A Dynamic Test Compaction Procedure for High-Quality Path Delay Testing

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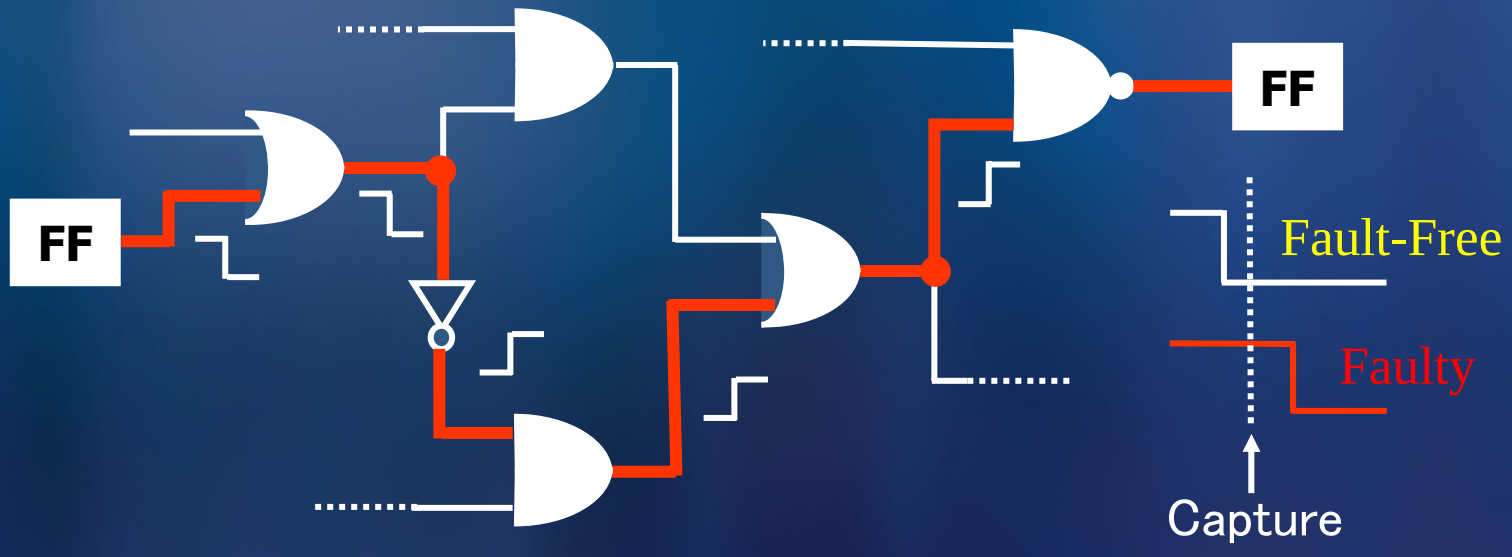
Outline

- Introduction
  - Path delay testing
  - Issues in path delay testing
  - Test pattern compaction in ATPG
  - Purpose of this work
- New Dynamic Compaction Method
  - Concept of common gate
  - Primary fault selection
  - Secondary fault selection
- Experimental Results
- Conclusions

