Embarrassingly Greedy Inconsistency Resolution of Qualitative Constraint Networks

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25 September 2023

Qualitative Spatial & Temporal Reasoning

- A major field of study in KR, and Symbolic AI in general[1]
- Abstracts from numerical quantities of space & time
- Grounded on *physics* and *human cognition*

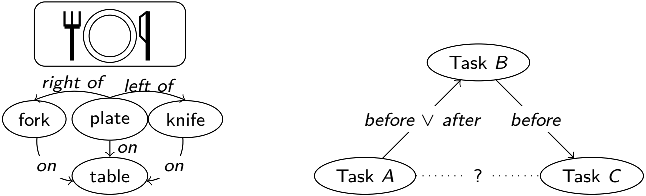

Figure: Abstraction of a spatial configuration (left), temporal constraint network of three variables (right); ? denotes complete uncertainty

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[1] G. Ligozat.: *Qualitative Spatial and Temporal Reasoning*. ISTE Series. Wiley, 2011

Example Calculus: RCC8

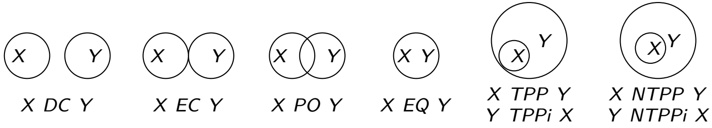

Figure: The base relations of RCC8; $\cdot i$ denotes the inverse of $\cdot$

Example Calculus: Allen's Interval Algebra

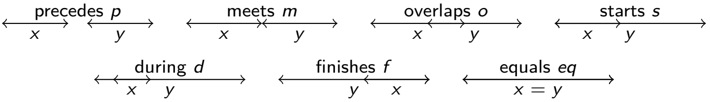

Figure: The base relations of Interval Algebra; inverses are omitted in the figure

Aspects of Space and Time ... and More

- Abundance of calculi dealing with trajectories, occlusion, intervals, and so on[2]

- Translating terminological knowledge into region spaces, e.g., *document PO paper*[3]

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[2] F. Dylla et al.: *A Survey of Qualitative Spatial and Temporal Calculi: Algebraic and Computational Properties*. ACM Comput. Surv. 50 (2017)

[3] Z. Bouraoui et al.: *Region-Based Merging of Open-Domain Terminological Knowledge*. In: KR 2022

Applications: Drone Monitoring

Figure: "Never fly over an urban area for more than 3 minutes": $\forall r \in$ UrbanRegion, $\Box(PO \vee TPP \vee NTPP(\text{Drone}, r) \rightarrow \Diamond_{[0,180s]} DC(\text{Drone}, r))$[4]

[4] F. Heintz, D. de Leng: *Spatio-Temporal Stream Reasoning with Incomplete Spatial Information*. In: ECAI 2014

Reasons of Inconsistency

- Inaccurate classifiers
- Human error
- Multi-source information
- Vagueness
- Noisy data
- . . .

Inconsistency Handling in Hybrid AI

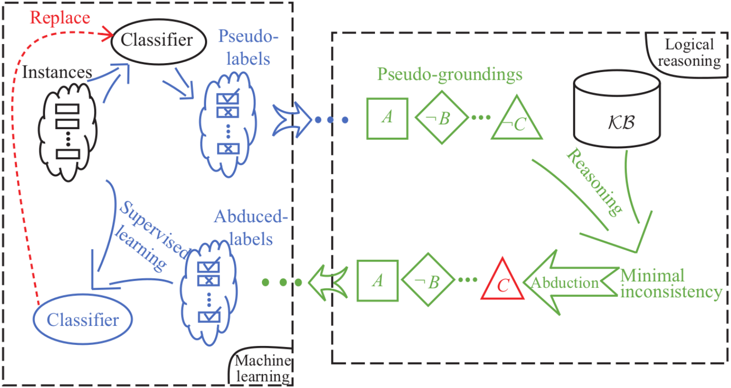
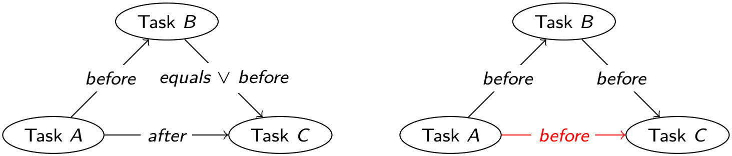


Figure: Minimizing inconsistency within the Abductive Learning framework[5]

[5] Z.-H. Zhou: *Abductive learning: towards bridging machine learning and logical reasoning*. Sci. China Inf. Sci. 62 (2019)

Repairing Inconsistent Information



(a) Inconsistent plan as simplified QCN (b) An *optimal* scenario of the QCN

Figure: An inconsistent QCN and an *optimal* scenario of it, where Task A {*before*} Task C is the only relation that does not satisfy the original constraint

We solve the MAX-QCN problem,[6] i.e., maximizing the number of satisfied constraints in a *qualitative constraint network* (QCN)

[6] J.-F. Condotta et al.: *A SAT Approach for Maximizing Satisfiability in Qualitative Spatial and Temporal Constraint Networks*. In: KR 2016

