Directed Test Generation for Validation of Cache Coherence Protocol

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Introduction

Background

- Modern Computers employed different cache coherence protocols to ensure the consistency of data (the goal is to ensure that a cache should read the latest most recently read data)
- However modern cache coherence protocols are very complicated, so their global finite state spaces are very complicated to analyze.

Background Continued ...

- One naive solution to generate random test cases. But for that, there are timing constraints, that we have to generate a huge number of test cases.
- Better improvement is to use Breadth First Search (BFS) to cover all the transitions. But the problems are twofold:
- For BFS worst-case space complexity is $\mathcal{O}(2^n)$
- For BFS number of repeated transactions is higher.

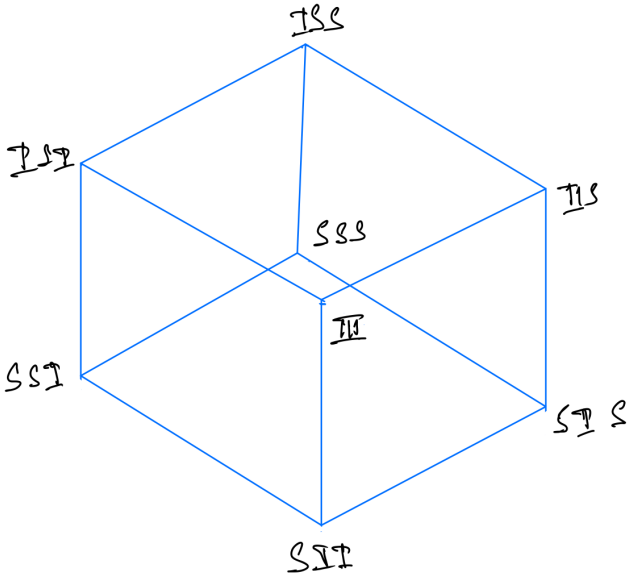
ON THE FLY Test Generation

SI Protocol

Reference: [1]

- SI is basically a trimmed version of MSI Protocol, in which we don't allow cores to allow to issue store operation.
- Let's say a system has n cores, a global valid state would be: m cores are in I state, and other $n - m$ states are in S state.
- So it can be easily seen that global state space has 2^n states.
- Any core can change its state $(S -> I)$ or $(I -> S)$ within one transaction.
- For every state there would be n outgoing edges and n incoming edges.

SI Protocol Continued...



Algorithm

Algorithm 1 Test generation for SI protocol with n cores

$CreateTestsSI(n)$

1: **for** $r = 0$ to $n - 1$ **do**
2: $\quad VisitHypercube(n, r)$

$VisitHypercube(m, r)$

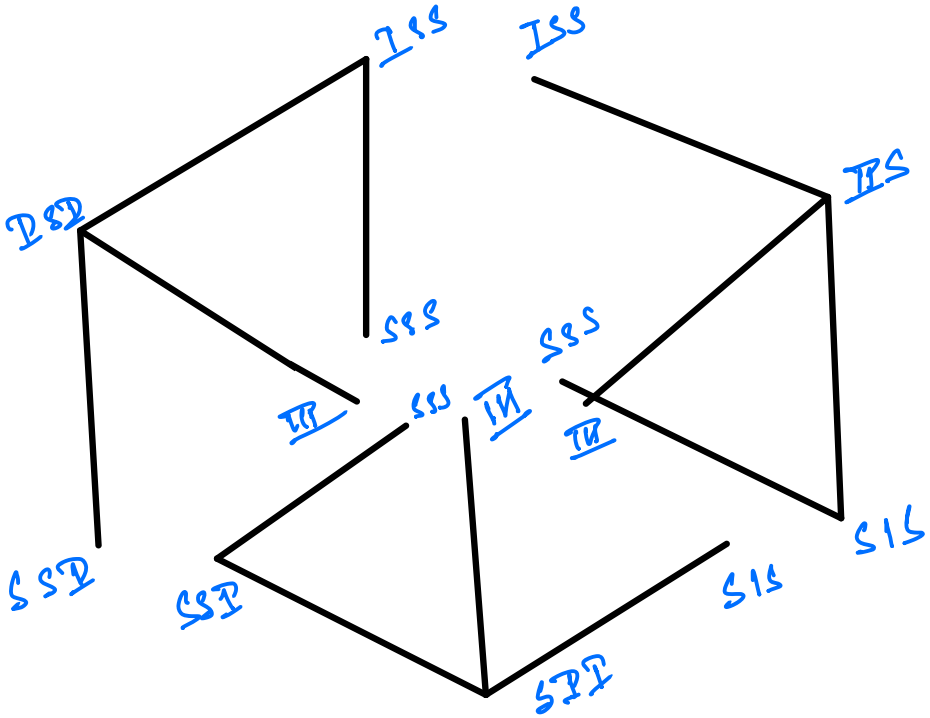
3: $p = (m + r) \bmod n$
4: Output "load(p)"
5: **for** $i = 1$ to $m - 1$ **do**
6: $\quad VisitHypercube(i, r)$
7: Output "evict(p)"
8: **return**

Analysis

Time and Space Complexity

- The n-dimensional hypercube is partitioned into n isomorphic trees with no overlapping edges.

Time and Space Complexity Continued...



Time and Space Complexity Continued...

- Once the hypercube is correctly formed we performed an Euler tour on the tree as all the edges are bidirectional.
- There are $n2^n$ transitions within state space.
- Transition sequence produced by the algorithm is $n2^n$
- No transition is visited more than once when we apply this algorithm.

Time and Space Complexity Continued...

- Time Complexity is still the same as BFS i.e $\mathcal{O}(2^n)$
- Space complexity is low i.e $\mathcal{O}(n)$

References I

Y. Lyu, X. Qin, M. Chen, and P. Mishra, "Directed test generation for validation of cache coherence protocols," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 38, no. 1, pp. 163–176, 2019.