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THE DISCRETE CHARM OF DIAGNOSIS BASED ON CONTINUOUS MODELS

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We can characterize both methods of fault detection and isolation (FDI) in control engineering and model-based diagnosis (MBD) developed in Artificial Intelligence (de Kleer and Kurien, 2003) in a very general way as searching for system models that agree with the observations of the system's behavior.

MBD, or more precisely consistency-based diagnosis, is based on a rigorous **logical** formalization to define and identify "models that agree with the observations". Model and observations are inconsistent if they entail **different values** for a variable. While there is no problem to distinguish discrete values, say 0 and 1 in a digital circuit, the absolute logical "either True or False" may appear inappropriate when a measurement of 12.7 is compared with a prediction of 12.83. Additionally, MBD often uses constraint-satisfaction techniques that operate on finite domains and, hence, are inadequate for handling real-valued models. This has lead to the opinion that MBD is inappropriate for dealing with continuous systems. – "Continuous systems"?

There are no continuous systems. There are real-valued algebraic and differential equations used for modeling physical systems. It is the model of the digital circuit that is discrete, not the circuit. If we look more closely, we can describe the behavior by a continuous model. At the level of quantum physics, we may prefer a discrete model again. So, we are not talking about properties of systems, but about properties of models, and we have to ask "**What kind of model is appropriate for (automated) diagnosis** of a system (for which a real-valued model might be common)?"

MBD is based on a model and the observations, but attempts to draw conclusions that are valid for the physical system. Hence, one has to look at how they are related. Every model is only an **approximation** of the system. Measurements are noisy, **always different from the physical quantities**, and only discrete samples over time. Moreover, faults, the target of diagnosis, and symptoms are actually defined as **significant deviations** from the intended system behavior. A response to this insight is to use a finite **qualitative model** that captures only the **distinctions** that are **relevant** to diagnosis (rather than using a real-valued model which is never precise and real-valued measurements that are always wrong and addressing this issue by envelopes, tolerances, etc. in the diagnostic interpretation.

Such qualitative models do not represent heuristic knowledge, but first principles at a level appropriate for the diagnostic task. They should be **proper abstractions** of an underlying (differential) equation model and avoid the spurious contradictions that are inevitable for any numerical models. When used by the consistency-based MBD algorithm, these models will not establish inconsistencies because of imprecision or noise. If they are refuted then it is guaranteed that a (unknown) precise model of the respective behavior and, hence, the behavior itself is refuted (They may, however, fail to detect an inconsistency if they are overly abstract). This guarantees that the correct diagnosis is always included in the set of generated hypotheses. One should note that qualitative domains are finite, but still continuous and that the models based on them capture continuity of functions and changes. Models which describe how **qualitative deviations** from reference values propagate through a system turned out to be especially useful for diagnosis.

While there is ongoing theoretical work, for instance, on diagnostic algorithms and on computing the significant distinctions ("landmarks") and automating the generation of qualitative models from existing numerical ones, e.g. (Struss 2002), the technology has already been applied to real industrial problems, such as automotive systems, e.g. (Sachenbacher et al. 2000), and spacecrafts (de Kleer and Kurien 2003).

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