Quantitative and Stream Extensions of ASP

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FWF Der Wissenschaftsfonds.

logics LOGICAL METHODS IN COMPUTER SCIENCE

Answer Set Programming

Answer Set Programming (ASP):

- Non-monotonic
- Default Negation

$$a \leftarrow b_1, \ldots, b_n, \text{not } b_{n+1}, \ldots, \text{not } b_m$$

- Solve NP-hard Problems

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- Quantitative Reasoning over Models (e.g. *asprin* [Brewka *et al.*, 2015]):

$$\#\text{optimize}(\text{temp})$$

- Quantitative Constraints (e.g. Weight Constraints [Niemela *et al.*, 1999]):

$$\text{fail} \leftarrow \text{temp}(X), X > 100$$

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Find and **analyze** a general framework that combines

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Challenge I: No One Fits All

Quantitative Reasoning over Models (QM):

- Probabilities of Models
- Preferences over Models
- Weighted Model Counting
- ...

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Quantitative Reasoning over Models (QM):

▶ Probabilities of Models	[Baral *et al.*, 2009] [Lee and Yang, 2017] [Nickles and Mileo, 2015] [De Raedt *et al.*, 2007]
▶ Preferences over Models	[Lee and Yang, 2017] [Buccafurri *et al.*, 1997] [Brewka *et al.*, 2015]
▶ Weighted Model Counting	[Kimmig *et al.*, 2011]
▶ ...	

Challenge I: No One Fits All

Quantitative Constraints (QC):

- Aggregates [Ferraris, 2011] [Dell'Armi *et al.*, 2003]
- Weight Constraints [Niemela *et al.*, 1999]
- Arithmetic Operations [Lierler, 2014]
- Choice Constraints [Niemela *et al.*, 1999] [Lierler, 2014]
- . . .

Challenge II: Entangle Time & Quantitative Reasoning

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- Differentiate aggregates at a given timepoint and aggregates over all timepoints
- Statements of the form $w : \phi$ insufficient!

State of the Art

Quantitative Constraints:

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Combination:

- telingo [Cabalar *et al.*, 2018]

Approach: Semirings

- Semirings can be used to parameterise calculations [Green *et al.*, 2007][Bistarelli *et al.*, 2018]

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- A semiring is an algebraic structure $(R, \oplus, \otimes, e_\oplus, e_\otimes)$, s.t.
  - $(R, \oplus, e_\oplus)$ is a commutative monoid with neutral element $e_\oplus$
  - $(R, \otimes, e_\otimes)$ is a monoid with neutral element $e_\otimes$
  - multiplication ($\otimes$) distributes over addition ($\oplus$)
  - multiplication by $e_\oplus$ annihilates R
    $(\forall r \in R : e_\oplus \otimes r = e_\oplus = r \otimes e_\oplus)$

Semiring Examples

Prominent examples are

- $\mathbb{Q} = (\mathbb{Q}, +, \cdot, 0, 1)$ rational numbers
- $\mathcal{R}_{\max} = (\mathbb{R} \cup \{-\infty\}, \max, +, -\infty, 0)$ max-plus
- $\mathcal{R}_{\min} = (\mathbb{R} \cup \{\infty\}, \min, +, \infty, 0)$ min-plus
- $\mathbb{B} = (\{\bot, \top\}, \vee, \wedge, \bot, \top)$ boolean
- $\mathcal{P}(A) = (\mathcal{P}(A), \cup, \cap, \emptyset, A)$ powerset

Weighted Logic

$$\alpha ::= k \mid p \mid \alpha \wedge \alpha \mid \alpha \vee \alpha \mid \ldots$$

