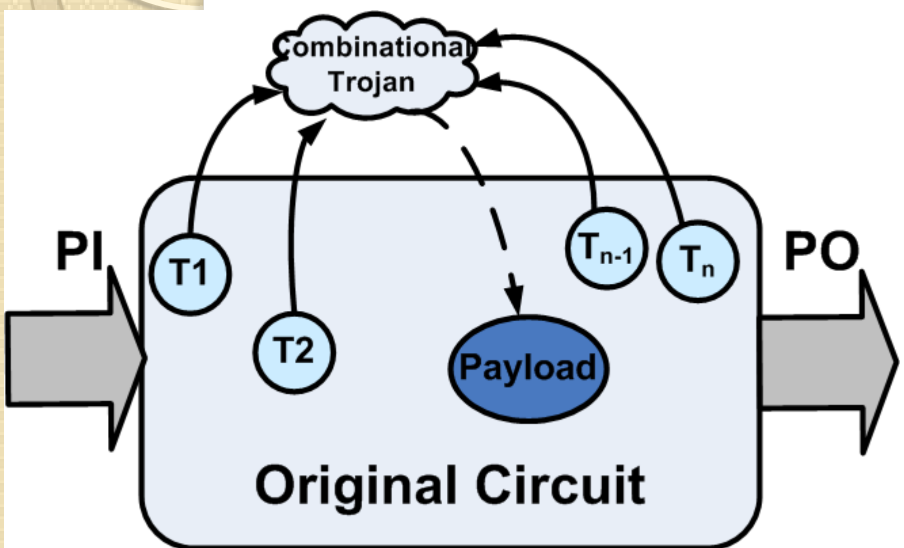




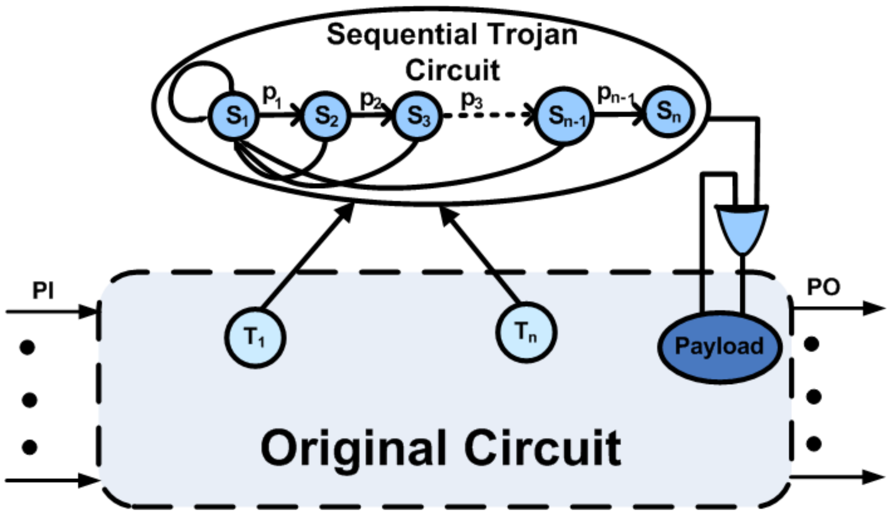
- **Malicious modifications to design**
  - **Causes IC to malfunction in-field**
  - **Can take place during design or fabrication**
  - **Inserted by an intelligent adversary**
  - ***Stealthy* => difficult to detect**
- **Results:**
  - **Potentially disastrous consequences in critical areas e.g. military installations, civilian infrastructures**

