Abstract

Pictorial languages occur in almost every field from roadsigns to technical design or abstract art. Computer science is no exception. Understanding the reasons for the success of visual information in human communication and exploiting them in an automated fashion has gained a prominent place in the artificial intelligence agenda. By considering several aspects of graphical languages in knowledge representation, this thesis positions conceptual graphs, a specific diagrammatic framework, at a crossroad of logic, language and computation.

Some of the cognitive and linguistic efficient features of drawings play an indisputable role in human and human-machine communication. Besides these interesting representational standpoints, the computational efficiency of reasoning we obtain on some classes of diagrams emphasises the relevance of pictures in automated reasoning.

In this dissertation, computational complexity is understood in traditional symbolic terms. As a result, this lays a common ground for a beneficial interaction between usual textual logics and graphical languages: in the first place, the diagrammatic systems we study reveal the attractive computational complexity of logical fragments that fall outside the usual paths of symbolic logic. Conversely, some symbolic characterisations adapt well to the diagrammatic frameworks. For instance, the notion of guards, which arose from the translation of modal logics into classical ones, defines a new visual notion of tree in the conceptual graph paradigm. Moreover, reasoning techniques can be exchanged between both sides or combined. Finally, cognitive aspects that are recognised in the perception and manipulation of diagrams offer new tracks for expanding established symbolic computational models with additional visual features.

The central issue of this thesis is to explore these interactions between conceptual graph fragments and symbolic logics, in the light of standard symbolic complexity models. The main results that are presented concern graphical proof methods for consequence problems and their complexity analysis in several conceptual graph languages. Furthermore, by bringing the study into the wider

perspective of visual information in artificial intelligence, we aim at contributing to the general issue of a better understanding of some properties of reasoning with diagrams; this appears to be the necessary basis for further promising connections between symbolic and graphical perspectives.

The work is organised in five chapters. The first two chapters position conceptual graphs in the perspective of several disciplines involved in artificial intelligence. Chapter 1 relates conceptual graphs to historical appearances of diagrams in logic, pictorial languages in knowledge representation, cognitive studies of visual information and drawings used in natural language processing. The wide scope of this overview stresses the relevance of fine-grained studies of visual properties to the artificial intelligence community as a whole. Computational logic may be seen as common ground for all these fields when applied to automated reasoning; this is the subject of the next chapter.

Chapter 2 presents the technical framework in which the graphical systems used in the rest of this work will be evaluated. Symbolic complexity analysis offers fine-structure formal analysis of reasoning with the graphs and connects the study of visual reasoning to current interests in expressiveness and complexity in symbolic logic. A geography of complexity results in classical and modal fragments is then depicted. It sets the scene for the study of conceptual graph languages: several decision problems are relevant and homomorphism-based methods rely on problem equivalence (between model comparison and consequence) that occur in low-expressive languages.

Chapter 3 introduces the core fragment of simple conceptual graphs and projection, a consequence calculus based on labelled graph homomorphism. In addition to the usual semantics of simple graphs, which is given by a translation to existential conjunctive FOL, a model-theoretic approach is also provided. It offers a direct handle for associating projections with model comparisons. By defining a notion of meta-acyclicity based on guarded quantification and an appropriate projection algorithm, a tractable guarded fragment of simple graphs is highlighted (Theorem 3.3.7). It includes all previously known tractable fragments of simple conceptual graphs (i.e. graphs that can be transformed into equivalent trees).

Chapter 4 explores different possible extensions of the core language. First, the addition of atomic negation is considered. In the graph representations, a separation criterion of positive from negative information defines a fragment of simple graphs with atomic negation in which projections apply (Theorem 4.1.19). Furthermore, in the guarded restriction of this fragment, consequence is polynomial (Corollary 4.1.22). Secondly, for a language of conceptual graphs equivalent to first-order logic, we propose a complete proof method combining tableau construction rules and projections (Chapter 4.2). Finally, in the remaining part of the chapter, a modal perspective for graph nesting is studied . Reimporting the notion of guards in this modal framework enables us to define a language of nested graphs with a tractable associated projection (Corollary 4.3.15).

In the last chapter, we draw our main conclusions from the complexity results obtained along our chosen route through conceptual graph landscapes. In particular, the successful interaction of graphical aspects with symbolic ones suggests promising further paths towards more visually oriented computation.