Automated Diagnosis

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What is Automated Diagnosis?

- Technologies to assist in Diagnosis
- Fault Detection
- Fault Isolation
- Fault Identification
- Fault Recovery

Fault Classifications

- Plant, Actuator, Sensor, Controller Faults
- Abrupt vs. Incipient
- Persistent vs. Intermittent

What makes Diagnosis difficult?

- Complex behavior including mix of discrete and continuous
- Limited Observability
- Uncertainty
  - Uncertain knowledge about system operation
  - Unknown environment
  - Noisy Sensors
- Non-local symptoms
- Time varying and time-delayed symptoms

Approaches

- Expert Systems
- Case-based Reasoning
- Data Driven
- Model-based
- Many others...

Expert Systems

- Encode human diagnostic knowledge in data structures
- Rules and Fault Trees common

- Certified by Experts
- Fast and bounded reasoning
- Does not require deep understanding of system behavior

- All fault symptom manifestations should be known
- Takes year to gather diagnostic knowledge
- Knowledge cannot be reused in new application

Case-based

- Past cases catalogued in case library for reference
- New cases matched against library for diagnosis

- Easily applied to any system
- Fast reasoning for known cases
- Does not require deep understanding of system behavior

- New cases cannot be diagnosed
- Takes year to build meaningful case library

Data Driven

- Analyze statistical properties of data
- Transform high dimensional noisy data to low dimension fault indicators
- Offline learning and online diagnosis steps

- Requires only data and no knowledge of system
- Can handle noisy and high dimensional data

- Learning requires large volumes of data from nominal and faulty scenarios
- Diagnosis is very sensitive to data set used

Model-based

- Uses model of system structure and behavior
- Discrepancies between model predictions and sensor observations used for diagnosis

- Only models need to be built for new system with same reasoning algorithms
- Model libraries can be reused
- Existing models can be modified for diagnosis

- Models have to be built
- Time and resource complexity not bounded

Model-based Diagnosis Approaches

- Consistency-based
  - Model simulates behavior
  - Model predictions and Sensor observations compared for diagnosis
- Mathematical model-based
  - Mathematical models transformed to a form that can indicate faults when supplied with observations
- Stochastic approaches
  - Maintain belief states
  - Updates based on observations

