Criteria for Dynamic Method Selection in Diagnostic Reasoning *

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Abstract

A task can in principle be realized by different problem solving methods. A meta level reasoner can dynamically choose the appropriate method for realizing a task. This results in a flexible reasoning process. We discuss method properties, that enable meta level reasoning, along with reasoning examples. The application domain is diagnosis of technical devices.

1 Introduction

A task is a relevant concept in approaches that aim at structuring problem solving knowledge ([1], [2], [3]). A task has a goal and is characterized by the type of input it gets and the type of output it produces. A task structure recursively decomposes a task into its subtasks until primitive tasks are reached. Task analysis is an important guide for designing and implementing knowledge based systems.

Recently there is a growing awareness that a task can be carried out in various ways. A task, then, has potentially different sets of subtasks which realize it. We call such a set a problem solving method (PSM) ([4]). The subtasks of PSMs themselves might also be realized by different methods. Thus the problem solving process is recursive (until primitive inferences are reached). Primitive inferences are undecomposable tasks, that constitute the building blocks of the reasoning process. Figure 1 illustrates an example of such a task-method decomposition for the diagnosis task.

Systems that exploit multiple PSMs for realizing the same task provide robustness and flexibility in their reasoning. The scope of the problems that such systems can solve is broader, because the failure of one PSM does not mean the failure of the overall system. Moreover, the actual problem solving can be tuned to the situation at hand, by applying the PSM that is best suitable for realizing a task.

In order to reason with multiple methods, meta level reasoning is required. The system has to evaluate characteristics of PSMs with respect to the case at hand, and has to come up with an estimation of the suitability of each potential PSM. We refer to such characteristics of PSMs as suitability criteria. Such ideas can be found in [1], [5], [6] and [7]. However, there, the suitability criteria for evaluating PSMs seem to be chosen rather ad hoc; the characteristics that PSM criteria refer to are not well understood.

In this paper we describe a classification framework, for such suitability criteria, that provides a basis for determining what kind of criteria to use for evaluating a PSM's appropriateness (Section 2). In Section 3 we give an example of dynamic PSM selection. Section 4 concludes the paper.

2 Framework for suitability criteria of PSMs

Suitability criteria reflect local properties of PSMs that determine their applicability. This means that only local aspects are taken into account for evaluation (i.e., criteria do not refer to other (potentially) applicable methods). The proposed framework classifies suitability criteria along three dimensions. The given classification encompasses the criteria mentioned in [1], [6] and [7].

The main dimension reflects the type of knowledge the criteria refer to and has four categories. Epistemological criteria specify the type of domain knowledge that has to be available in order to make the PSM applicable. E.g., a simulation method requires behavioral models of the components in a device model.
Table 1: Overview of the dimensions and categories of the framework.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Category</th>
</tr>
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<tbody>
<tr>
<td>type of knowledge</td>
<td>epistemological</td>
</tr>
<tr>
<td></td>
<td>environmental</td>
</tr>
<tr>
<td></td>
<td>computational</td>
</tr>
<tr>
<td></td>
<td>assumption</td>
</tr>
<tr>
<td>strictness</td>
<td>necessary</td>
</tr>
<tr>
<td></td>
<td>useful</td>
</tr>
<tr>
<td>persistency</td>
<td>static</td>
</tr>
<tr>
<td></td>
<td>dynamic</td>
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</tbody>
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in order to propagate consequences. Environmental criteria refer to environmental requirements that have to be met. E.g., a method for testing hypotheses by measuring, requires that the device is accessible for measurements, and that measuring tools are available. Computational criteria specify features such as the needed memory space of a method, its computational complexity and the expected cpu-time it consumes. Assumption criteria specify the assumptions that have to be valid for the method in order to be applicable (e.g., the single fault or non intermittency assumption).

Distinguishing method criteria based on the type of knowledge they refer to is useful because it leads to better understanding of the scope and limitations of PSMs. Another benefit is that it is possible to tune the weight of criteria when they vary in their relevance. E.g., in real time applications, (cpu) time is an important property. This can be expressed by giving the computational criteria extra weight during evaluation of the overall appropriateness of a method.

An additional dimension along which criteria can be classified reflects their strictness. Necessary criteria reflect properties, without which a PSM can not work. Useful criteria reflect properties that hint at the measure of applicability of PSMs.

The distinction between these two categories of criteria is beneficial because by means of the useful criteria, problem solving can be fine tuned to the situation at hand. When two methods are both applicable, an intelligent, rather than an arbitrary choice of PSMs can be made. Section 3 gives an example formula for combining individual useful scores into an overall score.

The second additional dimension for classifying criteria reflects the persistency of the properties they refer to. Static criteria reflect properties that are persistent during the reasoning process. For instance, the existence of causal relations in a device model does not change during the reasoning process. Dynamic criteria reflect properties that are not persistent, they change during the reasoning process. The status of the hypotheses in the hypothesis set and the number of observations, are examples of such properties.

Applying static (and necessary) criteria supports a certain amount of competence assessment. Given a particular problem with its characteristics, the static, necessary criteria enable the meta level reasoner to assess, before the actual reasoning process starts, whether there are suitable PSMs available for solving the problem.

Table 1 gives an overview of the three dimensions and their categories. A PSM's criterion is scored on each dimension.

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2.1 Examples of method criteria

Let us illustrate some criteria with the diagnostic task. Table 2 gives some examples of suitability criteria for PSMs in diagnosis (some of them are elaborated on in this subsection).