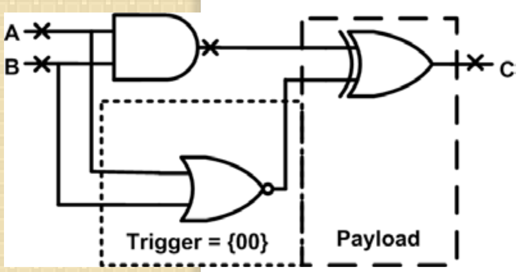
Hardware Trojan: Examples

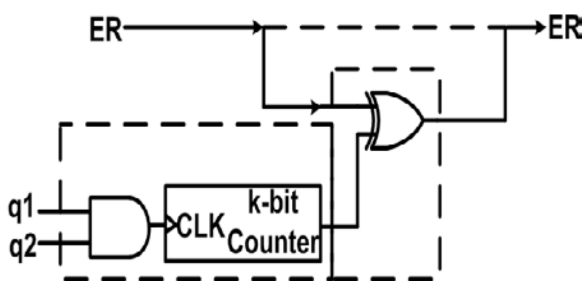
Combinational Trojan model

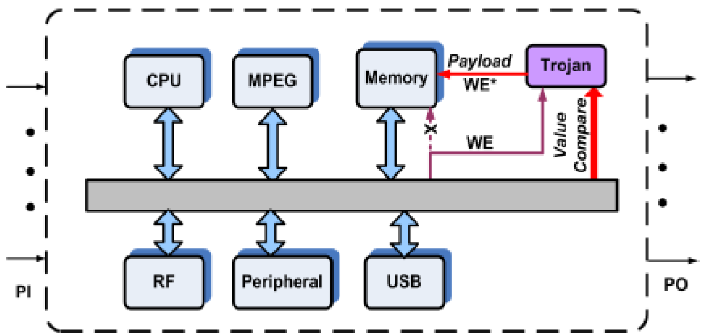


Sequential Trojan Model







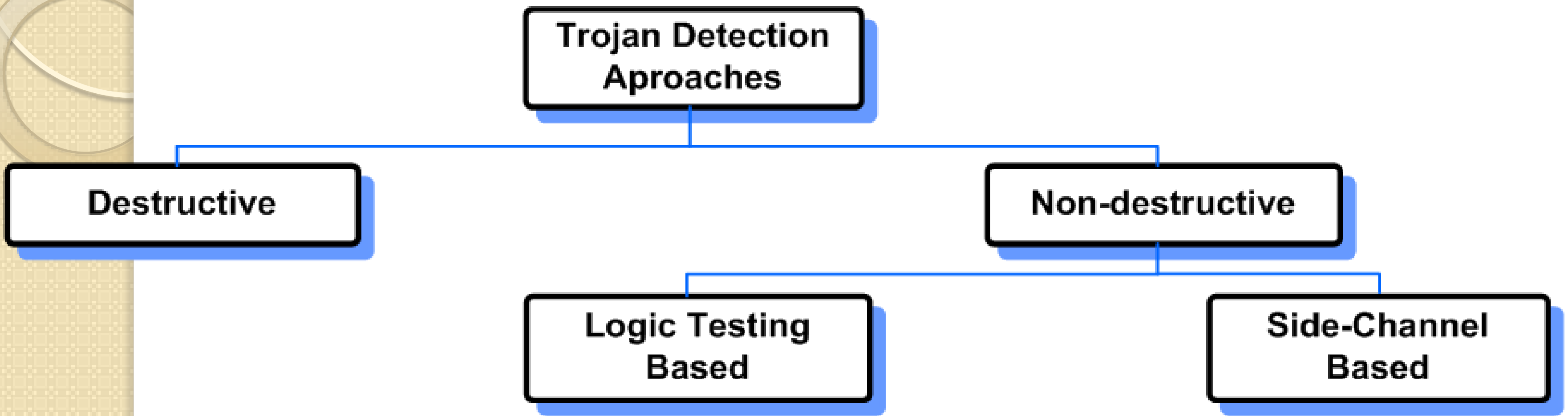


Comb Trojan Example

Seq Trojan (time-bomb) Example

System level view

Hardware Trojan Detection



	Logic Testing Approach	Side-Channel Analysis Approach
Pros	• Robust under process noise • Effective for ultra-small Trojans	• Effective for large Trojans • Easy to generate test vectors
Cons	• Difficult to generate test vectors • Large Trojan detection challenging	• Vulnerable to process noise • Ultra-small Trojan detection challenging

The proposed approach target both logic testing & side-channel analysis!

Chakraborty et al, HOST 2008

Wolff et al, DATE 2008

Why Statistical Approach?

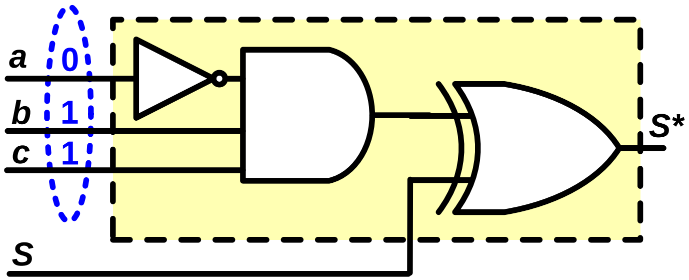
- **Feasible Trojan search space is inordinately large!**
  - **Combinatorial function of number of circuit nodes**
  - **Exhaustive enumeration impossible**
  - ***Deterministic* test generation computationally infeasible**
  - **Adversary likely to choose rarely triggered/observed Trojans**

- **A Statistical Approach for Trojan Detection**
  - **Finds the rare events in the circuit**
  - **Generates test vectors to trigger each trigger node multiple times**
  - **Provides high confidence about the *quality of testset***

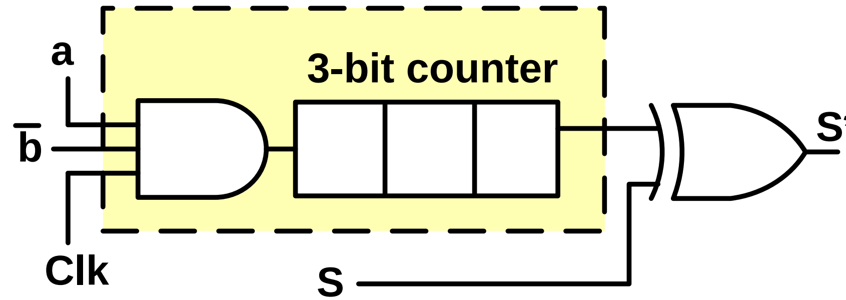
Multiple Excitation of Rare Occurrences (MERO) Approach

