Maintaining Uncertain Assumptions for Plausible Fault Diagnosis

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Abstract

A certainty factor style calculus is integrated into an Assumption based Truth Maintenance System, offering a unified basis upon which to perform fault diagnosis and to guide the gathering of required measurements.

1 Introduction

The General Diagnostic Engine (GDE) [2], a standard model-based fault diagnostic system, postulates plausible faults from given measurements by making extensive use of an Assumption based Truth Maintenance System (ATMS). However, it relies upon an entropy-based uncertainty calculus, separate from the ATMS [1], to compute optimal locations for measurements gathering. The practical usability of GDE is thus limited by the statistical information required and by the strong assumptions necessary for making subsequent simplifications. In this paper, a simple numeric certainty calculus is integrated in the ATMS. The integrated system, capable of handling uncertain assumptions, is employed as the unified basis upon which to guide the measurements gathering process at a low computational cost, in addition to facilitating the generation of fault hypotheses.

2 ATMS and certainty factors

Within the ATMS network employed by a GDE-style system, an assumption node is created for each component of the device under diagnosis representing the presumption of its correct functioning. Also, a non-assumption node is created for each considered plausible state of the connections in the model of the device. For each of these non-assumption nodes, n, a label $\mathcal{L}(n) = \{E_1, E_2, ..., E_l\}$ is computed. Within $\mathcal{L}(n)$, each *environment* $E_i, i = 1, 2, ..., l$, is a set of conjunctively joint assumptions supporting that node. This label is based on a set of justifications $\mathcal{J}$ generated by a constraint propagator which propagates the available data on the connections over the constraints that represent the device. Given $\mathcal{J}$, the label is guaranteed to be consistent ($\forall E_i \in \mathcal{L}(n) : E_i, \mathcal{J} \nvdash n_\perp$, with the specific node $n_\perp$ representing false), sound ($\forall E_i \in \mathcal{L}(n) : E_i, \mathcal{J} \vdash n$), complete ($\forall E', \exists E_i \in \mathcal{L}(n) : E', \mathcal{J} \vdash n \Rightarrow E_i \subset E'$) and minimal ($\forall E_i, E_j \in \mathcal{L}(n) : E_i \neq E_j \Rightarrow E_i \not\subseteq E_j$) [1].

A standard ATMS does the job of book-keeping for assumptions which are either true or false. To address the issue of uncertain assumption maintenance, without involving sophisticated uncertain reasoning mechanism, a certainty factor style calculus is used here. Every assumption-node in the ATMS network is assigned a numeric certainty value: a certainty factor. These certainty factors must then be propagated to all other nodes. This propagation is based solely on the labels of the non-assumption nodes. This is because the present interest, of using the ATMS in a GDE-type system to produce proposals for measurement locations, rests on the sets of assumptions that support a hypothetical state of a connection rather than the nodes themselves. Given this, the calculations on propagating certainty factors through the ATMS network will only involve logic conjunctive and disjunctive operators, denoted by $op_\wedge$ and $op_\vee$ respectively. There are alternative forms of defining the operators $op_\wedge$ and $op_\vee$, over the range $\forall x, y \in [0, 1]$, which are readily available for such use (as commonly utilised in fuzzy logics [3]).

3 The measurement guidance

At any one point in a GDE-type diagnostic session, either 0, 1 or more states are considered for each connection of the device. Connections for which multiple states are being considered are symptomatic for faulty behaviour but their exact cause has not been determined yet. By measuring such connections, GDE-type systems try to find the actual faults. With each plausible state, represented as a node in the ATMS, a supporting label is associated. If this state is determined to be false, at least one assumption of each environment in its label must be false. Therefore, when the state of a connection is determined, at least one assumption of all the environments of the labels associated with the other states is established to be false. This is the knowledge that is gained by measuring the state of a connection, and it is summarised into a set of minimal candidates.