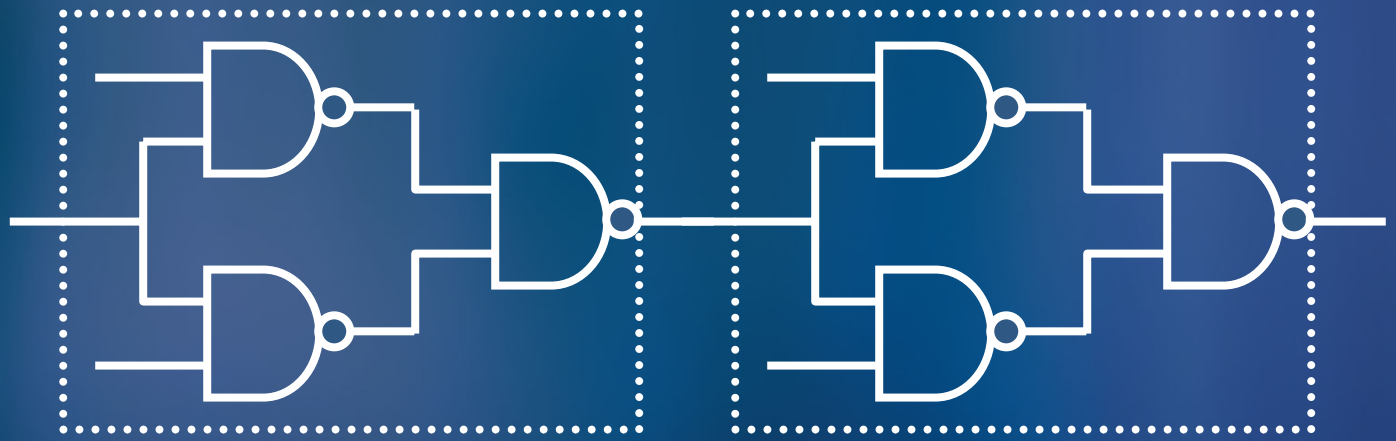
Background

- Defects affecting timing behavior are becoming dominant in the DSM era.
  - Path Delay Fault: Model the increased delay of a path between two FFs.
  - Test patterns generated for path delay faults can detect many other types of delay faults.



Path Delay Testing Issues - 1

- The extremely large number of paths makes it impossible to directly target **ALL** path delay faults in test generation.



16-bit multiplier : 2000 gates & 10^{19} paths

Only a subset of paths can be targeted : **Path Selection**

Path Selection

- *N* Longest Paths
  - Select *N* longest paths in a circuit.
  - The selected paths may be locally concentrated in a part of the circuit.
- Longest Path Through Each Line

  [Li, TCAD89], [Murakami, ITC00], [Sharma, ITC02], [Qiu, ITC03]
  - Select a set of paths that contains at least one of the longest paths through each signal line.
- Statistical Method / Dynamic Method

  [Liou, ICCAD00], [Liou, DAC02]
- Two Path Sets

  [Pomeranz, DATE02],[Pomeranz, ATS04]
  - The primary set consists of longest paths.
  - The secondary set consists of next-longest paths.

Path Delay Testing Issues - 2 & 3

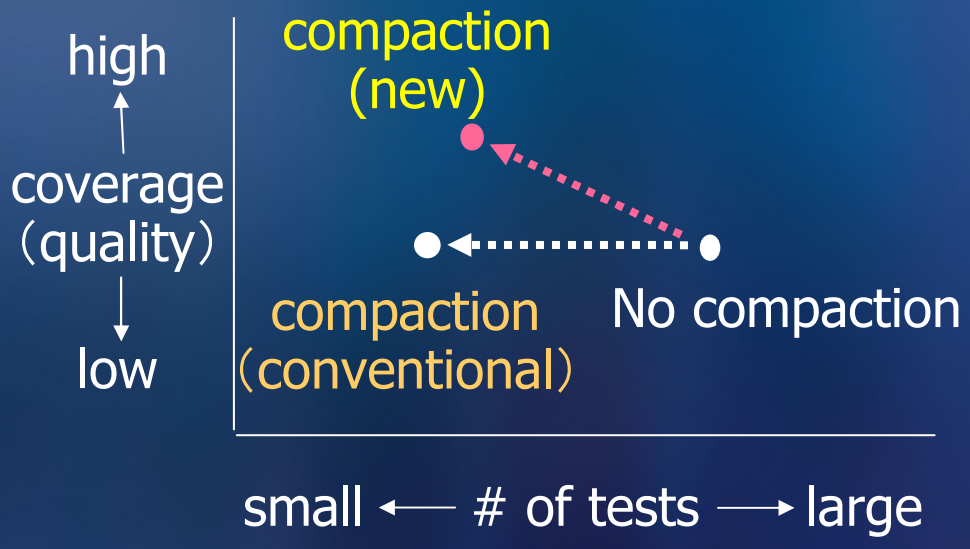
- Process Variation / Noise
  - Structurally longest paths may not be actual longest paths in a manufactured circuit due to process variation / noise.
  - It is difficult to know the exact delay distribution of a manufactured circuit.
  - The longest paths may be different in different manufactured circuit.
- Test Set Size
  - A two-pattern test is required to detect a path delay fault.
  - The constraints in test generation for path delay faults are more difficult than those for stuck-at faults.