- **Assumptions:**
  - **An inserted Trojan has a small but non-zero activation probability**
  - **Can be combinational/sequential consisting of *q* trigger nodes**
- **Method:**
  - **Apply test vectors that trigger each node to its rare value at least *N* times**
- **Main inferences of analysis:**
  - **Expected number of times of Trojan getting triggered proportional to *N***
  - **Trojan triggering probability decreases as number of trigger nodes (*q*) increase**
  - **Trojan triggering probability increases if trigger probability of individual trigger nodes (θ) increases**

Circuit Example



(i) Combinational Trojan



(ii) Sequential Trojan

- **Trojan Trigger Condition:**

  (i) a=0, b=1, c=1 ***(ii) a=1, b=0***
- **Generate vectors to satisfy each of these conditions multiple (*N*) times**
- **Probability of Trojan activation increases with *N***
- **The concept is similar to *N-Detect Tests****

** I. Pomeranz and S.M. Reddy, 2004.*

MERO Steps

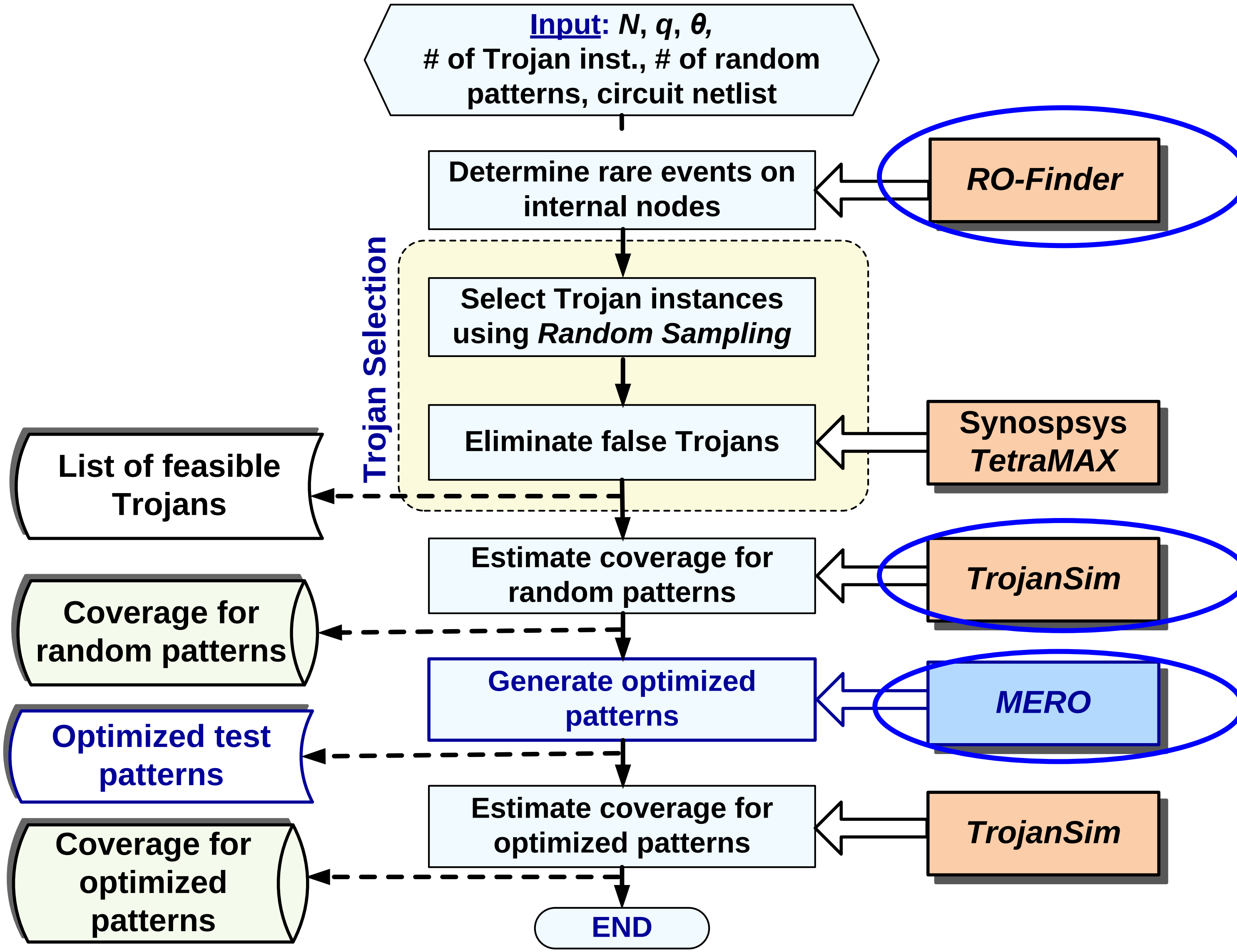
Test Generation Steps

- **Determine *rare nodes* and associated *rare values***
- **Generate random vectors**
- **Rank vectors with decreasing rare node trigger probability (*r*)**
- **For each vector in the ranked list**
  - **Perturb one/two bit(s) at a time**
  - **Retain the perturbation if *r* improves**
- **Stop if all rare nodes are excited to their rare values *N* times**

