HyDE – Model-based Diagnosis Engine for Stochastic Hybrid Systems

Introduction

HyDE (**Hy**brid **D**iagnostic **E**ngine) is a model-based diagnosis engine that uses candidate generation and consistency checking for diagnosis of discrete faults in stochastic hybrid systems. HyDE uses hybrid (discrete+continuous) models built by the users and sensor data from the system to deduce the state of the system over time, including changes in state indicative of faults. The key features of HyDE are:

- Model-based (build models and run same reasoning algorithms)
- Diagnose multiple discrete faults (instantaneous, persistent change in operating mode of system)
- Handle hybrid system behavior (discrete + continuous)
- Handle qualitative (Boolean, finite-domain) and quantitative (real, interval) data
- Stochastic reasoning (sensor noise, prior probabilities of faults etc.)

Terminology Definition

- *Model-based Diagnosis* uses a general-purpose model of the internal structure and/or behavior of systems to perform the diagnosis task.
- *Hybrid Systems* are dynamical physical systems whose behavior evolution combines discrete and continuous changes. Some naturally occurring systems are inherently hybrid while other embedded systems in the avionics, automotive, and robotics domains are modeled as hybrid systems.
- *Stochastic Hybrid Systems* are hybrid systems that contain elements of uncertainty in one or more of the following forms:
    - Sensor noise, resulting in noisy observations.
    - Incomplete knowledge about system resulting in approximate models.
    - Prior probabilities on occurrence of faults in the system.
    - Uncertainty about the conditions for change in the discrete and continuous behavior of the system.
- *Discrete Faults* are abrupt, instantaneous and persistent (across time) changes in the behavior of the system. It is assumed that each fault can be modeled as transition to a new mode of operation of the system.

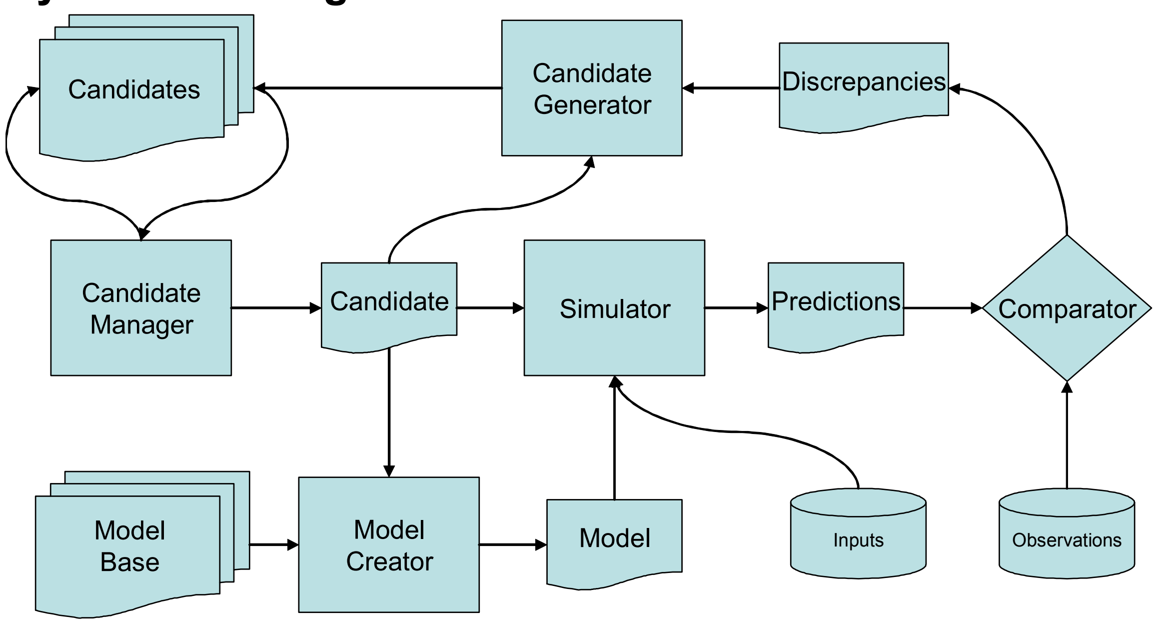
Key Issues

There are two key issues that make the diagnosis task hard, in addition to complexity introduced by the stochasticity and hybrid nature of the systems.

1. Limited Observability – The number of sensors providing observability into the system is limited for several reasons (like cost of sensors, inaccessible locations, limited bandwidth etc.). As a result, faults are typically not directly observable and have to be isolated by reasoning about the system using the available (limited) sensor information.

2. Time-delayed Symptoms – The manifestation of the effects of the faults (symptoms) is typically not seen immediately (at the same instant as the fault occurrence) for a variety of reasons. As a result the process to isolate faults has to reason backwards and forwards in time. Some possible reasons for the time delay in manifestation of fault effects are:
    a. Integrating effects due to the presence of components with state, such as capacitors and storage tanks.
    b. Observable variables may be affected by the faults only in certain discrete mode configurations.
    c. Presence of noise and uncertainty make it impractical to base decisions on a single point of comparison.

HyDE Reasoning Process



The HyDE reasoning process revolves around the maintenance of a set of candidates that are consistent with the observations seen so far. A candidate lists the fault transitions, if any, that are assumed to have been taken by the system.

At each time step when observations are available, HyDE checks each existing candidate for continued consistency with the new observations. If the candidate is consistent, it continues to remain in the candidate set. If it is not consistent, then the information about the inconsistency is used to generate successor candidates while discarding the candidate that was inconsistent.

The three main steps in the reasoning process are simulation, comparison and candidate generation. In the simulation step, the behavior of the system is simulated using the model of the system derived for the candidate being checked. The goal of the simulation step is to predict expected values of variables in the model that correspond to sensed observations. The comparison step then takes the predictions from the simulation step and compares them against actual sensor readings to identify any discrepancies. In case of discrepancies the model can be used to determine the causes for the discrepancy as well.

The third main component of the HyDE Reasoning process is the generation and maintenance of new candidates when existing candidates become inconsistent. This step uses a search process driven by the information about the causes of the inconsistency in the comparison step.

This entire reasoning process takes into account the hybrid nature of the system as well as the uncertainties present.

HyDE Models

The models used by HyDE are similar to simulation models. They describe the expected behavior of the system under nominal and fault conditions. The model can be constructed in modular and hierarchical fashion by building component/sub-system models (which may themselves contain component/sub-system models) and linking them through shared variables/parameters. The component model is expressed as operating modes of the component and conditions for transitions between these various modes. Faults are modeled as transitions whose conditions for transitions are unknown (and have to be inferred through the reasoning process). Finally, the behavior of the components is expressed as a set of variables/parameters and relations governing the interaction between the variables (for example equations). The hybrid nature of the systems being modeled is captured by a combination of the above transitional model and behavioral model. Stochasticity is captured as probabilities associated with transitions (indicating the likelihood of that transition being taken) as well as noise on the sensed variables.