Quantitative and Stream Extensions of ASP

Rafael Kiesel

Supervisor: Thomas Eiter

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Answer Set Programming Extensions

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

Introduction Problem Answer Set Programming Our Work Extensions Summary





$fail \gets overheat$





ASP

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Temporal Domain (e.g. LARS [Beck et al., 2018]):

 $\text{fail} \gets \boxplus^5 \square \text{overheat}$





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#optimize(temp)







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Temporal Domain (e.g. LARS [Beck et al., 2018]):

 $\text{fail} \gets \boxplus^5 \square \text{overheat}$

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

#optimize(temp)

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

fail \leftarrow temp(X), X > 100

Problem Statement State of the Art Methodology

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Goal

Find and analyze a general framework that combines

succinct specifications reasoning over answer sets temporal domain

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Introduction Problem Our Work

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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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Challenge I: No One Fits All

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]

Problem Statement State of the Art Methodology

Challenge I: No One Fits All

Quantitative Constraints (QC):

- Aggregates
- Weight Constraints
- Arithmetic Operations
- Choice Constraints

[Ferraris, 2011] [Dell'Armi *et al.*, 2003] [Niemela *et al.*, 1999] [Lierler, 2014] [Niemela *et al.*, 1999] [Lierler, 2014]

. . .

Problem Statement State of the Art Methodology

Challenge II: Entangle Time & Quantitative Reasoning

Time domain and specification of quantities not orthogonal

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- Time domain and specification of quantities not orthogonal
- Differentiate aggregates at a given timepoint and aggregates over all timepoints

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Challenge II: Entangle Time & Quantitative Reasoning

- Time domain and specification of quantities not orthogonal
- Differentiate aggregates at a given timepoint and aggregates over all timepoints
- Statements of the form *w* : ϕ insufficient!

State of the Art

Quantitative Constraints:

- Hybrid ASP [Cabalar et al., 2020]
- Nested Expressions [Ferraris, 2011]

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Quantitative Reasoning over Models:

- ▶ LP^{MLN} [Lee and Yang, 2017]
- Algebraic Prolog [Kimmig *et al.*, 2011; Belle and De Raedt, 2016]

State of the Art

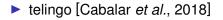
Quantitative Constraints:

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Combination:



Approach: Semirings

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

Approach: Semirings

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

Weighted Logic

$$\alpha ::= \boldsymbol{k} \mid \boldsymbol{p} \mid \alpha \land \alpha \mid \alpha \lor \alpha \mid \dots$$

k semiring value, p atomic formula

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Weighted Logic

$$\alpha ::= \mathbf{k} \mid \mathbf{p} \mid \alpha \land \alpha \mid \alpha \lor \alpha \mid \dots$$

k semiring value, p atomic formula

"Disjunction is addition and conjunction is multiplication"

$$\llbracket k \rrbracket_{\mathcal{R}}(\mathcal{I}) = k$$
$$\llbracket p \rrbracket_{\mathcal{R}}(\mathcal{I}) = \begin{cases} e_{\otimes}, & \text{if } p \in \mathcal{I} \\ e_{\oplus}, & \text{otherwise.} \end{cases}$$
$$\llbracket \alpha \land \beta \rrbracket_{\mathcal{R}}(\mathcal{I}) = \llbracket \alpha \rrbracket_{\mathcal{R}}(\mathcal{I}) \otimes \llbracket \beta \rrbracket_{\mathcal{R}}(\mathcal{I}) \\ \llbracket \alpha \lor \beta \rrbracket_{\mathcal{R}}(\mathcal{I}) = \llbracket \alpha \rrbracket_{\mathcal{R}}(\mathcal{I}) \oplus \llbracket \beta \rrbracket_{\mathcal{R}}(\mathcal{I}) \end{cases}$$