Trojan Coverage Steps

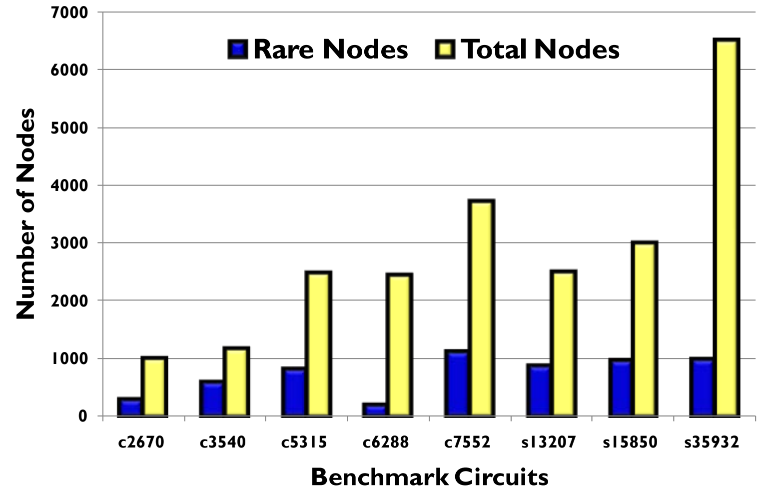
- **Create Trojans with trigger node probability < *θ* *(trigger-threshold)***
- **Perform *Random Sampling* over Trojan space**
- **Eliminate *False Trojans* (by justification)**
- **Perform functional simulation for an input testset**

MERO Implementation & Validation

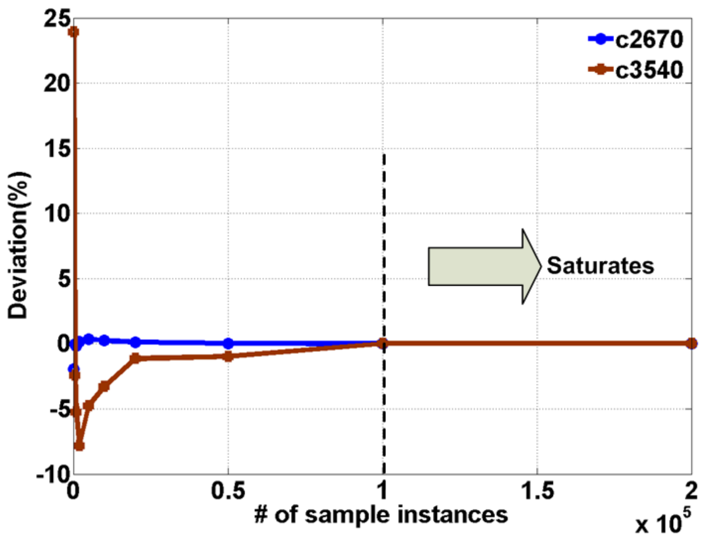


Simulation Results

- **ISCAS'85 and ISCAS'89 ckts**
  - **Comb/seq Trojans**
  - **# of trigger nodes (*q*) set to 2 or 4**
  - ***Θ* set to 0.2**

