Model-Based Expert Systems

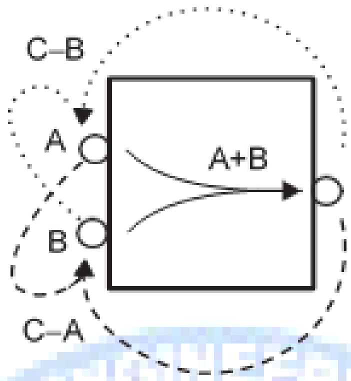
Introduction to Model-Based Reasoning

Human expertise is an extremely complex amalgamation of theoretical knowledge, experience-based problem-solving heuristics, examples of past problems and their solutions, perceptual and interpretive skills and other abilities that are so poorly understood that we can only describe them as intuitive. Through years of experience, human experts develop very powerful rules for dealing with commonly encountered situations. These rules are often highly "compiled", taking the form of direct associations between observable symptoms and final diagnoses, and hiding their more deeply explanatory foundations.

For example, the MYCIN expert system would propose a diagnosis based on such observable symptoms as "headaches", "nausea", or "high fever". Although these parameters can be indicative of an illness, rules that link them directly to a diagnosis do not reflect any deeper, causal understanding of human physiology. MYCIN's rules indicate the results of an infection, but do not explain its causes. A more deeply explanatory approach would detect the presence of infecting agents, note the resulting inflammation of cell linings, the presence of inter-cranial pressures, and infer the causal connection to the observed symptoms of headache, elevated temperatures, and nausea.

Qualitative model-based reasoning includes:

1. A description of each component in the device. These descriptions can simulate the behavior of the component.
2. A description of the device's internal structure. This is typically a representation of its components and their interconnections, along with the ability to simulate component interactions. The extent of knowledge of internal structure required depends on the levels of abstraction applied and diagnosis desired.
3. Diagnosis of a particular problem requires observations of the device's actual performance, typically measurements of its inputs and outputs. I/O measurements are easiest to obtain, but in fact, any measure could be used.



The behavior description of an adder

For the above figure, there will be three expressions:

If we know the values at A and B, the value of C is A + B (the solid line). If we know C and A the value at B is C - A (the dashed line).
If we know C and B, the value at A is C - B (the dotted line).

We need not have used an algebraic form to represent these relationships. We could equally well have used relational tuples or represented the constraints with Lisp functions. The goal in model-based reasoning is to represent the knowledge that captures the functionality of the adder.

The advantages of model-based reasoning include:

1. The ability to use functional/structural knowledge of the domain in problem- solving. This increases the reasoner's ability to handle a variety of problems, including those that may not have been anticipated by the system's designers.
2. Model-based reasoners tend to be very robust. For the same reasons that humans often retreat to first principles when confronted with a novel problem, model- based reasoners tend to be thorough and flexible problem solvers.
3. Some knowledge is transferable between tasks. Model-based reasoners are often built using scientific, theoretical knowledge. Because science strives for gener- ally applicable theories, this generality often extends to model-based reasoners.
4. Often, model-based reasoners can provide causal explanations. These can convey a deeper understanding of the fault to human users, and can also play an important tutorial role.

The disadvantages of model-based reasoning include:

1. A lack of experiential (descriptive) knowledge of the domain. The heuristic methods used by rule-based approaches reflect a valuable class of expertise.

2. It requires an explicit domain model. Many domains, such as the diagnosis of failures in electronic circuits, have a strong scientific basis that supports model- based approaches. However, many domains, such as some medical specialties, most design problems, or many financial applications, lack a well-defined scientific theory. Model-based approaches cannot be used in such cases.
3. High complexity. Model-based reasoning generally operates at a level of detail that leads to significant complexity; this is, after all, one of the main reasons human experts have developed heuristics in the first place.
4. Exceptional situations. Unusual circumstances, for example, bridging faults or the interaction of multiple failures in electronic components, can alter the functionality of a system in ways difficult to predict using an a priori model.