Information Sciences

Biased Randomized Algorithm for Fast Model-Based Diagnosis

The bias increases the likelihood of making a minimal diagnosis.

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A biased randomized algorithm has been developed to enable the rapid computational solution of a propositional-satisfiability (SAT) problem equivalent to a diagnosis problem. The closest competing methods of automated diagnosis are described in the preceding article "Fast Algorithms for Model-Based Diagnosis" and "Two Methods of Efficient Solution of the Hitting-Set Problem" (NPO-30584), which appears elsewhere in this issue.

It is necessary to recapitulate some of the information from the cited articles as a prerequisite to a description of the present method. As used here, "diagnosis" signifies, more precisely, a type of model-based diagnosis in which one explores any logical inconsistencies between the observed and expected behaviors of an engineering system. The function of each component and the interconnections among all the components of the engineering system are represented as a logical system. Hence, the expected behavior of the engineering system is represented as a set of logical consequences. Faulty components lead to inconsistency between the observed and expected behaviors of the system, represented by logical inconsistencies. Diagnosis — the task of finding the faulty components — reduces to finding the components, the abnormalities of which could explain all the logical inconsistencies. One seeks a minimal set of faulty components (denoted a minimal diagnosis), because the trivial solution, in which all components are deemed to be faulty, always explains all inconsistencies.

In the methods of the cited articles, the minimal-diagnosis problem is treated as equivalent to a minimal-hitting-set problem, which is translated from a combinatorial to a computational problem by mapping it onto the Boolean-satisfiability and integer-programming problems. The integer-programming approach taken in one of the prior methods is complete (in the sense that it is guaranteed to find a solution if one exists) and slow and yields a lower bound on the size of the minimal diagnosis. In contrast, the present approach is incomplete and fast and yields an upper bound on the size of the minimal diagnosis.

The encoding of the diagnosis problem as an SAT problem for the purpose of the present method is basically the same as the encoding of the diagnosis problem as a hitting-set problem in the methods of the cited articles. In the present case, one seeks a minimal solution to the SAT problem — that is, a solution in which the fewest variables are set to TRUE. In a typical prior local-search algorithm for solving the SAT problem, one guesses at a complete solution and then, through a sequence of partly random and partly greedy flips, tries to adjust the guess to reduce the number of unsatisfied clauses while increasing, or leaving unchanged, the number of satisfied clauses. Eventually, one converges toward a complete solution. Although such local-search algorithms are not complete, in practice, they outperform other algorithms for solving the SAT problem.

The prior local-search algorithms used to solve the SAT problem sometimes flounder in the search space without converging to the solution, making it necessary to restart the algorithms from time to time. Usually, in such a case, one randomly assigns a value of TRUE or FALSE to each variable in the SAT problem. In the present algorithm, one biases this otherwise random assignment toward FALSE in the effort to make the subsequent random and greedy flips lead to a solution in which the fewest variables are TRUE. Hence, one increases the probability of reaching a minimal solution. If the solution is not a minimal diagnosis, it is nevertheless guaranteed to provide an upper bound on the minimal diagnosis, and thereby to be useful as a guide to the use of other diagnostic algorithms.

This work was done by Colin Williams and Farrokh Vartan of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40065

Fast Algorithms for Model-Based Diagnosis

Methods based on Boolean functions and linear programming are more practical for complex systems.

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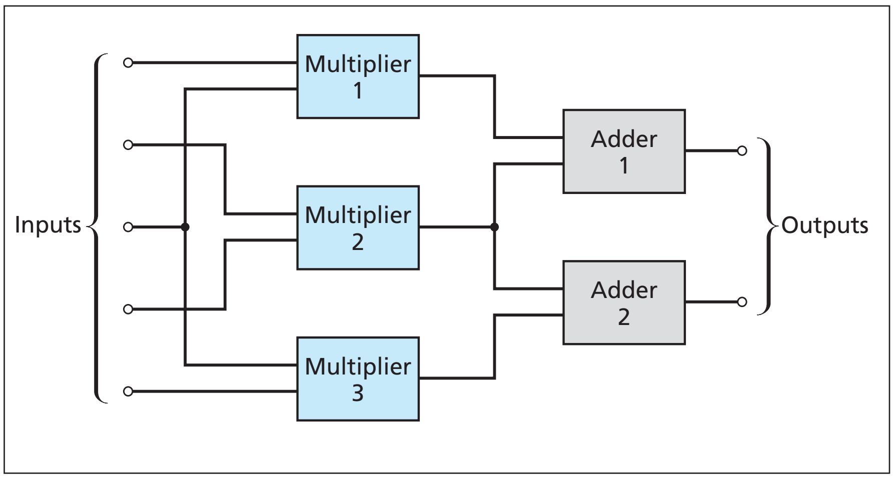
Two improved new methods for automated diagnosis of complex engineering systems involve the use of novel algorithms that are more efficient than prior algorithms used for the same purpose. Both the recently developed algorithms and the prior algorithms in question are instances of model-based diagnosis, which is based on exploring the logical inconsistency between an observation and a description of a system to be diagnosed.

As engineering systems grow more complex and increasingly autonomous in their functions, the need for automated diagnosis increases concomitantly. In model-based diagnosis, the function of each component and the interconnections among all the components of the system to be diagnosed (for example, see figure) are represented as a logical system, called the system description (SD). Hence, the expected behavior of the system is the set of logical consequences of the SD. Faulty components lead to inconsistency between the observed behaviors of the system and the SD. The task of finding the faulty components (diagnosis) reduces to finding the components, the abnormalities of which could explain all the inconsistencies. Of course, the meaningful solution should be a minimal set of faulty components (called a minimal diagnosis), because the trivial solution, in which all components are assumed to be faulty, always explains all inconsistencies. Although the prior algorithms in question implement powerful methods of diagnosis, they are not practical because they essentially require exhaustive searches among all possible combinations of faulty components and therefore entail the amounts of computation that grow exponentially with the number of components of the system.

For the purpose of establishing the basis of an algorithmic approach that entails more efficient computation, and, more specifically, translating the diagnosis problem from a logical problem to a computational problem, it was shown that the calculation of minimal diagnosis can be mapped as the solution of two well-known problems — the Boolean satisfiability and the integer-programming. The first new method is based on the connection between the diagnosis problem and the Boolean satisfiability problem. This connection makes it possible to use Boolean function theory to reduce the diagnosis problem to the problem of finding prime-implicants (which is one of the basic problems in the theory of Boolean functions). This, in turn, makes it possible to utilize powerful and efficient algorithms, recently developed for the satisfiability problem, to compute the minimal diagnosis. The algorithm thus developed to solve the diagnosis problem requires an amount of computation proportional to a superpolynomial function of n (meaning that the computation time is proportional to $n^{\log n}$), where n is the number of components of the system.



This **Network of Multipliers and Adders** is a relatively simple example of an engineering system amenable to model-based diagnosis.

The second new method is based on the mapping of the diagnosis problem onto the integer-programming problem. This mapping makes it possible to utilize the large and versatile body of computational techniques developed previously for linear integer programming optimization to solve the diagnosis problem in an approach more practical than that of the prior exhaustive-search algorithms. Some of the integer programming techniques, modified to make them suitable for solving the diagnosis problem, can efficiently diagnose a system that contains as many as several thousand components.

This work was done by Amir Fijany, Anthony Barrett, Farrokh Vatan, and Ryan Mackey of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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