GEQCA: Generic Qualitative Constraint Acquisition

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Abstract

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Many planning, scheduling or multi-dimensional packing problems involve the design of subtle logical combinations of temporal or spatial constraints. On the one hand, the precise modelling of these constraints, which are formulated in various relation algebras, entails a number of possible logical combinations and requires expertise in constraint-based modelling. On the other hand, active constraint acquisition (CA) has been used successfully to support non-experienced users in learning conjunctive constraint networks through the generation of a sequence of queries. In this paper, we propose GEQCA, which stands for *Generic Qualitative Constraint Acquisition*, an active CA method that learns qualitative constraints via the concept of *qualitative queries*. GEQCA combines qualitative queries with time-bounded path consistency (PC) and background knowledge propagation to acquire the qualitative constraints of any scheduling or packing problem. We prove soundness, completeness and termination of GEQCA by exploiting the *jointly exhaustive and pairwise disjoint* property of qualitative calculus and we give an experimental evaluation that shows (i) the efficiency of our approach in learning temporal constraints and, (ii) the use of GEQCA on real scheduling instances.

1 Introduction

Reasoning about time and space is essential for solving many practical problems, such as automated planning (Belhadji and Isli 1998) and scheduling (Barták, Salido, and Rossi 2008). In this context, qualitative reasoning provides an algebraic framework that establishes relationships between pairs of entities using a language Γ that is *exhaustive and pairwise disjoint*. This results in a qualitative constraint network (QCN), where the entities are the nodes and the edges are the relations.

Examples of qualitative reasoning include (but are not limited to) point algebra (Vilain and Kautz 1986) or Allen's interval algebra (Allen 1983) for reasoning about temporal tasks, and the Region Connection Calculus (RCC) (Randell, Cui, and Cohn 1992) for reasoning about topological relations between spatial regions.

In this context, Constraint Satisfaction Techniques and Constraint Programming (CP) are practical frameworks for modeling and solving networks of qualitative constraints. To facilitate the modeling of constraint programming problems, Bessiere et al. (2005) introduced a framework for learning constraint models through passive learning from a set of labeled assignment examples or through active learning with specific queries to classify complete assignments.

This abstract introduces the concept of GEQCA (Generic Acquisition of Qualitative Constraints), a novel active constraint acquisition algorithm that can learn various qualitative constraints between entities. GEQCA uses qualitative queries, path consistency (PC), dedicated selection heuristics, and propagation of given background knowledge to acquire constraints. The algorithm overcomes the limitations of existing constraint acquisition algorithms, such as their inability to handle disjunctions, control the number of queries, and limited knowledge of the context. The primary aim of GEQCA is to simplify the modeling of complex constraint networks in practical scenarios, such as scheduling problems.

2 GEQCA: Constraint Acquisition via Qualitative Queries

We propose GEQCA, a generic algorithm for acquiring qualitative constraints. We introduce the concept of a *qualitative query* Q-ASK(X_i, r, X_j), where the user is asked to confirm whether an entity variable X_i can be placed under a basic relation r with respect to another entity variable X_j.

GEQCA takes as input a vocabulary of entity variables, a language of atomic relations, background knowledge, and a timeout as a parameter. Initially, the algorithm builds a network containing only universal constraints between entities. Then, it iterates over pairs of entities to narrow down the set of possible relations to a locally consistent subset that aligns with the user's intentions. To reduce user intervention, GEQCA includes a propagation procedure that automatically eliminates relations that are incompatible with the current learning state. For instance, in a temporal context, if *"X_i and X_j tasks have respectively, duration of* 1 *and* 2 *hours"*, the propagation step will remove *Equals*, *Contains*, *Started-by* and *Finished-by* from X_i to X_j.

The theoretical analysis presented in the paper shows that GEQCA is a correct algorithm to learn any constraint network representing a qualitative concept over Γ language with a waiting time between two queries not exceeding a given time boundary.

GEQCA can be improved by making the constraint selection less brute-force. That is, selecting constraints in different ways can have a significant impact on PC and background knowledge propagation, thus leading to great improvements in the number of asked queries until convergence. We introduce a dedicated constraint selection heuristic based on traversal of a complete graph. The rationale behind is to maximize the impact of PC and the transitivity between constraints with a constraint selector building paths.