Example

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

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Example

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

Over the semiring \mathbb{Q} :

$$\llbracket lpha
rbracket_{\mathbb{Q}}(\mathcal{I}) = \mathsf{15} \cdot \mathsf{1} + \mathsf{20} \cdot \mathsf{0} = \mathsf{15}.$$

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Example

$$\alpha = 15 \land \text{Circus} \lor 20 \land \text{Restaurant}$$
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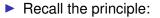
Over the semiring \mathbb{Q} :

$$\llbracket \alpha \rrbracket_{\mathbb{Q}}(\mathcal{I}) = 15 \cdot 1 + 20 \cdot 0 = 15.$$

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

$$\llbracket \alpha \rrbracket_{\mathcal{R}_{\min}}(\mathcal{I}) = \min(15 + 0, 20 + \infty) = 15.$$

Appeal of Weighted Logic



"Disjunction is addition and conjunction is multiplication"

Appeal of Weighted Logic

Recall the principle:

"Disjunction is addition and conjunction is multiplication"

Semantics often defined via disjunction and conjunction

Appeal of Weighted Logic

Recall the principle:

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- Semantics often defined via disjunction and conjunction
- E.g. existential quantification over timepoints is sum over timepoints
 - \hookrightarrow Weighted Logic as a generic tool

Appeal of Weighted Logic

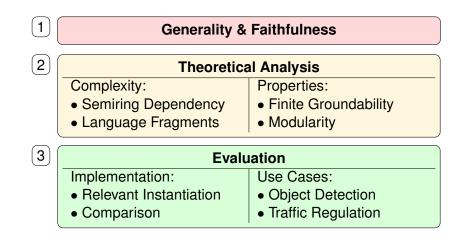
Recall the principle:

"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 → non-monotonicity → Weighted Here-and-There Logic → non-monotonic calculation

Plan Progress Current Research

Research Questions





Thomas Eiter and Rafael K_, Weighted LARS for Quantitative Stream Reasoning, European Conference on Artificial Intelligence, 2020



- 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



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- LARS is a stream reasoning framework with answer set semantics
- Introduced a weighted version of LARS
 - $\hookrightarrow \mathsf{Addresses} \ \mathsf{challenge} \ \mathsf{II}$



- 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
 - $\hookrightarrow \mathsf{Addresses} \ \mathsf{challenge} \ \mathsf{I}$



Thomas Eiter and Rafael K_, ASPAC: Answer Set Programming with Algebraic Constraints, International Conference on Logic Programming, 2020



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- Introduced First-Order Weighted Here-and-There Logic
 Calculations over semirings with non-monotonic dependency



- Thomas Eiter and Rafael K_, ASPAC: Answer Set Programming with Algebraic Constraints, International Conference on Logic Programming, 2020
- Introduced First-Order Weighted Here-and-There Logic
 Calculations over semirings with non-monotonic dependency
- Algebraic Constraints subsume
 - Aggregates
 - Choice Constraints
 - Weight Constraints with Conditionals
 - ▶ ...
 - $\hookrightarrow \mathsf{Addresses} \ \mathsf{challenge} \ \mathsf{I}$



- Thomas Eiter and Rafael K_, ASPAC: Answer Set Programming with Algebraic Constraints, International Conference on Logic Programming, 2020
- Introduced First-Order Weighted Here-and-There Logic
 Calculations over semirings with non-monotonic dependency
- Algebraic Constraints subsume (with mild practical restrictions)
 - Aggregates
 - Choice Constraints
 - Weight Constraints with Conditionals
 - ▶ ...
 - $\hookrightarrow \mathsf{Addresses} \ \mathsf{challenge} \ \mathsf{I}$

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What is next?

Combination of Weighted LARS and Algebraic Constraints



What is next?

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



What is next?

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





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





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





- We use Weighted Logic as a generic tool for quantitative specifications ...
- to unify quantitative extensions
- ... that we can adjust to the given domain





- 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 → analysis and implementation ongoing



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Rafael Kiesel



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