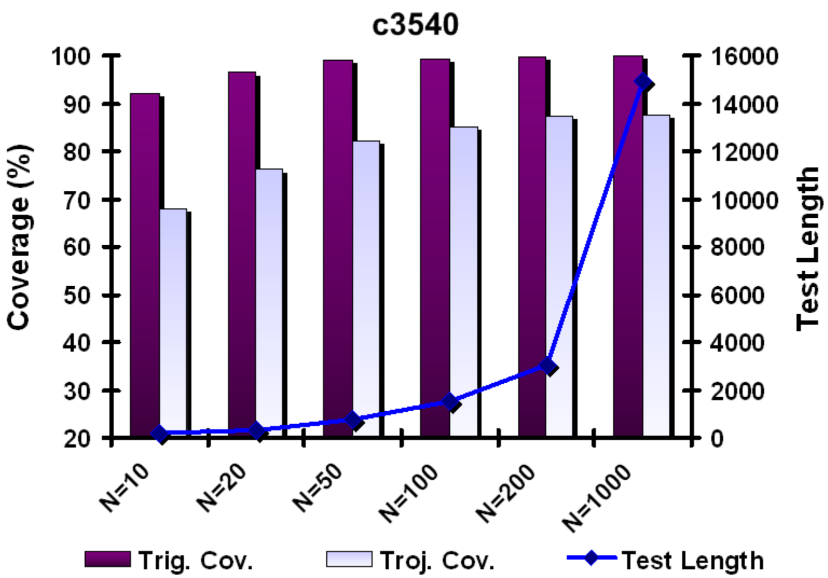


Effect of Sample Size on Coverage



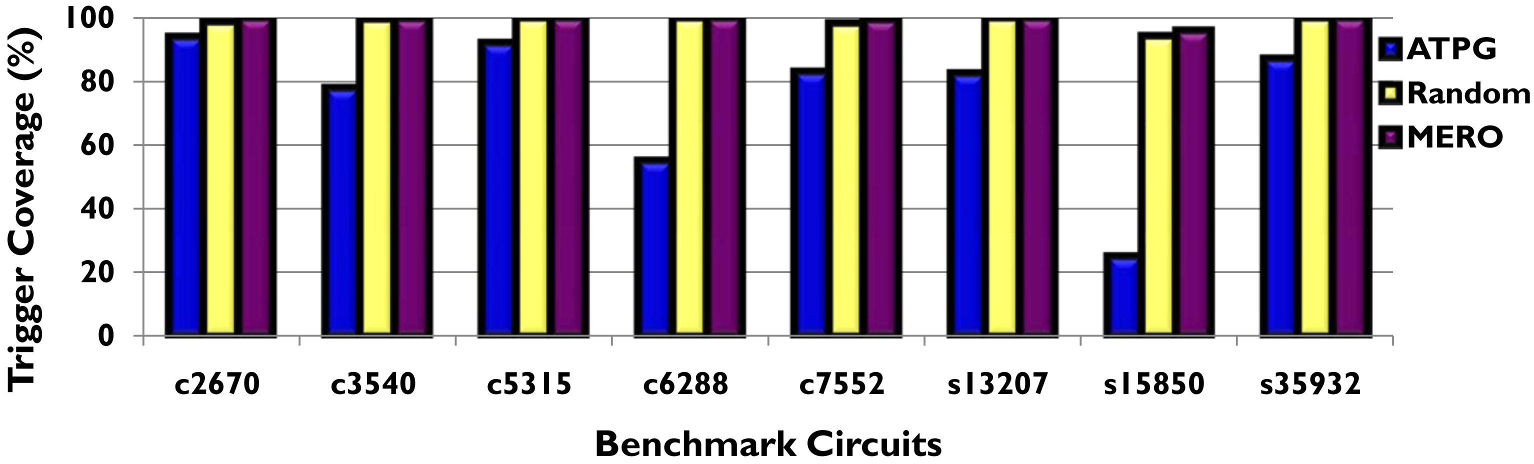
Sample size = 100,000

Effect of *N* on coverage

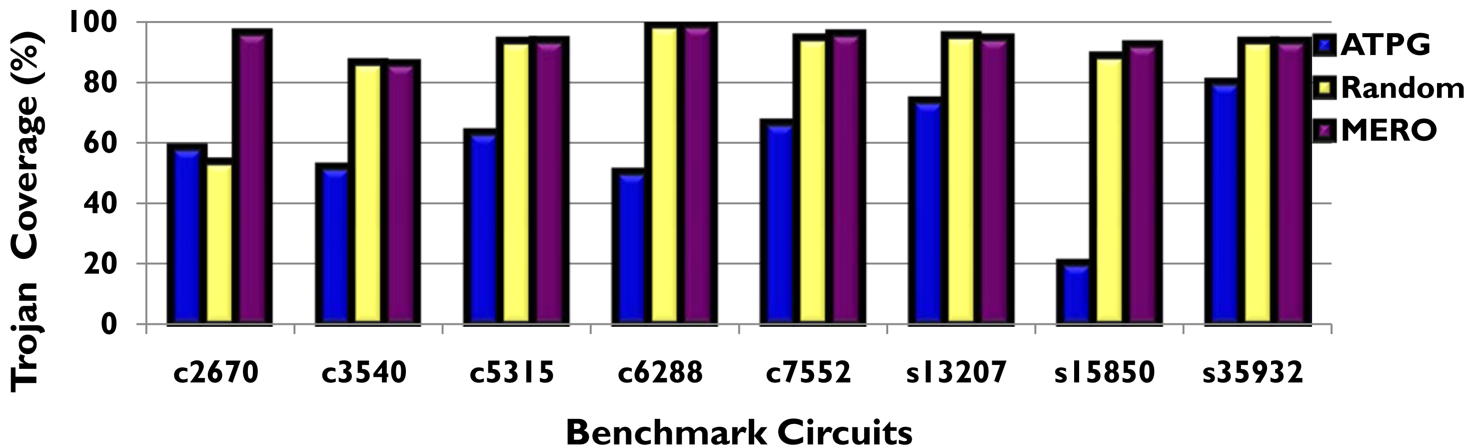


***N* = 1000**

Simulation Results: Coverage (q=2)



