An Advanced Model-Based Diagnosis Engine

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Abstract

Diagnosis is a vital necessity for any autonomous system. The diagnosis of a system is the task of identifying faulty components that cause the system not functioning as it was intended. The diagnosis problem arises when some observations of the system's actual behavior is in contradiction with the system's expected behavior. The solution to the diagnosis problem is the *minimal* sets of faulty components that explain all the symptoms.

In the current state of practice, the most disciplined approach to fault detection and diagnosis is the "model-based" approach, employing knowledge of device operation and connectivity in the form of models. This approach, which reasons from first principles, provides far better diagnostic coverage than traditional approaches based upon collection of symptom-to-suspect rules. However, there are two major drawbacks in current model-based diagnosis systems that severely limit their practicality. First, these systems tend to be large, complex, and difficult to apply. Second, in order to find the minimal diagnosis set (viz. the minimal set of components that, if faulty, would fully explain the anomalous behavior detected), they rely on algorithms with an exponential computational cost. This computational explosion makes their application highly impractical for many systems of interest.

In this paper, we present a two-fold approach to overcome these two limitations and to develop a new and powerful diagnosis engine:

1. We propose a novel and compact reconstruction of General Diagnosis Engine (GDE), as one of the most fundamental approaches to model-based diagnosis.
2. We present a novel algorithmic approach for calculation of minimal diagnosis set.

We have developed a novel and compact reconstruction of GDE. Traditionally GDE has been implemented using an inference engine to reason about the model combined with an Assumption-based Truth Maintenance System (ATMS) to keep track of the assumptions. Our rational reconstruction of GDE merges the ATMS with the inference engine. The two pieces have many similarities, and combining them dramatically simplifies the algorithm; our implementation contains fewer than 150 lines of LISP code. Directly linking these functions also facilitates the use of computation reduction heuristics, such

as tagging each assumption with a probability to focus the system on relatively likely faults.

The GDE engine provides the collection of the *conflict sets* that encapsulate all information that logically follows from observations and the system model. The next step is to find the minimal diagnosis as the minimal sets that intersect all conflict sets (i.e., minimal hitting sets). To solve this problem, by utilizing a powerful yet simple representation of the calculation of minimal diagnosis set, we map the problem onto two well-known problems, that is, the Boolean Satisfiability and 0/1 Integer Programming problems. The mapping onto Boolean Satisfiability enables the use of very efficient algorithms with a super-polynomial rather than an exponential complexity for the problem. The mapping onto 0/1 Integer Programming problem enables the use of variety of algorithms that can efficiently solve the problem for up to several thousand components. These new algorithms significantly improve over the existing ones, enabling efficient diagnosis of large complex systems. Moreover, these two separate approaches allow us to choose the algorithm that best suits a specific problem

In addition, mapping onto 0/1 integer programming allows, for the first time, to determine the bound on the solution, i.e., the minimum and maximum number of faulty components, before solving the problem. We show how this powerful insight can be exploited to develop yet more efficient algorithms for the problem.

Integrating the novel reconstruction of GDE and the new algorithms for calculation of minimal diagnosis set, we have developed a novel model-based diagnosis engine. In this paper, we report and discuss the successful results of validating and benchmarking of our engine.