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Monotonicity-Based Parent-Child Inference for the Efficient Computation of Signatures and Minimal Cut/Path Sets in Coherent Systems

In binary reliability systems, the minimal cut-sets, path-sets and signature vector [1, 2], provide the basis for computing key reliability measures, such as the survival function and the mean time to failure [1, 3]. However, these quantities are typically obtained by exhaustive evaluation of the structure function over the Boolean state space [1], whose size grows exponentially with the number of components: if n is the number of components in the system, there are 2^n possible states of the system [2]. Thus, as system size increases, this becomes computationally burdensome, and exact calculation becomes practically impossible even for moderate-sized systems.

In this work, we propose a new method to compute minimal cut-sets, path-sets and the signature vector for monotonous binary systems. We make no assumptions about the structure of the system and consider its structural function a black box. The proposed approach explores the Boolean state space by failure level, defined as the number of failed components. At each iteration, a level is selected from an adaptive biased distribution, then an "unchecked"state within that level is sampled uniformly at random and evaluated using the structure function, and then its status (working or failed) is propagated through the state lattice using monotonicity-based parent-child inference [2]. Indeed, if the sampled state is working, all of its ancestors toward lower failure levels are inferred working; and if it is failed, all of its descendants toward higher failure levels are inferred failed. In this way, a single exact evaluation can determine the status of many additional states without further structural-function calculations. With this, we propose confidence intervals for the signature vector. And in the cases where all states can be checked, we can compute the minimal cut- and path-sets, and also the signature of all intermediate states.

Preliminary results across multiple tested systems indicate a substantial reduction in computation time when using our algorithm.

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[3] J.-L. Marichal, P. Mathonet, and T. Waldhauser, "On signature-based expressions of system reliability," Journal of Multivariate Analysis, vol. 102, no. 10, pp. 1410–1416, 2011.

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