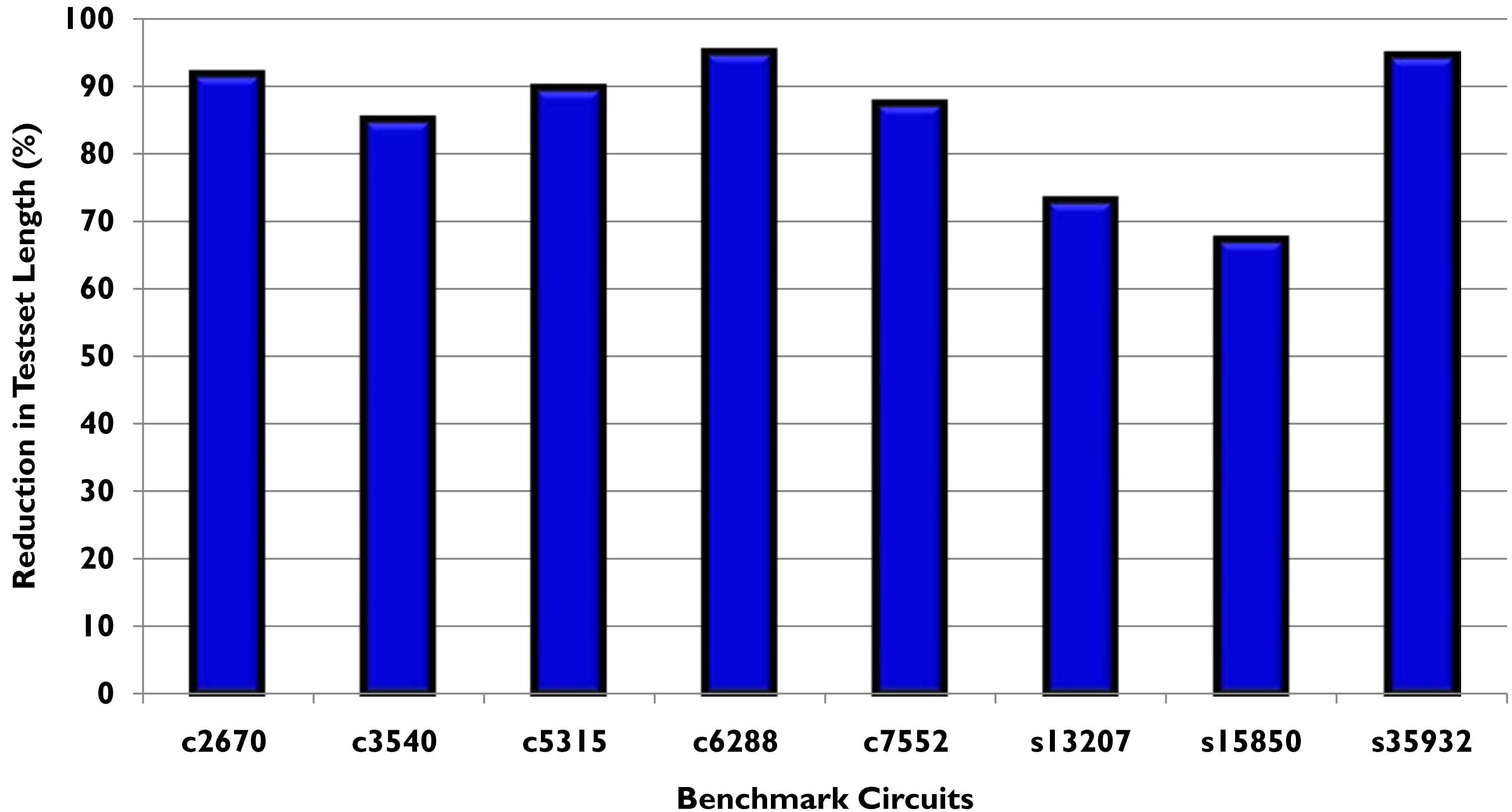
Trigger Coverage



Trojan Coverage

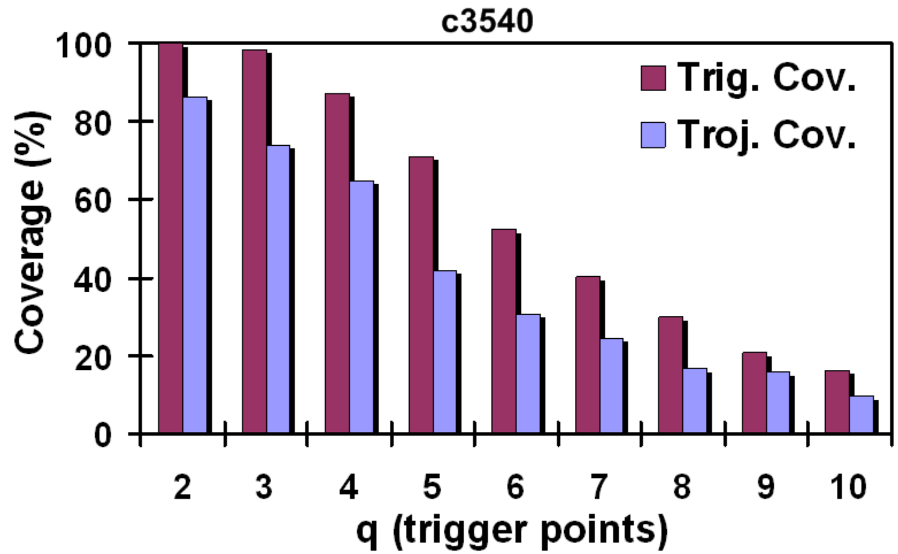
Trigger Coverage is inferior to Trojan Coverage!