Test Compaction

- Generate a test set such that the number of test patterns is reduced without sacrificing fault coverage.
- Dynamic Compaction
  - Using unspecified values in a test cube to detect other faults DURING ATPG.
    - test for the primary fault: 0xx1xx0
    - test for one secondary fault: 01x1x00
    - test for one more secondary fault: 0101100
- Static Compaction
  - Merging compatible test patterns AFTER ATPG.
    - test for a fault : 0x10
    - test for another fault : x1x0
    - Merged test : 0110

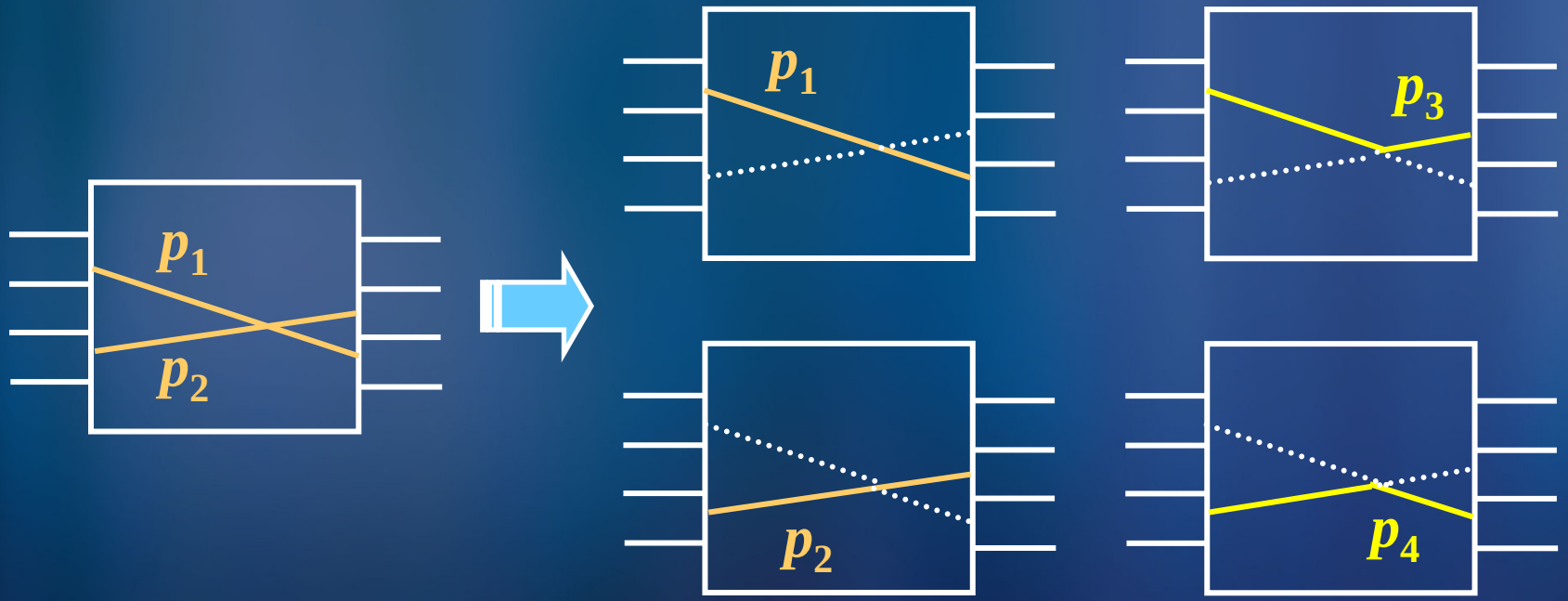
New Test Compaction

- Conventional Test Compaction
  - Reduce test patterns and KEEP fault coverage.
- New Test Compaction
  [Kajihara, DAC2005]
  - Reduce test patterns and IMPROVE fault coverage.



Observation

- When two paths with a common gate are tested simultaneously, non-target paths are also tested.



Basic Idea

Select target faults in ATPG in a way such that the number of accidental detections is increased.

Higher Process-Variation-Tolerance Capability

With many accidental detections related to targeted paths (longest by analysis), the chances of detecting a real critical path (longest by fabrication) in a manufactured circuit are higher.

Targeted paths
in ATPG

Longest path
in a manufactured circuit

Purpose of This Work

- Previous Work
  [Kajihara, DAC2005]
  - Cross-path-based test compaction is used for static compaction.

Dynamic compaction can usually lead to a smaller test set than static compaction.

To propose a dynamic test compaction procedure to generate a small and high-quality test pattern set.