<table>
<thead>
<tr>
<th>Category</th>
<th>Epistemological</th>
<th>Environmental</th>
<th>Computational</th>
<th>Assumption</th>
</tr>
</thead>
</table>

One subtask for discriminating between hypotheses is aimed at collecting data (see Figure 1). Two possible methods for realizing this task are collecting data by taking measurements (probing method), and by applying an input vector to the device and observing the resulting output (manipulating method). An environmental criterion for the probing method is that the device at hand is accessible for measurements. It is a necessary criterion because otherwise no measurements can be taken. Moreover it is static because this property does not change during diagnosis. An epistemological criterion for the manipulating method is that the device model contains dependencies, that enable simulating the behavior at the outputs. It is a necessary and static criterion. A computational criterion of this method requires that a large working memory is available, because simulation is a computationally expensive process. This is a dynamic criterion, because the amount of available working memory is not persistent; it depends on other processes that simultaneously occupy the working memory.

One subtask of the probing method is selection of a measuring point (see Figure 1). Smart selection aims at reducing the overall cost of diagnosis, for example by applying a PSM that minimizes the number of measurements to be carried out for testing the hypothesis set. An environmental criterion for this method states, that the failure rates of the components in the hypothesis set are more or less equal, otherwise considering the number of measurements as a sole criterion for determining the cost of diagnosis, is not appropriate. This criterion is useful, because minimizing the number of measurements is still possible when failure rates are not equal, but the PSM is less suitable.

3 Meta level reasoning with criteria

The criteria described in the previous section constitute the concepts at the meta level, that the meta reasoner has at its disposal for selecting the most suitable method in a particular situation. In this section we show examples of such meta level reasoning.

A useful meta rule for evaluating the applicability of a PSM is:

```
if evaluate(strictness(necessary, M)) is ok
then applicable(M) is ok
evaluate(strictness(useful, M))
else applicable(M) is not-ok
endif
```

The meta rule states that for evaluating the applicability of a PSM $M$, first its necessary criteria $\text{strictness}(\text{necessary}, M)$ (of the strictness dimension) have to be checked and only if they are ok, useful criteria $\text{strictness}(\text{useful}, M)$ are evaluated to estimate the measure of usefulness of the method $M$.

The usefulness measure of a method can be estimated by formula (1):

$$s_{\text{strictness}}(\text{useful}, M) = \sum_{\text{Cat}} s_{\text{type}}(\text{Cat, M})$$

Where $s_{\text{strictness}}(\text{useful}, M)$ denotes the overall applicability score of the PSM $M$ based on its useful criteria. $\text{type-set}$ is the set of different categories of criteria within the "type of knowledge" dimension $\text{type}$: epistemological, environmental, computational and assumption. $s_{\text{type}}(\text{Cat, M})$ stands for the average applicability score of the method $M$ regarding its criteria of category $\text{Cat}$ along dimension $\text{type}$. $s_{\text{type}}(\text{Cat, M})$ is defined in formula (2):

$$s_{\text{type}}(\text{Cat, M}) = \frac{1}{|c(\text{Cat, M})|} \sum_{C \in c(\text{Cat, M})} s(C)$$
Where \( w(C) \) represents the weight (importance) of the criteria of category \( C \). \( c(C, M) \) denotes the set of criteria belonging to category \( C \) that are defined for PSM \( M \), and \( s(C) \) is the value of the score on criterion \( C \). \( w(C) \) provides us with the possibility of giving certain categories of criteria more weight in a particular situation. In other words, the formula states that the overall usefulness of a method is the weighted sum of the average scores on each criterion.

Another meta level reasoning step is the following: if a method is not applicable due to the (currently) negative evaluation of one of its criteria of the knowledge type dimension, the meta level reasoner can set up a subgoal to try to still satisfy this criterion. For example, if knowledge about the reachability of measuring points, referred to in one of a PSM's epistemological criteria, is not available, a subgoal can be set up to deduce this missing knowledge. Such an approach is discussed in [8].

Regarding static, useful criteria, the meta level reasoner can, to some extent, plan the execution of PSMs. These criteria enable a tentative planning of the PSMs that will solve the problem (which PSMs will preferably be used to realize tasks).

4 Discussion and conclusion

In this paper we propose a framework for classifying problem solving method (PSM) criteria that specify the relevant conditions under which PSMs are suitable for realizing tasks. The framework constitutes a basis for determining what kind of PSM features should be reflected in the criteria for supporting proper PSM selection. The framework classifies suitability criteria according to the type of knowledge they refer to, being epistemological, environmental, computational and assumption. Moreover, the framework provides two additional dimensions that are useful for meta level reasoning. These dimensions reflect the strictness (necessary or useful) and the persistency (static or dynamic) of the properties that the criteria refer to.

The research extends the work reported in [5], [6] and [7], where dynamic method selection is dealt with. However, their choice of suitability criteria, used for meta level reasoning seems rather ad hoc. The proposed framework is a step towards a methodology for PSM selection based on method features. Although, in this paper, the framework is applied to diagnosis, it can be generalized to other tasks.

Describing suitability criteria for PSMs is also important for knowledge acquisition. The static, epistemological criteria indicate the kind of domain knowledge that needs to be represented in order to make methods applicable.

We have implemented (using Prolog) a diagnostic system (FAULTY-II) that applies suitability criteria for reasoning with multiple methods ([9]).

References