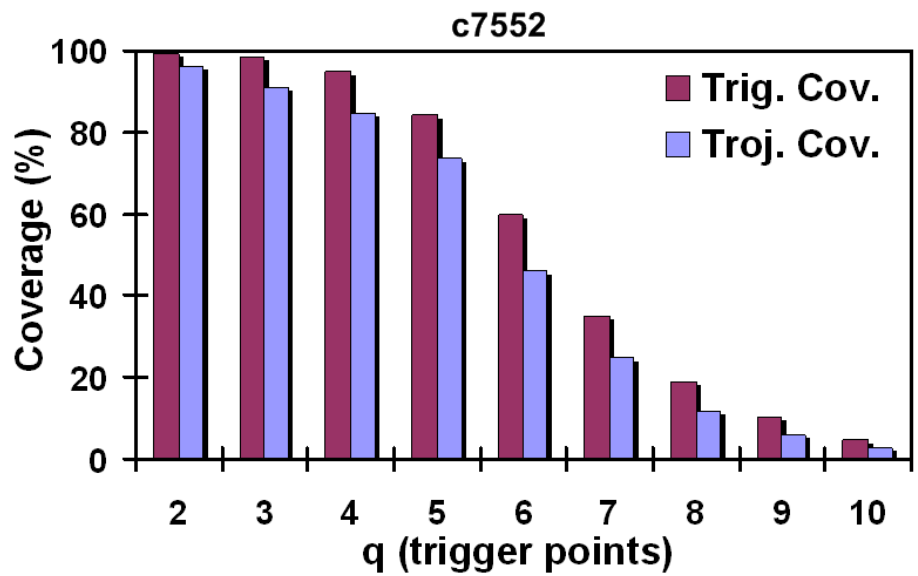
Simulation Results: Test Length



% Reduction in Test length compared to weighted random patterns (average: ~85%)