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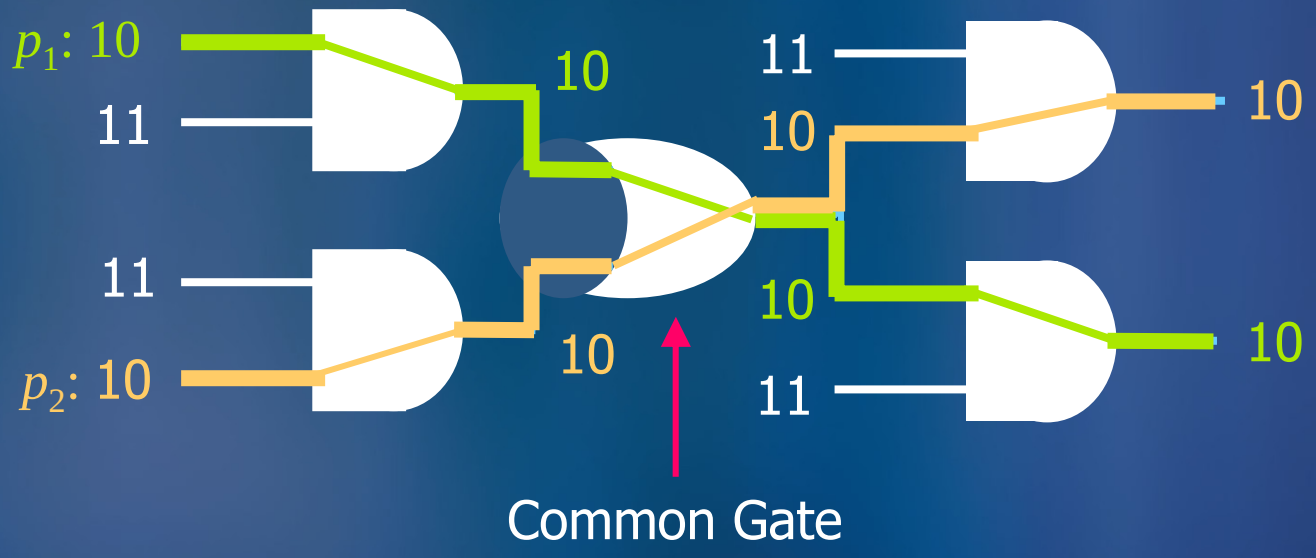
Common Gate



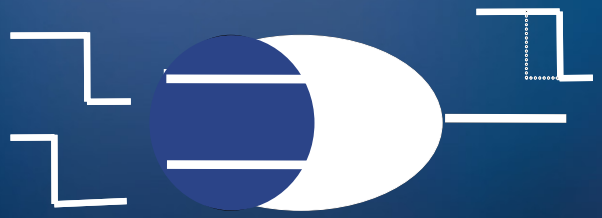
- *p*1 and *p*2 are tested by the same two-pattern test.
- Simultaneous testing can be achieved by dynamic (multi-targeting) or static compaction (merging).
- Certain conditions need to be satisfied at the common gate in order for accidental detection to occur.

Conditions for Accidental Detection

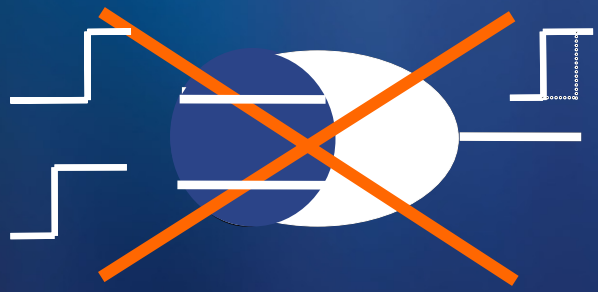
(1) The common gate has fanout branches.

(2) Two paths have the same type of transition at the inputs of the common gate.

(3) The transition at the common gate is from the controlling value to the non-controlling value.

