Qualitative Reasoning about 2D Cardinal Directions using Answer Set Programming (Extended Abstract)

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Spatial representation and reasoning about position of objects is an essential aspect of geographical information systems, artificial intelligence, cognitive robotics, computer vision, spatial databases, semantic web and digital forensics. Many tasks in these areas, such as satellite image retrieval, navigation of a robot to a destination, robotic manipulation, describing the location of a landmark, constructing digital maps involve dealing with spatial properties of the objects and the environment such as direction, distance, size, shape. In contexts where robots interact with humans, qualitative expressions about spatial configuration of objects are more preferable than quantitative terms for the sake of sociable and convenient communication, for example "the library is in front of the cafeteria and near to the Erasmus Building" is cognitively more understandable by a human, compared to "the library is 97^o northwest of the cafeteria and 72 m to the Erasmus Building". In addition, commonsense knowledge and assumptions are usually stated in natural language such as "the monitor is normally placed to the back of the keyboard", "fork and spoon are by default at the right or left of the plate". Moreover qualitative reasoning is relevant in domains where quantitative data is not available or data obtained from sensors is coarse e.g., "the yacht is near and starboard of the tanker ship".

In this paper, we focus on a particular sort of qualitative spatial relations, cardinal directions (e.g., west/left, south/front, north/back, east/right, and their combinations), to describe the orientation of spatial objects relative to each other in 2-dimensional space. In order to represent cardinal directions, we use the formalism Cardinal Directional Calculus (CDC) (Goyal and Egenhofer 1997; Skiadopoulos and Koubarakis 2004; Skiadopoulos and Koubarakis 2005). In CDC, objects are extended (non-point) regions in the Euclidean space, they can be connected or disconnected. Motivated by real life applications, we extend CDC with two new types of constraints, called default CDC constraints and inferred CDC constraints. Default CDC constraints represent commonsense knowledge and presumed information; inferred CDC constraints represent inference of unknown directional relations between objects. We define default CDC constraints using nonmonotonic semantics of Answer Set Programming (ASP)—a logic programming paradigm based on answer set semantics (Gelfond and Lifschitz 1988; Gelfond and Lifschitz 1991). Due to its nonmonotonic aspects, we call this extension of CDC as nonmonotonic CDC *(nCDC)*. An *nCDC constraint* can be a basic, disjunctive, default or an inferred CDC constraint.

To illustrate the use of nCDC, we consider a scenario where two parents are looking for their missing child in a shopping mall. The assistive agent has received sightings of the child at the south or west of the pool. The agent also knows that the child is by default at the ice-cream truck; the ice-cream truck is by default in the free area which is to the north, east or northeast of the movie theater, and south or southeast of the pool. Then it will be desirable for the agent to find out possible locations of the child and express it in human language like "the child might be to the southeast of the food court and to the east of the park".

One of the main problems in qualitative spatial reasoning and CDC is checking the consistency of a given set of CDC constraints, i.e., checking whether a feasible configuration of the objects exists on the plane with respect to the given CDC constraints. In the missing child scenario, the agent needs to verify that the collected information is consistent so that it can infer the possible locations of the child. In general, when the constraint network is incomplete or includes disjunctive constraints, consistency checking in CDC is an NP-complete problem (Liu 2013; Liu and Li 2011; Liu et al. 2010; Skiadopoulos and Koubarakis 2005). Note that consistency checking is defined over continuous space, we show how this problem can be solved over the discrete space in the spirit of Liu et al. (2010), by viewing the spatial objects as a set of cells on a grid. We also identify bounds on the grid size so that the discretized problem has the same answer with the original one.

In addition to nCDC formalism, another contribution of this paper is developing a novel framework named NCDC-ASP for reasoning with nCDC using ASP. This framework can check consistency of a set of nCDC constraints, explain the source of inconsistency, infer unknown cardinal directions and generate a configuration of objects on the grid. NCDC-ASP can reason with uncertain and presumed information, it can be utilized in different domains where objects are connected or possibly disconnected.

ASP provides a formal framework for knowledge reasoning and declaratively solving computationally hard problems. The language of ASP includes choice rules, nonmonotonic constructs, aggregates, hard and weak constraints which allow us to encode different types of nCDC constraints and perform the above reasoning tasks in the discrete space. The answer sets of an ASP program includes occupied cells of the objects which characterize a layout of objects. We also develop an improved version of our ASP formulation and reduce the bound on the grid size for computational efficiency. Note that since objects are extended regions, they may occupy a large area on the grid and they may overlap. For robotic placement applications, we need to better identify the position of objects on the surface, hence we develop ASP subprograms to optimize the layout by minimizing the occupied area and the number of overlapping objects.

In the literature, there exists a method (Liu et al. 2010) for CDC consistency checking, but this algorithm can only solve polynomial time problem instances and cannot integrate commonsense knowledge into reasoning. The generic spatial toolkits *QAT* (Condotta, Saade, and Ligozat 2006), *GQR* (Gantner, Westphal, and Wölfl 2008), *SparQ* (Wallgrün et al. 2006) require the inverse relation to be a basic relation and they employ path consistency for deciding consistency. However, the inverse of a CDC relation is usually not a basic relation and path consistency is insufficient for deciding consistency of CDC networks (Liu et al. 2010; Skiadopoulos and Koubarakis 2004). In this sense, our nCDC formalism and NCDC-ASP framework theoretically and practically contribute to qualitative reasoning about cardinal directions.

In the literature, there is no available benchmarks for CDC consistency checking and reasoning. Therefore, in order to evaluate computational efficiency of our ASP formulation, we create handcrafted and random benchmark problem instances by varying the number of objects, network size, domain (connectedness of objects) and including different type of nCDC constraints. For each parameter combination, consistent and inconsistent problem instance are created. In this way, we assess the impact of various factors such as input size, connectedness of objects, presence of disjunctive and default constraints on the computation time and program size. We make experiments to evaluate the benefit of improved ASP formulation and reduced grid size. We also compare our method with the existing solver (Liu et al. 2010) over polytime and NP-complete (by exhaustive search) problem instances.

We show the soundness and completeness of NCDC-ASP , and its usefulness by sample scenarios in dynamic environments that involve incomplete information, commonsense knowledge, and inference. These scenarios are taken from social/service robotics applications, which involve interaction of an agent (e.g., a robot) with humans.

The ASP code, benchmark problem instances and example scenarios can be found at an online repository[1]. We have also created a software which takes input from the user and performs the automated reasoning tasks using these ASP programs. This software is available at another repository[2].

For further information about the theoretical and practical aspects of nCDC and NCDC-ASP briefly mentioned above, we refer the reader to our journal article (Izmirlioglu and Erdem 2023).

[1] https://github.com/yizmirlioglu/nCDC

[2] https://github.com/yizmirlioglu/nCDC-ASP-Software

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