Given a hypothetical measurement of a connection, a set of assumptions $C_i = \{a_{i1}, a_{i2}, ..., a_{iq}\}$ becomes a candidate if for any node n, $\neg a_{i1} \wedge \neg a_{i2} \wedge ... \wedge \neg a_{iq} \wedge n \vdash n_{\perp}$. The certainty factor of such a candidate C_i is then calculated by: $CF(C_i) = op_{\wedge}(CF(a_{i1}), CF(a_{i2}), ..., CF(a_{iq}))$. Given that, in general, the diagnostic system computes a set of plausible minimal candidates $\mathcal{C}(n) = \{C_1, C_2, ..., C_p\}$ with respect to a hypothetical measurement n, the certainty factor of this set of candidates is: $CF(\mathcal{C}(n)) = op_{\vee}(CF(C_1), CF(C_2), ..., CF(C_p))$. In a similar fashion, a certainty factor expressing the falsehood of the label of a node supporting a certain state of a connection can be computed. Suppose that a node's label is $\{\{a_{ij} \mid j \in \{1, 2, ..., t_i\}\} \mid i \in \{1, 2, ..., s\}\}$, then it is false if $\neg(\vee_{i=1}^{s} \wedge_{j=1}^{t_i} a_{ij}) \vdash \top$ or $(\wedge_{i=1}^{s} \vee_{j=1}^{t_i} \neg a_{ij}) \vdash \top$. Therefore, $CF(\mathcal{L}(n)) = op_{\wedge}{}_{i=1}^{s} op_{\vee}{}_{j=1}^{t_i} CF(\neg a_{ij})$.

The question is now how to make an informed proposal for the location of the next measurement, such that the largest part of the search space of potential fault candidates can be eliminated. After measuring a connection, only one node associated with it remains, with all the others contradicting the measurement outcome and hence being pruned. It is therefore a good idea to measure the connection that will eliminate the largest total of certainty factors of the candidate sets associated with the nodes that are to be discarded. The idea behind the entropy theory based method that is used by the GDE is in fact very similar. From this, the next measurement point is determined by checking if it would lead to the maximum measure as one of the following heuristic metrics is used:

$$\frac{v-1}{v} \sum_{k=1}^{v} CF(\mathcal{C}(n_k)) \tag{1}$$

$$\frac{v-1}{v} \sum_{k=1}^{v} CF(\log(\mathcal{C}(n_k))) \tag{2}$$

$$\frac{v-1}{v} \sum_{k=1}^{v} CF(\mathcal{L}(n_k)).CF(\mathcal{C}(n_k)) \tag{3}$$

where $\{n_1, n_2, ..., n_v\}$ is the set of nodes representing the states considered for a particular connection.

Heuristic (1) is based on the unweighted average of certainty factors of the plausible set of candidates. Heuristic (2) is similar in nature although it decreases the relative importance of the larger certainty factors. The candidates that have higher certainty factors often cause the associated metric to be overestimated, as it may be more likely that they are retained. Heuristic (3) explicitly accounts for this problem by weighting each certainty factor with another certainty factor representing the certainty that the associated node is false and therefore discarded after making the proposed measurement.

4 Results

A simple device, consisting of a sequential construction of components is used for illustration, due to the limit of space. Given the values in the first and last connections and different certainty factors attached to different components, the diagnostic system biases its selection of measurement positions towards the components which are more likely to fail. This permits the system to reduce the total number of measurements required to locate a faulty component. As the components which are more likely to fail appear to function correctly, the diagnostic system recovers from its bias and focuses its search towards the faulty sub-sequence of less error-prone components. Should the certainty factors become equal for all components, the system will equivalently perform a binary search for a faulty component.

5 Conclusion

The main advantage of integrating a certainty factor style calculus with the ATMS, for the explicit purpose of GDE style diagnosis, is that it requires only weak assumptions on component failures and limited numerical data. Yet, such an integration is able to effectively guide a diagnostic process with simple computations, offering the potential for complex artifacts to be diagnosed.

References

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