Mapping Inferences: Constraint Propagation and Diamond Satisfaction

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Writing my Ph.D. thesis consisted of several tasks. Above all it meant trying to recast my research work in a homogeneous setting. As a result of this, two main research fields converge in the present thesis: the field of constraint satisfaction (Part I) and that of automated theorem proving in modal logics (Part II). Underlying the material in both Parts I and II is a persistent shared concern with knowledge representation and reasoning, on the chosen representation, in an efficient manner. This is the main link between both parts, which is in rationale and methodology rather than subject matter.

The material of this thesis is thus organised into three main parts, as explained below. This introduction is meant to be a guide for the reader through the tree parts of the present thesis. In the remainder of this chapter, I attempt to explain what follows: who could benefit from reading this thesis, and why so; the structure of this thesis, i.e., how its parts and chapters are organised.

1.1 Who Could Benefit from This Thesis

Before starting the actual writing, I was suggested to always bear in mind an idealised, non-expert reader for the thesis, the main reason being that the areas of constraint programming and modal logics, both treated in the present thesis, seem to pertain to two separate communities. As a matter of fact, the phrase "modal logic" never occurs in the two main manuals for constraint programming and satisfaction problems, see [MS98, Tsa93]; a similar fate is shared by the words "constraint satisfaction problem" and "constraint programming" in manuals for modal logics, for instance see [BdRV01].

Part I of the thesis is devoted to constraint satisfaction problems and, in particular, to a theoretical analysis of a class of algorithms, devised to boost the search for solutions to constraint satisfaction problems by inferring constraints. Bearing in mind an idealised reader, non-expert of the constraint literature, I devote part of Chapter 2 to introduce some basic concepts and fix the notation.
Part II of the thesis is concerned with boosting automated theorem proving for basic modal logics. The non-expert readers of modal logics should find enough background material in Chapter 7 to enjoy the remainder of this second part. In particular, the background material could be useful to constraint programmers who would like to see, in Chapter 9, how a constraint solver for basic modal logics can be developed.

As anticipated at the start of this chapter, in both Parts I and II there is a persistent shared concern with knowledge representation and reasoning, on the chosen representation, in an efficient manner. This is the main link between both parts of this thesis; even though Chapter 9 establishes a close connection between algorithms for solving constraints (as explained in Part I) and modal reasoning (as explained in Chapter 7, Part II). In Part III, I elaborate on these issues and provide some conclusions.

Thus the material presented in the three parts of this thesis can be of interest to an ensemble of various researchers such as:

1. the programmer who wishes to grab a general and uniform view of the so-called constraint propagation algorithms, many of which are already implemented in all constraint programming environments;

2. in particular, the constraint programmer, who might be interested in what constraint programming can do for modal automated theorem proving, or wish to get familiar with non-standard constraint problems, for which the task is to return an optimal partial solution;

3. the logician or linguist with an interest in automated theorem proving or constraint satisfaction problems;

4. the computer scientist, interested in satisfiability problems;

5. the relational database theorist who wishes to explore the similarities and differences between her/his field and that of constraint satisfaction problems;

6. in general, everybody who is interested in Artificial Intelligence — e.g. Temporal or Spatial Reasoning, Scheduling, Planning, Reasoning under Uncertainty.

In the following subsection, I briefly explain the structure of this thesis: i.e., how its parts and chapters are organised and what their dependencies are. This is meant to facilitate, to each reader, the creation of a personal reading path.
1.2 Structure of This Thesis

Parts

As explained above, this thesis is tripartite. The parts are rather voluminous, so a brief outline is given at the start of each of them.

Part I can be read independently of the remainder of the thesis. In addition, Chapters 7 and 8 in Part II can be read without any prior knowledge of the first part. Instead, Chapter 9 in Part II requires some knowledge of Chapter 2 in Part I and Section 4.2. Part III can be read only after the other two parts.

Furthermore, both Parts I and II begin with a preliminary chapter (Chapters 2 and 7, respectively), where the terminology is fixed and the background material is explained; in these preliminary chapters, a series of examples are proposed to the non-expert reader, and each key definition is accompanied by a motivating toy example, easy to grasp and remember.

Chapters

Instead of providing a detailed overview of the whole thesis in this introduction, I decide to provide each of the remaining chapters with a rather detailed, mainly non-technical introduction. Those introductions are organised in three subsections as explained below: motivations; outline; structure.

An analogous choice holds for the conclusions: in Parts I and II, each chapter is concluded by a synopsis of the presented material, and its connections with the remainder of this thesis; when pertinent, there is also a discussion on the chapter results.

Motivations. At the beginning of each chapter, I go through the effort of motivating why the proposed material could be of interest to the reader. For instance, Chapter 2 pertains to the so-called constraint satisfaction problems; thus that chapter begins by informally introducing the topic and surveying some of its current applications. Similarly, Chapter 7, at the start of Part II (Diamond Satisfaction), introduces the non-expert reader to modal logics by surveying some of the areas where those logics can be traced, and have been successfully applied.

Outline. Each introduction continues with a preliminary account of the main points that are covered in the chapter, in a brief and non-technical manner; ideally, this should give a glimpse of the chapter contents, without the burden of too many technical details at a first reading.

Structure. Finally, at the end of each introduction, the structure of the chapter is illustrated so that the expert reader can easily navigate through this.
Origins of the chapters. Some examples and definitions in Chapter 2 are taken from [Gen98]. Chapter 3 presents a new version of material first presented in [Gen00] and [Gen02]. Chapter 5 is largely based on the following articles: [BGR02], first appeared as [BGR00], both written with S. Bistarelli and F. Rossi; [Gen01a], whose longer version is [Gen01b]. Chapter 8 is based on the joint paper [AGHdR00], written with C. Areces, J. Heguiabhere and M. de Rijke. Chapter 9 presents the results of on-going work with S. Brand and M. de Rijke.