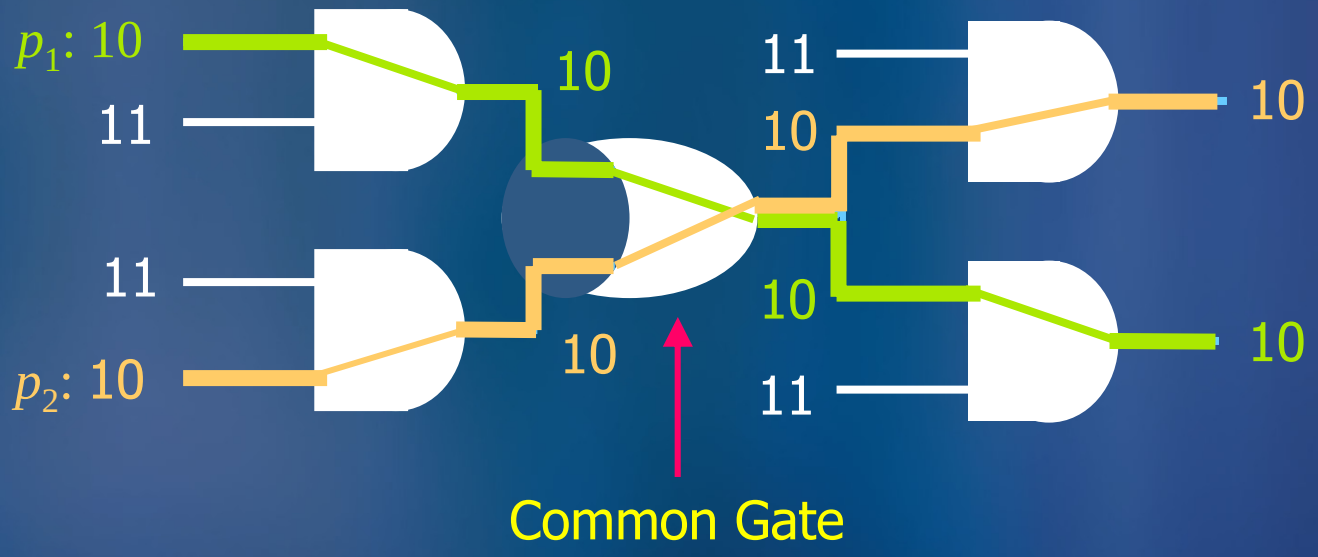


Transition from CV to NCV



Transition from NCV to CV

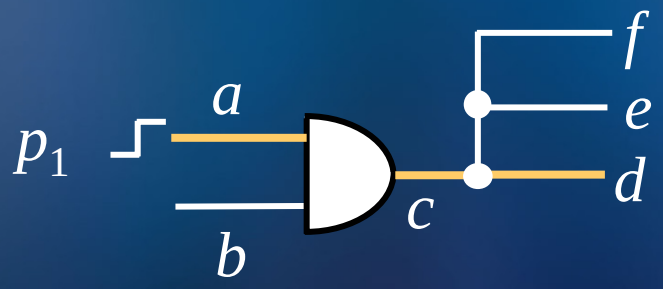
Example of Common Gate



All three conditions are satisfied.

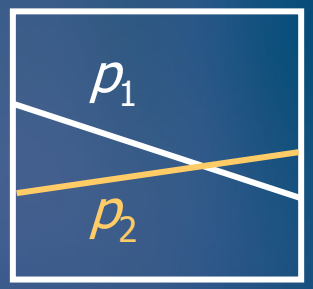
Primary Fault Selection

- Select a primary fault such that
  - [Input-Side] The path has many off-inputs on each gate having the transition from the controlling value to the non-controlling value.
  - [Output-Side] The path has many fan-out branches.

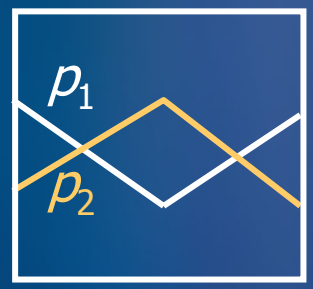


Secondary Fault Selection

- Select a secondary fault that
  - crosses the primary fault (path) as many times as possible.



4 paths are tested



8 paths are tested

The more common gates, the more accidental detections.

