Reasoning About Uncertainty in AgentSpeak Using Dynamic Epistemic Logic

Extended Abstract

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ABSTRACT

We propose DEL-AgentSpeak, an AgentSpeak extension for reasoning about belief uncertainty using dynamic epistemic logic (DEL). An uncertain navigation example is presented, motivating the need for DEL-AgentSpeak. DEL-AgentSpeak is evaluated against a less-expressive extension, showing that performance declines linearly with the degree of expressivity required to model changes to uncertainty.

KEYWORDS

BDI; AgentSpeak; Uncertainty; Dynamic Epistemic Logic

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1 INTRODUCTION

AgentSpeak is an abstract agent-oriented programming language based on the Belief-Desire-Intention (BDI) agent model. Although AgentSpeak offers a simple and computationally efficient approach to modelling beliefs, it lacks the ability to meaningfully reason about belief uncertainty [4]. This paper proposes an extension to AgentSpeak, called DEL-AgentSpeak, which employs dynamic epistemic logic (DEL) to qualitatively model and reason about belief uncertainty. DEL is a dynamic modal logic which uses Kripke semantics to model the statics and dynamics of uncertainty.

Definition 1.1 (Dynamic Epistemic Logic). A standard epistemic formula φ is a propositional modal formula with modalities B and $\hat{B}$. $B\varphi$ and $\hat{B}\varphi = \neg B \neg \varphi$ are read as 'φ is believed' and 'φ is possible' respectively. S5 semantics are given by an epistemic model $M = (W, V)$ with a set of possible worlds W and a valuation V which maps worlds to propositional states. Dynamics are captured by DEL event models $\varepsilon = (E, pre, post)$, where E is a set of possible events, $pre(e)$ is a precondition formula, and $post(e)$ is the post-condition for event e. When applied to an epistemic model, a resultant model is created where worlds modelling $pre(e)$ are kept and valuations are modified according $post(e)$. See [7] for a full definition of DEL.

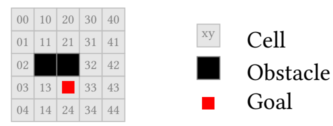

Figure 1: The navigation map definition.

Example 1.2. Agent Bob must navigate to a *goal cell* under partial observability given a map definition (Figure 1) and surrounding perceptions. Bob's location is represented by $\texttt{loc}(X, Y)$. At $loc(X, Y)$, $\texttt{obs}(d)$ represents an obstacle in the direction d and $\texttt{dir}(d)$ where d is the shortest-path direction to the goal. The action $move(d)$ updates Bob's location and perceptions accordingly. All directions are relative: $d \in \{\downarrow, \uparrow, \leftarrow, \rightarrow\}$. The initial state is: $\{\, loc(1,1), obs(\downarrow), dir(\leftarrow) \vee dir(\rightarrow) \,\}$ but partial observability limits Bob to $\{obs(\downarrow)\}$ which infers multiple *possible* locations and navigation directions. A language that supports possibilistic reasoning allows Bob to strategically act using possible movement directions; i.e., he will avoid moving in a direction that won't bring him to the goal.

DEL-AgentSpeak enables uncertainty reasoning in the navigation example, allowing for a description of the initial uncertainty and any event models that capture the dynamics of the move action and perception changes. DEL-AgentSpeak also introduces a new modality $\texttt{poss(\_)}$ for querying possible beliefs.

2 RELATED WORK

Various works in the literature have extended AgentSpeak with quantitative approaches to uncertainty, such as [1, 2]. Although precise, quantitative approaches are not available when probabilistic distributions for the domain do not exist. Moreover, usage of probabilistic values in the program description complicates development and fails to integrate idiomatically with AgentSpeak [9]. Alternatively, various qualitative extensions exist [1, 3, 5] but fail to capture the dynamics of uncertainty. In [9], Vezina and Esfandiari address the gap in the literature with "PAL-AgentSpeak," an AgentSpeak extension which uses public announcement logic (PAL).

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```
+!navigate : poss(dir(D))
    <-  move(D); ...
```

(a) Navigation under uncertainty.