Greedy Approach

We use various constraint ordering strategies in a portfolio-like approach

Greedus($\mathcal{N}, \mathcal{A}$)

in : A QCN $\mathcal{N} = (V, C)$ and a set $\mathcal{A}$ of bijections $\alpha : E \rightarrow \{0, 1, \ldots, |E| - 1\}$, where $E = E(G(\mathcal{N}))$ (i.e., roughly, a set of orderings of the constraints in $\mathcal{N}$)

output : A subset $p \subseteq E(G(\mathcal{N}))$ corresponding to feasible constraints in $\mathcal{N}$

$P \leftarrow \emptyset$;
foreach $\alpha \in \mathcal{A}$ **do**
    $p \leftarrow \emptyset$;
    $\mathcal{N}' = (V, C') \leftarrow \mathcal{N}_\top$;
    for i **from** 0 **to** $|E(G(\mathcal{N}))| - 1$ **do**
        $\{u, v\} \leftarrow \alpha^{-1}(i)$;
        $C'(u, v) \leftarrow C(u, v)$;
        if $\mathrm{SAT}(\mathcal{N}')$ **then**
            $p \leftarrow p \cup \{\{u, v\}\}$;
        else
            $C'(u, v) \leftarrow \mathsf{B}$;
    $P \leftarrow P \cup \{p\}$;
return $p \in \arg\max_{p' \in P}(|p'|)$;

Some Ordering Strategies

- **max**: choose the constraint that has the base relation with the most *local models*[7]
- **sum**: choose the constraint with the highest cumulative count of local models
- **weight**: choose the constraint with the largest weight[8] (the larger the weight, the more permissive the constraint)
- **card**: choose the constraint whose smallest decomposition into sub-relations of a (maximal) tractable subset is the largest one
- **card + weight**: the card heuristic, with the weight heuristic acting as tie-breaker
- **random**: choose a constraint randomly

[7] M. Sioutis et al.: *Dynamic Branching in Qualitative Constraint Networks via Counting Local Models*. In: TIME 2020

[8] P. van Beek, D. W. Manchak : *The design and experimental analysis of algorithms for temporal reasoning*. J. Artif. Intell. Res. 4 (1996)

Optimal Partial MaxSAT Encoding[9]

Given a QCN $\mathcal{N} = (V, C)$ over some calculus $\mathcal{C}$ we have

- the hard clauses encoding a theory of $\mathcal{C}$: $\mathrm{Th}_{\mathcal{C}}(\mathcal{N})$
- the soft clauses encoding the constraints of $\mathcal{N}$: $\mathrm{In}_{\mathcal{C}}(\mathcal{N})$

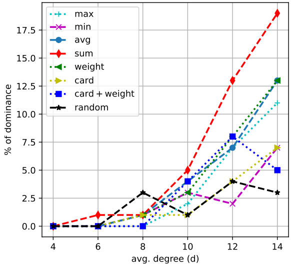
Specifically, regarding $\mathrm{In}_{\mathcal{C}}(\mathcal{N})$, we have:

$$\bigwedge_{(i,j) \in E(G(\mathcal{N})) \text{ s.t. } i<j} (r_{ij} \rightarrow \bigwedge_{l=1}^{m} c_l)$$

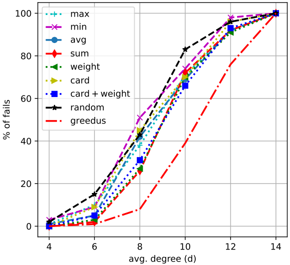
The soft part is the r_{ij} unit clauses, which correspond to constraints of $\mathcal{N}$

[9]M. Westphal et al.: *On the Propagation Strength of SAT Encodings for Qualitative Temporal Reasoning*. In: ICTAI 2013

Results



(a) % of dominance

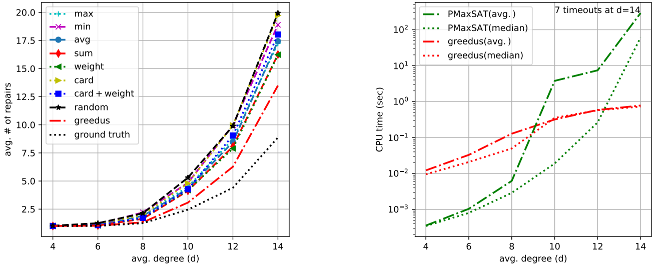


(b) % of fails for optimal

Figure: Assessing the performance of ordering strategies (and Greedus) with Interval Algebra network instances of model A($n = 20, d, l = 6.5$)[10]

[10] J. Renz, B. Nebel: *Efficient Methods for Qualitative Spatial Reasoning*. J. Artif. Intell. Res. 15 (2001)

Results



(a) Avg. # of repairs required (b) Runtime performance

Figure: Assessing the performance of Greedus and the Partial MaxSAT encoding with Interval Algebra network instances of model A($n = 20, d, l = 6.5$) (same as before)

Perspectives and Discussion

- Insight on the trade-off between obtaining repairs optimally vs fast
- Freely available source code
- Application to other inconsistency-related reasoning tasks
- Use Greedus as first bound for optimal techniques
- Explore more on the use of MaxSAT solvers (e.g., local search)
- Extend Greedus into an optimal technique (e.g., via BnB)

Thank you for your interest and attention!

`http://msioutis.gitlab.io`

The purpose of abstraction is not to be vague, but to create a new semantic level in which one can be absolutely precise

Dijkstra