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"Disjunction is addition and conjunction is multiplication"

$$\begin{aligned}
[\![k]\!]_{\mathcal{R}}(\mathcal{I}) &= k \\
[\![p]\!]_{\mathcal{R}}(\mathcal{I}) &= \begin{cases} e_{\otimes}, & \text{if } p \in \mathcal{I} \\ e_{\oplus}, & \text{otherwise.} \end{cases} \\
[\![\alpha \wedge \beta]\!]_{\mathcal{R}}(\mathcal{I}) &= [\![\alpha]\!]_{\mathcal{R}}(\mathcal{I}) \otimes [\![\beta]\!]_{\mathcal{R}}(\mathcal{I}) \\
[\![\alpha \vee \beta]\!]_{\mathcal{R}}(\mathcal{I}) &= [\![\alpha]\!]_{\mathcal{R}}(\mathcal{I}) \oplus [\![\beta]\!]_{\mathcal{R}}(\mathcal{I}).
\end{aligned}$$

Example

$$\alpha = 15 \land \text{Circus} \lor 20 \land \text{Restaurant}$$
$$\mathcal{I} = \{\text{Circus}\}$$

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Over the semiring $\mathbb{Q}$:

$$[\![\alpha]\!]_{\mathbb{Q}}(\mathcal{I}) = 15 \cdot 1 + 20 \cdot 0 = 15.$$

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Over the semiring $\mathbb{Q}$:

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Over the min tropical semiring $\mathcal{R}_{\mathrm{min}} = (\mathbb{R} \cup \{\infty\}, \min, +, \infty, 0)$:

$$[\![\alpha]\!]_{\mathcal{R}_{\mathrm{min}}}(\mathcal{I}) = \min(15 + 0, 20 + \infty) = 15.$$

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Appeal of Weighted Logic

- Recall the principle:

  "Disjunction is addition and conjunction is multiplication"
- Semantics often defined via disjunction and conjunction
- E.g. existential quantification over timepoints is sum over timepoints

  $\hookrightarrow$ Weighted Logic as a generic tool
- E.g. Here-and-There Logic $\rightarrow$ non-monotonicity

  $\hookrightarrow$ Weighted Here-and-There Logic $\rightarrow$ non-monotonic calculation

Research Questions

1 **Generality & Faithfulness**

2 **Theoretical Analysis**

Complexity:	Properties:
• Semiring Dependency	• Finite Groundability
• Language Fragments	• Modularity

3 **Evaluation**

Implementation:	Use Cases:
• Relevant Instantiation	• Object Detection
• Comparison	• Traffic Regulation

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- Introduced a weighted version of LARS
  $\hookrightarrow$ Addresses challenge II

Quantitative Reasoning over Models

- Thomas Eiter and Rafael K_, Weighted LARS for Quantitative Stream Reasoning, *European Conference on Artificial Intelligence, 2020*
- LARS is a stream reasoning framework with answer set semantics
- Introduced a weighted version of LARS
  $\hookrightarrow$ Addresses challenge II
- Showed its power as an underlying framework for
  - Probabilities
  - Preferences
  - Weighted Model Counting

  $\hookrightarrow$ Addresses challenge I

Quantitative Constraints

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  $\hookrightarrow$ Calculations over semirings with non-monotonic dependency

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- Introduced First-Order Weighted Here-and-There Logic
  $\hookrightarrow$ Calculations over semirings with non-monotonic dependency
- Algebraic Constraints subsume
  - Aggregates
  - Choice Constraints
  - Weight Constraints with Conditionals
  - ...

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Quantitative Constraints

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- Introduced First-Order Weighted Here-and-There Logic
  $\hookrightarrow$ Calculations over semirings with non-monotonic dependency
- Algebraic Constraints subsume (with mild practical restrictions)
  - Aggregates
  - Choice Constraints
  - Weight Constraints with Conditionals
  - ...

  $\hookrightarrow$ Addresses challenge I

What is next?

- Combination of Weighted LARS and Algebraic Constraints

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- Analysis of the complexity in dependence on the semiring parameter

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- Combination of Weighted LARS and Algebraic Constraints
- Analysis of the complexity in dependence on the semiring parameter
- Implementation of a reasonable fragment

Summary

- We use Weighted Logic as a generic tool for quantitative specifications . . .

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- We use Weighted Logic as a generic tool for quantitative specifications . . .
- . . . to unify quantitative extensions
- . . . that we can adjust to the given domain
- General formalism is found
  $\hookrightarrow$ analysis and implementation ongoing

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