```
range(loc(X,Y)) :- (0,0)..(4,4).
~loc(X, Y) :- loc(X2, Y2) &
              (X, Y) \== (X2, Y2).
~loc(1, 2).
~loc(2, 2).
```

(b) Ranges and constraints.

```
+on(obs(D)) : obs(D).
...
+on(move(right)):loc(X,Y) & X<4
   <- -loc(X,Y); +loc(X+1,Y).
```

(c) Event models for *obs*/*moved*.

Figure 2: DEL-AgentSpeak listings.

PAL-AgentSpeak has various limitations, such as the lack of formal semantics, which limits clarity, reproducibility, and generalizability. Most critically, PAL is a restrictive subset of DEL that can only handle monotonic knowledge changes, thus PAL-AgentSpeak fails to capture changes to uncertainty beyond PAL's capabilities, including event uncertainty, nondeterminism, and event post-conditions. These limitations are addressed with DEL-AgentSpeak.

3 METHODOLOGY

AgentSpeak lacks syntactic representations for initialization, change, and querying of belief uncertainty. DEL-AgentSpeak[1] provides syntactic mechanisms that address this, and expands the standard reasoning cycle with three processes: model creation, updates, and queries, which integrate with a DEL reasoner[2] to create, update, and query an epistemic model representing belief uncertainty.

DEL-AgentSpeak introduces two new syntactic components that describe initial uncertainty: *ranges* and *range constraints*. A range is an uncertain belief ℓ_r denoted by $\texttt{range}(\ell_r)$ and a range constraint is a belief that defines the truth condition φ of a ranged literal, e.g.; ℓ_r :- φ. During model creation, these components are transformed into corresponding propositional sentences that describe the uncertainty of all ranged literals, allowing a SAT solver to generate all propositional states corresponding to the possible worlds in the initial epistemic model. Figure 2b shows the ranges and constraints that initialize all non-obstacle locations as possible worlds in the initial model.

The model update process of DEL-AgentSpeak extends the standard belief addition and deletion processes, utilizing DEL event models to appropriately update the epistemic model. By default, an ontic change (post-condition-only) event model is assigned to belief changes. Alternatively, the agent may use DEL-AgentSpeak's "on" plans to describe custom event models: $te_{on} : c \leftarrow b$, where $te_{on} = +on(\ell)$ or $-on(\ell)$ for belief additions $+\ell$ or deletions $-\ell$. DEL event pre- and post-conditions are given by context c and addition/deletion operations in body b. Figure 2c shows the "on" plans that transform into DEL event models capturing uncertainty changes from *obs* perceptions and the *move* action.

Belief queries occur during the evaluation of plan contexts and test goals. The model querying process of DEL-AgentSpeak transforms belief queries into modal formulae that can be evaluated by the epistemic reasoner. Possibility literals $\texttt{poss}(\ell_p)$ are assigned the modality $\hat{B}\ \ell_p$ while all other literals ℓ_b are assigned $B\ \ell_b$. The plan in Figure 2a utilizes the poss modality to consider possible navigation directions when the agent's location is uncertain.

[1]Implementation of DEL-AgentSpeak and navigation environment available at [8]
[2]The DEL reasoner implementation from Hintikka's World is used [6]

4 RESULTS AND CONCLUSION

This section evaluates the scalability of DEL-AgentSpeak and its impact on the agent's reasoning cycle. Symbols $|W|$ and $|E|$ refer to the number of worlds in the epistemic model and the number of possible events in a DEL event model, respectively. We use the same methodology for evaluation as PAL-AgentSpeak [9], which scales the size of the navigation map to 100x100 ($|W| = 10,000$) to evaluate the impact on model creation, update, and querying times. By directly comparing D-AS (DEL-AgentSpeak) and P-AS (PAL-AgentSpeak), we examine how the increased expressibility of DEL's event models affects extension performance.

