Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence (IJCAI 2015)

Diagnosis of Technical Systems

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Abstract

Increasing complexity of technical systems requires a precise fault localization in order to reduce maintenance costs and system downtimes. Model-based diagnosis has been presented as a method to derive root causes for observed symptoms, utilizing a description of the system to be diagnosed. Practical applications of model-based diagnosis, however, are often prevented by the initial modeling task and computational complexity associated with diagnosis. In the proposed thesis, we investigate techniques addressing these issues. In particular, we utilize a mapping function which converts fault information available in practice into propositional horn logic sentences to be used in abductive model-based diagnosis. Further, we plan on devising algorithms which allow an efficient computation of explanations given the obtained models.

1 Introduction

Fault identification of technical systems is becoming increasingly difficult due to their rising complexity and magnitude. Economic and safety considerations have put accurate diagnosis not only into research focus but also have led to a growing interest in practice.

Model-based diagnosis has been proposed as an improvement to root cause identification [Reiter, 1987]. Resting on a formalization of the system behavior, it derives possible faults for observable malfunctions. Even though decades on research have yielded a solid theoretical background, there has not been a widespread acceptance among industries. Two main contributing factors can be identified: the initial model development effort and the computational complexity.

This thesis aims at bridging the gap between the theoretical foundations of model-based diagnosis and industrial applications. In particular, we provide a methodology which automates the modeling process and develop diagnosis algorithms efficient and effective enough to be used in industrial settings.

Since the representational adequacy of the models can only be verified empirically, we are currently working with our industrial partners on a framework to test the overall approach in the domain of industrial wind turbines [Gray *et al.*, 2014]. Reliable diagnosis is especially important within this context as maintenance activities are associated with high costs due to remote onshore or offshore locations, required specialized human resources, tooling, and spare parts.

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2 Related Work

Model-based diagnosis research provides a sound foundation for fault localization. Over the years two approaches have unfolded: consistency-based and abductive diagnosis. The former utilizes models of the correct system behavior and obtains diagnoses through inconsistencies [de Kleer and Williams, 1987]. In contrast, abductive diagnosis reasons on the knowledge of the faulty behavior. By the notion of entailment, consistent explanations for effects can be derived. Despite relying on different underlying principles, the two techniques are in close relation to one another [Console *et al.*, 1991].

A large body of literature has been published in the field of model-based diagnosis with focus on various application domains, such as space probes [Williams and Nayak, 1996], environmental decision support systems [Wotawa, 2011] or the automotive industry [Struss and Price, 2003]. Furthermore, there have been proposals on how to intercalate model-based diagnosis into industrial practices [Milde *et al.*, 2000]. However, especially in the context of abductive model-based diagnosis, real-world applications are few.

3 Abductive Model-Based Diagnosis

Our method aims at improving and automating the diagnosis process, by identifying faults through the usage of expert knowledge on failures and their effects. Currently, we are following an abductive approach as we are taking advantage of Failure Mode And Effect Analysis (FMEA) data, which can be converted into abductive models.

3.1 Modeling Methodology

We devised a modeling methodology based on failure assessments, such as the FMEA. FMEA is an established practice for reliability analysis in different industrial fields and considers possible component faults as well as their implications on the system's behavior.

As an FMEA already represents the relation between defects and their manifestations, the conversion to a suitable system description is straightforward. By utilizing a mapping function $\mathfrak{M} : 2^{FMEA} \mapsto HC$, which generates a corresponding propositional horn clause for each entry, we can automatically associate an FMEA with an abductive diagnosis model [Wotawa, 2014]. Hence,in this respect the approach only requires some relatively minor efforts in extracting the models from the failure assessment.

3.2 Efficient Diagnosis Algorithms

It is well known that in general abductive reasoning is an NP-hard problem. Certain subsets of logic, however, allow diagnoses to be computed in polynomial time. We draw upon these findings and convert the knowledge stored in the FMEAs into definite propositional horn clauses. As they require limited computational resources in the context of fault identification, we are able to derive diagnoses efficiently.

Currently, we employ an assumption-based truth maintenance system to compute abductive explanations. We conducted several experiments utilizing artificial examples as well as project internal and publicly available FMEAs and tested our implementation on the obtained abductive models [Koitz and Wotawa, 2015]. The median of the runtimes is located around and below ten milliseconds, and maximum computation times do not exceed five seconds. Even though these evaluation results seem promising, we are currently investigating the usage of SAT solvers to efficiently compute abductive explanations. By formulating the abductive model as an unsatisfiable formula, we can recast the abduction problem to finding the set of conflicting hypotheses. Several algorithms have been proposed within the context of infeasbility analysis which compute conflicts and thus can be utilized within the abductive diagnosis domain.

3.3 Improving Diagnosis Results

It is well known that diagnosis can yield an exponential number of logical possibilities. In a practical context, however, a single solution is preferred. Hence there have to be discrimination procedures available to diminish the solution size and ideally return a single fault diagnosis. Currently we use two approaches in this context: diagnoses discrimination through additional observations and diagnoses ranking based on probability theory.

4 Conclusion and Future Work

In this thesis we focus on methods to facilitate the adoption of model-based diagnosis in industrial practice. FMEAs provide information on the relation of faults and their symptoms and enable us to automatically generate models suitable for abductive diagnosis offline. The modeling methodology is a practicable approach since failure assessments, such as the FMEAs, are becoming increasingly important. Furthermore, models obtained from the FMEA are computationally feasible. Although our empirical results indicate that the approach is suitable for practical applications, we investigate the possibilities to utilize direct conflict generation to compute abductive diagnoses. For future work we are considering to include consistency-based diagnosis, as it provides a less restricted framework for deriving root causes.

Acknowledgments

The thesis described in this article is supervised by Professor Franz Wotawa. This research has been supported by the Austrian Research Promotion Agency (FFG) project Applied Model-Based Reasoning (AMOR) under grant 842407. We would further like to express our gratitude to our industrial partner, Uptime Engineering GmbH.

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