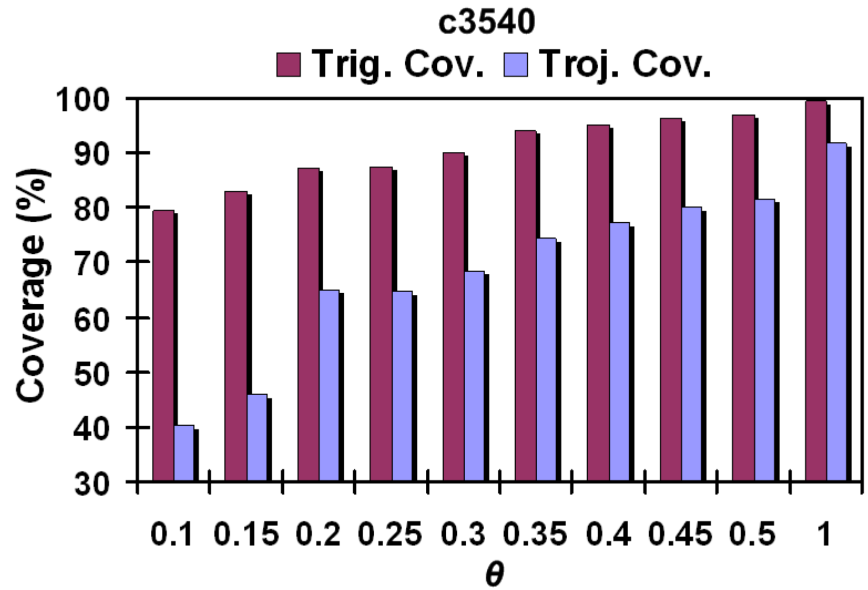
Simulation Results: Effect of *q*

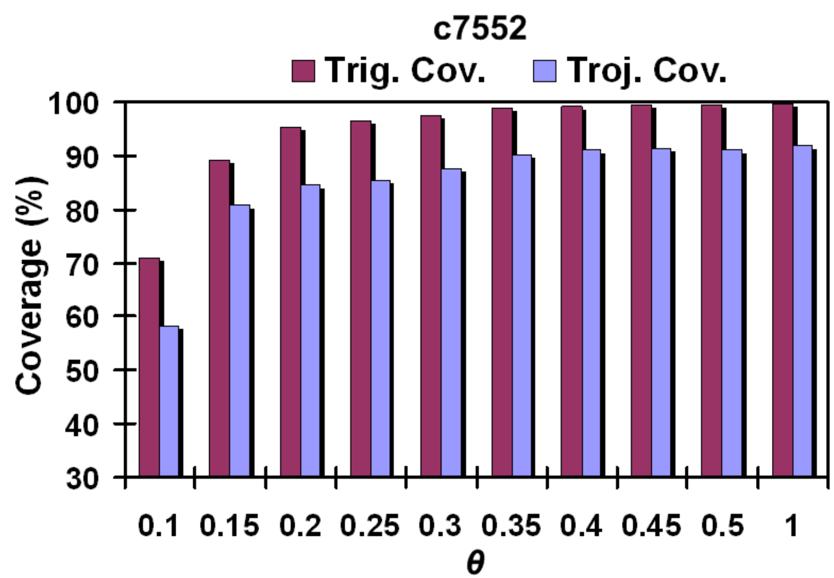




Coverage Decreases with *q*!

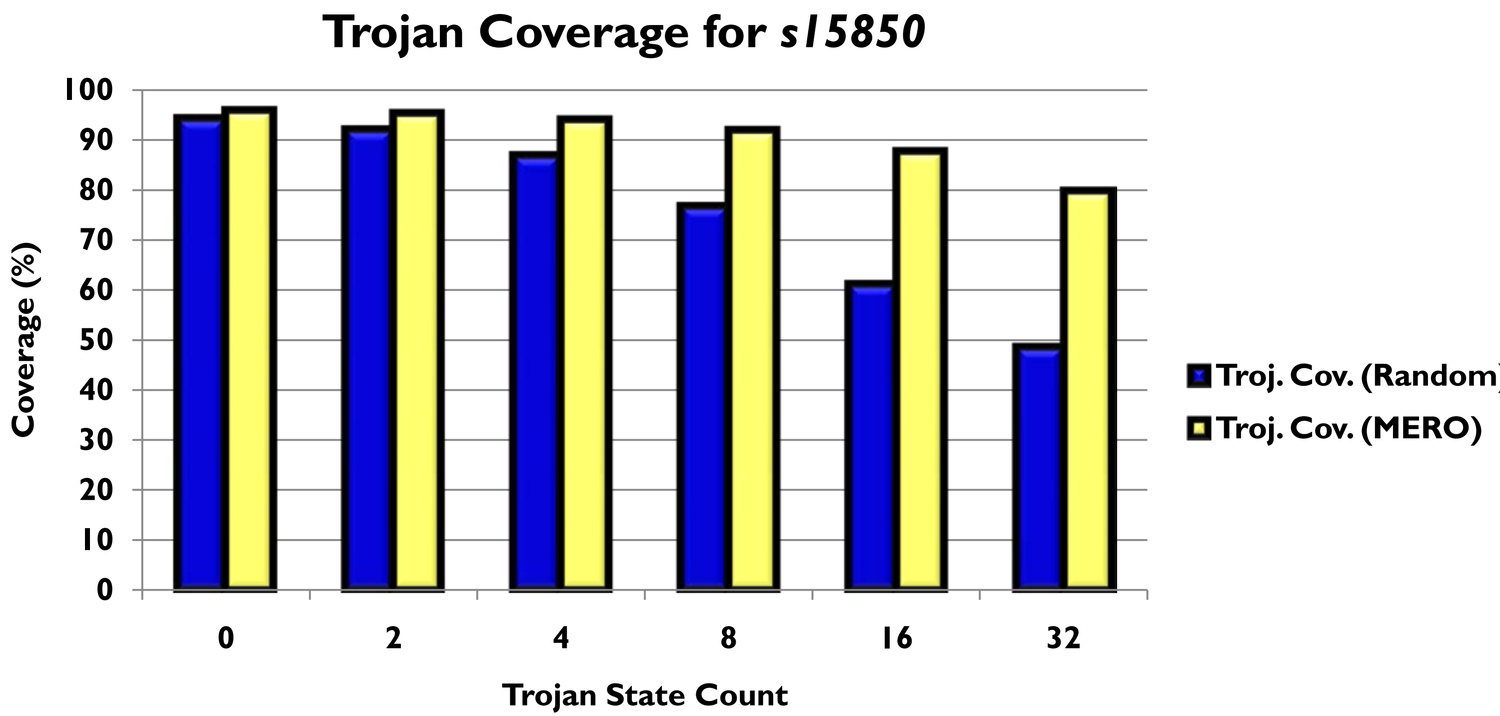
Simulation Results: Effect of ϑ





Coverage Improves with *θ*!

Sequential Trojan Coverage



- ***Counter-like Trojans triggered by internal node conditions (q = 2)***
- ***MERO patterns provide better coverage***
- ***Coverage Better for Smaller Trojans***

Conclusions

- **We have presented a *statistical approach* for hardware Trojan Detection**
  - **Provides superior coverage compared to random or ATPG vectors**
  - **~85% reduction in testset length**
  - **Effective for both *combinational* and *sequential* Trojans**
  - **High trigger coverage facilitates side-channel analysis**

- **Future Work**
  - ***Integration of logic testing and side-channel analysis in MERO framework***
  - **Blind testing**