3 Experiments

Our experimental evaluation of GEQCA focuses on Allen's interval algebra applied to temporal entities. The language Γ used contains the 13 known atomic relations of this algebra.

Table 1 shows that GEQCA has a significant impact on large instances, with a constant effort saved of 35%. The results are promising for the use of GEQCA on real-world instances, whether they are sparse or large.

Table 1 presents the user effort required to solve 5 scheduling instances using GEQCA with a pair selection heuristic that we introduced in this work. We used the publicly available RCPSP3 instances, considering the problem structure including task durations, resource requirements, and source capacities, denoted K_1. In addition, some constraints may already be known to the user, such as the cumulative global constraint and the delay constraint. We call K_2 the background knowledge including the cumulative constraint and the delay constraint. We also used a time limit (`cutoff`) of one hour and denoted by T_{max} the maximum waiting time between two queries. Each scheduling instance is characterized by the number of tasks (for example, `sch_30_1` refers to instance number 1 with 30 tasks).

The first observation is that using GEQCA with knowledge of the problem structure K_1 significantly reduces the user effort (an average reduction of 38%). The second observation is that user effort is also reduced when using knowledge that concerns known constraints such as the *cumulative* constraint and delay constraints. We observe a reduction of 41% using K_1 for propagation. The use of $K_1 \wedge K_2$ brings a small but not significant improvement (an average reduction of 41% instead of 38%). Furthermore, in terms of CPU time, the waiting time between two queries can reach the one-hour threshold under $\mathcal{K}= K_1 \wedge K_2$. This is due to a propagation step that can take more than an hour to try to prove the consistency of a relation with the learned network.

	$\mathcal{K}$					
	$\varnothing$		K_1		$K_1 \wedge K_2$	
Instance	`eF`	T_{max}	`eF`	T_{max}	`eF`	T_{max}
`sch_30_1`	95%	0.7	55%	0.9	53%	1
`sch_30_2`	98%	0.6	52%	0.9	48%	393
`sch_60_1`	99%	4.8	65%	8.5	62%	13
`sch_60_2`	99%	7.7	64%	8.0	61%	12
`sch_60_3`	98%	5.9	59%	9.6	57%	3 600

Table 1: User effort `eF` with GEQCA acting on RCPSP instances (with `cutoff` $= 3,600s$, T_{max} in seconds).

4 Conclusion

In conclusion, this work introduces GEQCA, an active learning algorithm for acquiring qualitative networks through qualitative queries. The approach is grounded in the JEPD property of qualitative reasoning and utilizes path consistency to improve convergence and reduce the number of necessary queries. The experiments demonstrate the effectiveness of the approach in practical applications, highlighting its potential to outperform existing approaches.

Overall, GEQCA represents a promising step forward in the field of constraint acquisition and qualitative reasoning. Its use of qualitative queries provides a more intuitive interface for users, while its theoretical guarantees ensure convergence and correctness. Moreover, the algorithm's ability to minimize the number of queries needed to achieve a satisfactory result is particularly appealing for practical applications.

Future work could explore further enhancements with new query types and real-world applications. The generality of the algorithm makes it suitable for use in a wide range of practical scenarios, such as natural language processing, computer vision, and robotics. Future studies could investigate how GEQCA performs in these domains and compare its performance to other state-of-the-art approaches.

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References

Allen, J. F. 1983. Maintaining knowledge about temporal intervals. *Communications of the ACM* 26(11):832–843.

Barták, R.; Salido, M.; and Rossi, F. 2008. Constraint satisfaction techniques in planning and scheduling. *Journal of Intelligent Manufacturing* 21:5–15.

Belhadji, S., and Isli, A. 1998. Temporal Constraint Satisfaction Techniques in Job Shop Scheduling Problem Solving. *Constraints* 3(2):203–211.

Bessiere, C.; Coletta, R.; Koriche, F.; and O'Sullivan, B. 2005. A SAT-based version space algorithm for acquiring constraint satisfaction problems. In *European Conference on Machine Learning*, 23–34. Springer.

Randell, D. A.; Cui, Z.; and Cohn, A. G. 1992. A spatial logic based on regions and connection. *KR* 92:165–176.

Vilain, M. B., and Kautz, H. A. 1986. Constraint propagation algorithms for temporal reasoning. In *AAAI*, volume 86, 377–382.