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Experimental Results

Experiment Set-Up:

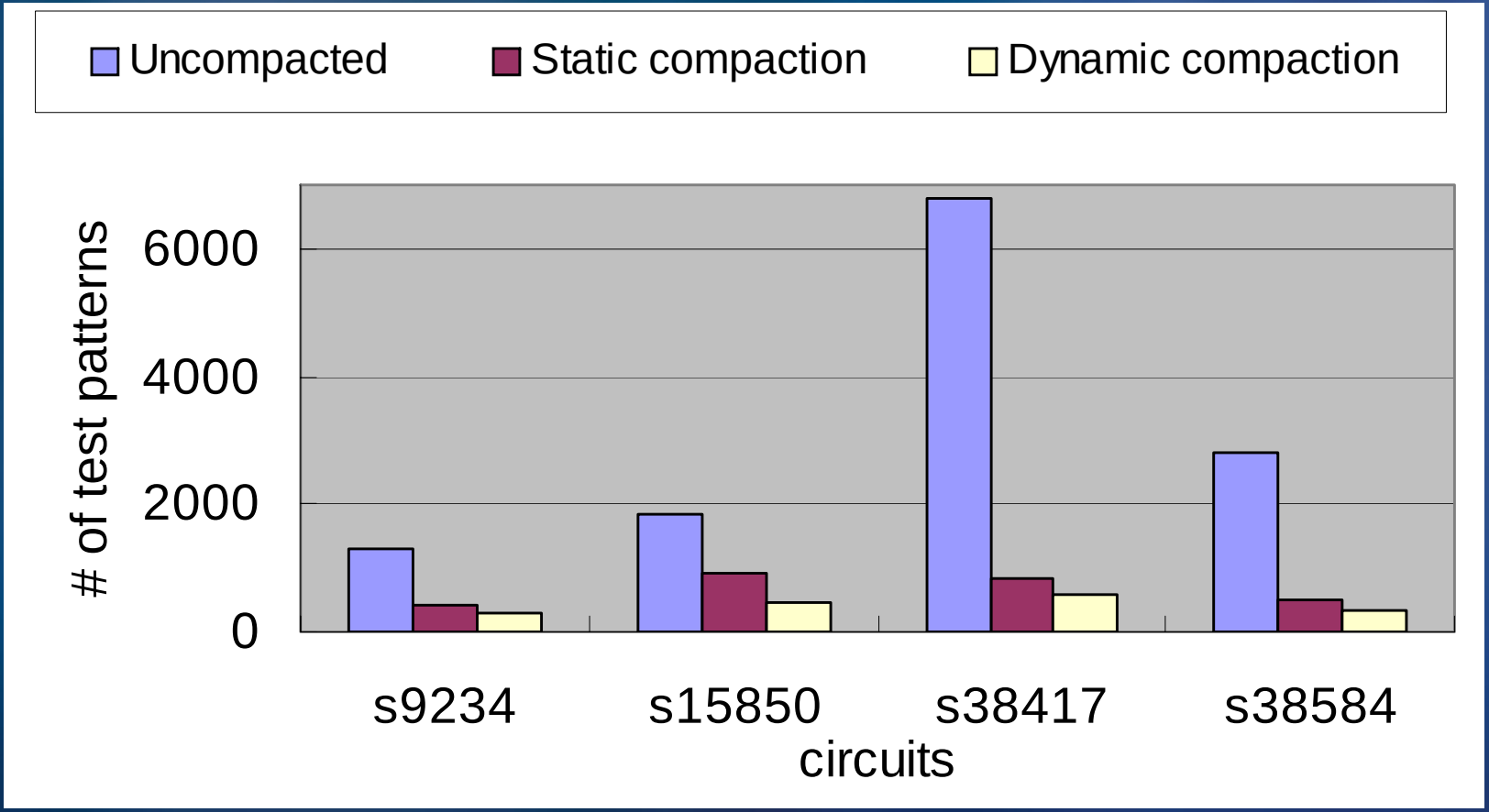
- Machine: Pentium III Xeon 2.0GHz, Memory 4GB
- OS: FreeBSD 4.5-release
- Programming Language: C
- Circuit: Combinational parts of ISCAS'89 benchmark circuits.
- Path Length: The number of gates along the path.