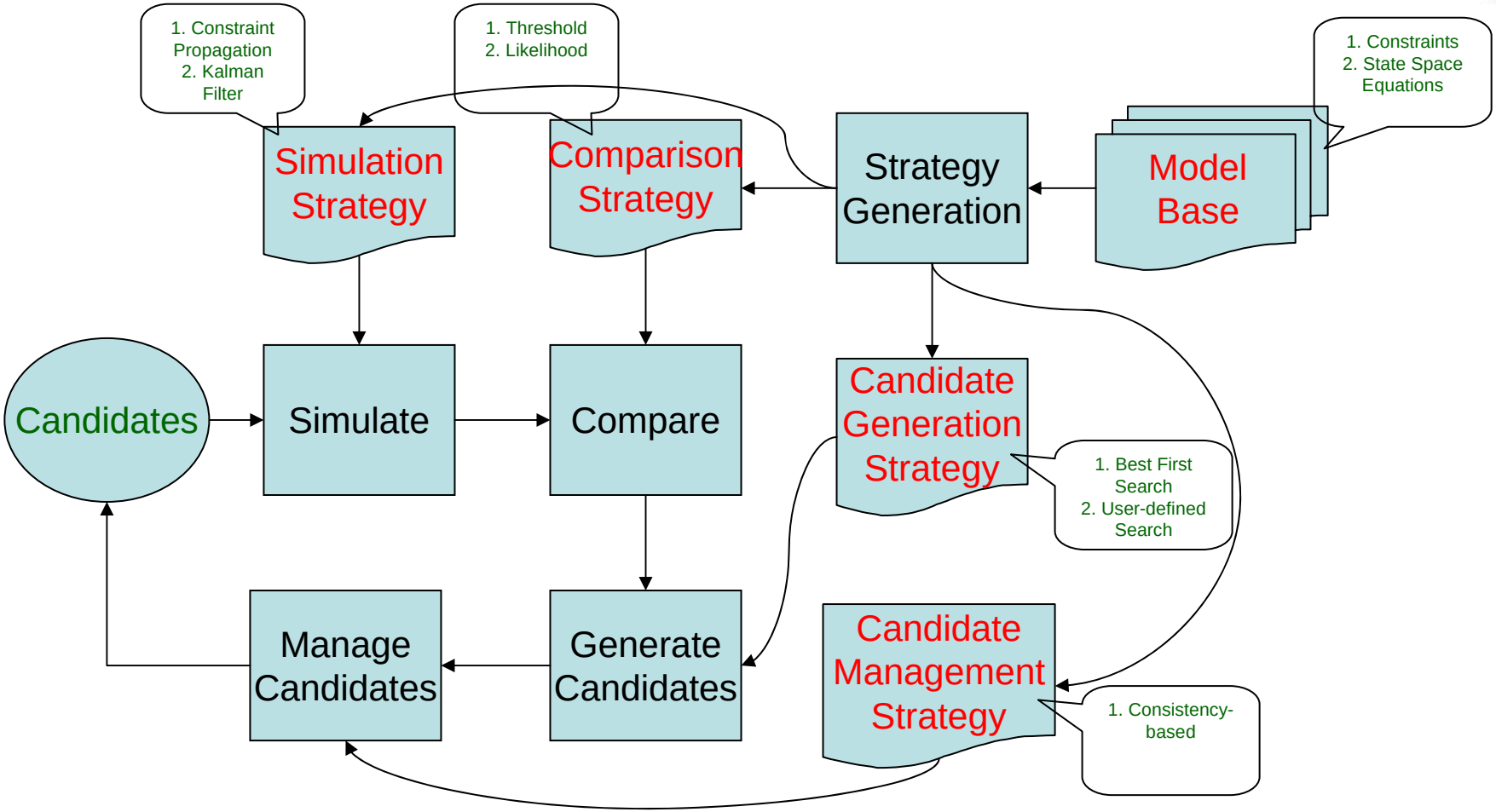
Hybrid Diagnosis Engine (HyDE)

- Diagnosis application development tool
- Support for multiple Modeling paradigms
  - Boolean Formulae, ODE's, State Space Equations
- Support for multiple Reasoning algorithms
  - Constraint Propagation, Kalman Filter, Particle Filter, Conflict-directed A*
- Hybrid Models and Reasoning
- Stochastic Models and Reasoning

Diagnosis Engine Synthesis

- User selects modeling paradigm(s) to used in reasoning
- User selects reasoning strategies (consistent with chosen modeling paradigms)
- User sets configuration parameters
- User's preferences are used to "synthesize" a diagnosis engine

HyDE Architecture



How HyDE works?

- Maintains set of weighted candidates
- At each time step (when data available) test consistency of each candidate with observations
- Update the state and weight for candidates
- Prune candidates that do not satisfy user criteria
- Add new candidates based using a directed search process

Implementation Status

- Implemented in C++
- GME used as modeling environment
- Support for
  - Boolean, Enumeration, Real, and Interval variables
  - Boolean Expressions, Enumeration equality and inequality, ODE's over real and interval variables
  - State Space Equation models and Kalman filter
  - Best-first and A* Search for Candidate Generation
  - Consistency-based candidate management

Applications

- DAME – Real-time diagnosis of a drill operating in Mars-like conditions at Haughton Crater on Devon Island - ODE models, Lots of uncertainty
- ADAPT – Real-time diagnosis of a power system test-bed – Discrete Models, Large scale
- ALDER – Real-time diagnosis for simulation of a conceptual spacecraft – Algebraic equation models, Integration with autonomy software

Other Applications

- Systems Autonomy for Vehicles and Habitats (SAVH) - NASA Ames Research Center
- Aircraft Landing Gear diagnosis – NASA Langley Research Center
- Spacecraft Engine Diagnosis – NASA Marshall Space Flight Center
- Integration into CLARAty architecture – NASA Ames Research Center and NASA Jet Propulsion Lab

Future Work

- Support for more modeling paradigms (Bond Graphs, Bayes Net etc.)
- Support for more reasoning strategies
- Support for Parametric fault isolation and identification