Chapter 1

Introduction

Research on qualitative reasoning about the physical world has provided a number of major results, which at a first glance appear to be rather different (cf. [9]): the component centred approach [57], the process centred approach [70], and the constraint centred approach [93]. Based on these initial approaches qualitative reasoning has gradually evolved into an independent area of research concerned with 'automated reasoning about the physical world using qualitative representations' (cf. [137]).

Many researchers in the area of qualitative reasoning agree that there are similarities between the three main approaches, but little effort has been spent on uncovering what they are. The goal of the research presented in this thesis is to construct a theory of qualitative prediction of behaviour that encompasses the original approaches and that points out the essential conceptualisations of this problem solving task, thus enabling a better understanding of the similarities and differences between the original approaches.

1.1 Unifying Approaches to Qualitative Reasoning

Unification of the three main approaches to qualitative reasoning can be motivated by the following points:

- it is important to understand how the three basic approaches to qualitative reasoning are related,
- the hypothesis that these approaches are specific instances of the same theory rather than fundamentally different, and
- the notion of a knowledge level analysis [109] as a means of describing problem solving expertise.

We view analysis of reasoning tasks at the knowledge level as a fundamental prerequisite for a thorough understanding of artificial intelligence models of such tasks. In particular in the field of qualitative reasoning, where different terminology and approaches are being developed, there is a need for bringing the fundamental concepts and techniques together. This can be done only by abstracting from the details of the actual techniques and implementations and focusing on the different generic types of knowledge and problem solving methods that are the basic ingredients of a qualitative model.

1.2 The *KADS* Methodology: a Method for Unification

We use the *KADS* methodology (cf. [141; 25; 144]) for building knowledge based systems as a method for unification. *KADS* distinguishes between a conceptual model which describes the problem solving expertise of an expert independently from a specific implementation, and a design model which describes how this problem solving potential can be realised in a computer program. *KADS* provides a framework for developing these models. Unification of the three main approaches to qualitative prediction of behaviour is essentially accomplished by constructing a conceptual model of expertise for this problem solving task. The viability of the unified approach is shown by implementing a computer program that realises the problem solving potential specified in the model of expertise. It is expected that this computer program manifests problem solving behaviour that has a wider functionality than can be realised with artifacts based on each of the original approaches.

An important objective of the *KADS* methodology is supporting the knowledge acquisition process by providing general descriptions of problem solving tasks [26]. These descriptions are called interpretation models. Unification of the three main approaches to qualitative reasoning enhances the *KADS* library of interpretation models, because it delivers such a model for qualitative prediction of behaviour.

1.3 Cognitive Plausibility and Strategic Knowledge

As mentioned before, a crucial aspect in *KADS* is the distinction between the conceptual model and the design model. The conceptual model constitutes a knowledge level description of the expertise, whereas the design model specifies how the problem solving potential can be realised in a computer program. However, the borderline between these two models is not always clear. In order to support the distinctions that we make in this respect, we present a protocol analysis that investigates to what extent the conceptual model for qualitative prediction of behaviour accounts for the data found in think-aloud protocols of human subjects who performed a behaviour prediction task.

In the different approaches to qualitative reasoning the notion of strategic knowledge, which controls the overall reasoning process, has not been given much attention. In addition to the conceptual model and the design model, we present a tentative approach for 'reflective control' (cf. [6]) of qualitative problem solving engines.

1.4 Overview of the Presented Research

Below an overview is given of the research presented in this thesis.

- In chapter 2 an overview of the current approaches to qualitative reasoning is described in three sections. The first section gives an introduction to the field. The second section gives a detailed description of the three classical approaches to qualitative reasoning. The third section discusses the major unsolved problems for each of these approaches.

- In chapter 3 a theory of modelling problem solving, based on *KADS*, is presented in two sections. The first section describes the conceptual framework for modelling problem solving expertise. The second section describes how this problem solving model can be transformed into a design model for implementing a computer program.

- In chapter 4 the integrated approach to qualitative prediction of behaviour is described. The first section of this chapter points out three tasks relevant to behaviour prediction. The second section constitutes the major part of this chapter. It describes a *KADS* model of expertise for qualitative prediction of behaviour. In particular, the problem solving roles 'played by' the domain knowledge are an important part in this section.

- In chapter 5 the problem solving behaviour of *GARP*, a reasoning shell for qualitative prediction of behaviour, is presented in four sections. The first section describes the functional view on the artifact. The second section describes how each of these functions is realised through a computational method. The third section describes how the methods are assembled into modules that implement the artifact. The last section describes two examples to illustrate the problem solving behaviour of *GARP*: a model of the cooling mechanism of a refrigerator and a model of two heart diseases.

- In chapter 6 the results of a protocol analysis are presented, where think-aloud protocols of human subjects predicting the behaviour of a complex configuration of balances are compared with a computer model of that same problem solving task implemented in *GARP*.

- In chapter 7 a preliminary knowledge level theory for reflective improvement of problem solving artifacts is presented. In particular, the notion of knowledge conflicts for representing impasses in the problem solving process of *GARP*, is discussed in this section.

- In chapter 8 the contributions of the presented research are described in two sections. The first section discusses the important results. The second section points out a number of research issues that are of interest for further investigation.