Circuit Statistics

Circuits	# total paths	# faults in fault list	# testable faults in fault list
s9234	489,708	5,193	5,159
s15850	329,476,092	10,027	9,950
s38417	278,3158	28,713	27,496
s38584	2,161,446	30,891	30,730

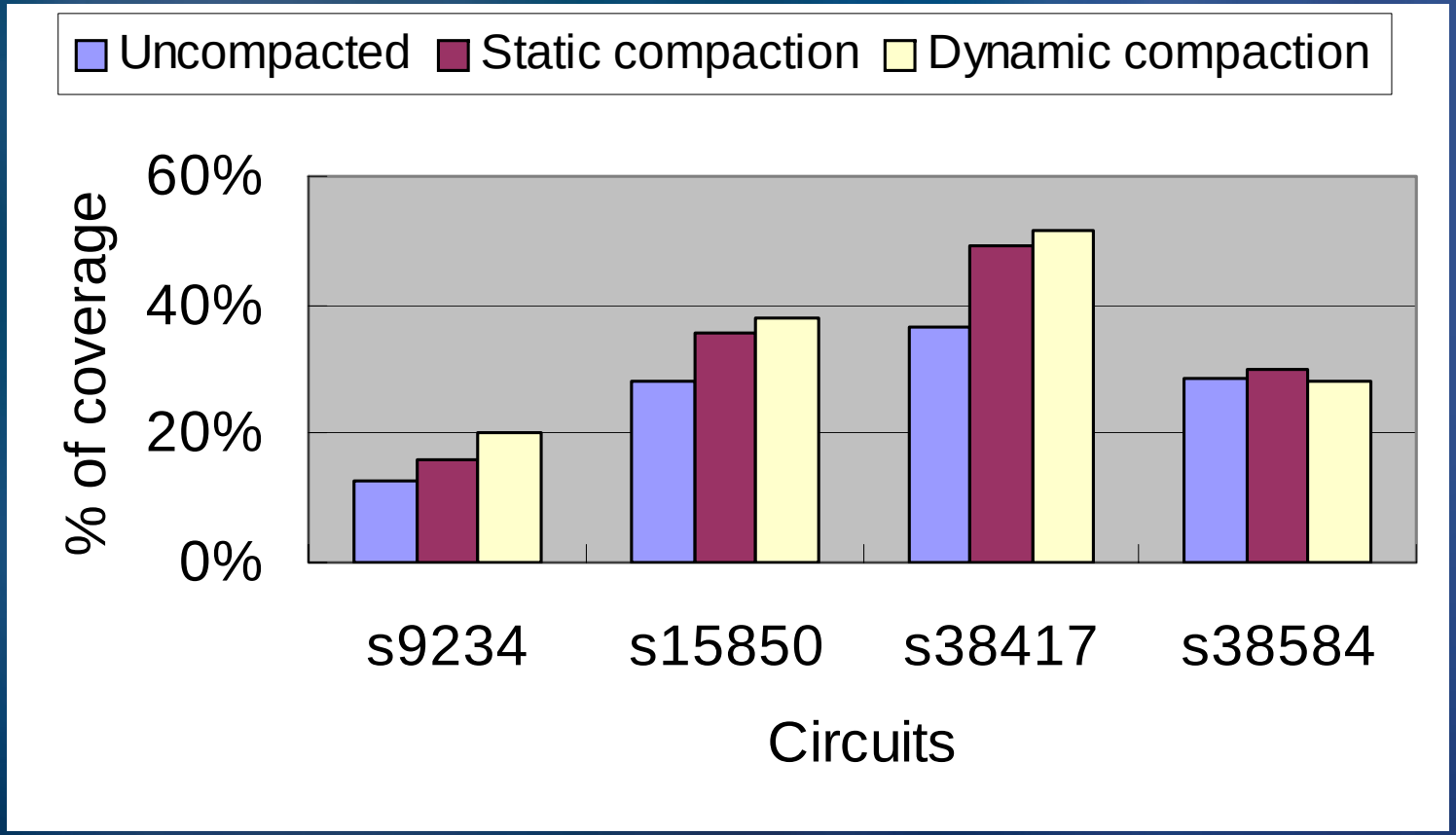
- Untestable Path: Non-robust untestable path.
- Fault List: {longest potentially testable path through each line in a circuit}

Comparison of Test Set Size



On average, 6 times reduction for dynamic compaction vs. no compaction.

Coverage of 10000 Longest Paths



On average, 10% more detections of 10000 longest paths for dynamic compaction vs. no compaction.

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Conclusions

- We proposed a dynamic compaction procedure to detect many faults, which may not be included in the target fault list, by accidental detections.
- The basic idea is to increase the number of common gates for multiple paths detected simultaneously, by carefully selecting primary and secondary faults in dynamic compaction.

A smaller test set with higher test quality.