At the largest map size, $|W| = 10,000$, P-AS creates the model in under 250 seconds and D-AS takes up to 3100 seconds. P-AS relies on an ad hoc technique for creation and D-AS uses a SAT solver. Although P-AS is significantly quicker, it lacks formal semantics making it unclear whether it is generalizable to other domains. Fortunately for D-AS, model creation can be done offline and cached, and does not have to impact the time-sensitive reasoning cycle.

Model update times are measured by applying an event model to the current epistemic model. P-AS is limited to single-event event models, whereas D-AS can express any number of events. We test two scenarios for D-AS: $|E| = 1$ and $|E| = 2$, where $|E|$ corresponds to the number of defined *"on"* plans for a given belief event. P-AS and D-AS perform similarly when $|E| = 1$ (44ms with $|W| = 10,000$), but for multi-event models in D-AS, the model update time increases linearly with a factor of $|E|$ and $|W|$ due to DEL's product update semantics (95ms when $|E| = 2$ and $|W| = 10,000$).

Model querying times are obtained by evaluating 100 ground belief queries for P-AS and D-AS on varying model sizes up to $|W| = 10,000$. Since PAL and DEL share entailment semantics, model querying performance is identical. Model querying performance grows linearly with W; when $|W| = 10,000$ the querying time for P-AS and D-AS is 900ms.

Overall, D-AS and P-AS have similar performance on average. DEL-AgentSpeak's use of a SAT solver may result in a slower model creation time, but this may be acceptable given that it can be done offline. The computational cost of DEL's event models increases linearly with the number of relevant "on" plans, but come with the ability to capture complexity in the dynamics of uncertainty.

In the full paper, the formal semantic definitions for the model creation, update, and querying processes of DEL-AgentSpeak are provided. We give a full treatment to Example 1.2, including a full DEL-AgentSpeak listing, and the corresponding initial epistemic model and event model transformations.

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REFERENCES

[1] Kim Bauters, Kevin McAreavey, Weiru Liu, Jun Hong, Lluis Godo, and Carles Sierra. 2017. Managing Different Sources of Uncertainty in a BDI Framework in a Principled Way with Tractable Fragments. *Journal of Artificial Intelligence Research* 58 (04 2017), 731–775. https://doi.org/10.1613/jair.5287

[2] AC Adrián Biga and Ana Casali. 2014. G-jason: An extension of jason to engineer agents capable to reason under uncertainty. In *Proc. of 14th Intelligent Agent and Systems Workshop*.

[3] Ana Casali, Lluís Godo, and Carles Sierra. 2009. g-BDI: A Graded Intensional Agent Model for Practical Reasoning. In *Modeling Decisions for Artificial Intelligence*, Vicenç Torra, Yasuo Narukawa, and Masahiro Inuiguchi (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 5–20.

[4] Andreas Herzig, Emiliano Lorini, Laurent Perrussel, and Zhanhao Xiao. 2017. BDI Logics for BDI Architectures: Old Problems, New Perspectives. *KI - Künstliche Intelligenz* 31, 1 (01 Mar 2017), 73–83. https://doi.org/10.1007/s13218-016-0457-5

[5] Mark Jago. 2009. Epistemic Logic for Rule-Based Agents. *Journal of Logic, Language and Information* 18, 1 (01 Jan 2009), 131–158. https://doi.org/10.1007/s10849-008-9071-8

[6] François Schwarzentruber. 2018. Hintikka's World: Agents with Higher-order Knowledge. In *Proceedings of the Twenty-Seventh International Joint Conference on Artificial Intelligence, IJCAI-18*. International Joint Conferences on Artificial Intelligence Organization, 5859–5861. https://doi.org/10.24963/ijcai.2018/862

[7] Hans Van Ditmarsch, Wiebe van Der Hoek, and Barteld Kooi. 2007. *Dynamic epistemic logic*. Vol. 337. Springer Science & Business Media.

[8] Michael Vezina. 2023. *DEL-AgentSpeak (Source Code)*. https://doi.org/10.5281/zenodo.7662978

[9] Michael Vezina and Babak Esfandiari. 2022. Epistemic Reasoning in Jason. In *Proceedings of the 21st International Conference on Autonomous Agents and Multiagent Systems* (Virtual Event, New Zealand) *(AAMAS '22)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 1328–1336.