

Formalizing AMR Inference via Hybrid Logic Tableaux

CL Masters Thesis Defense

Eli Goldner

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Introduction

- ▶ Semantic representation:
 - ▶ Capture meaning of natural language content.
 - ▶ Designed for manipulation via software.
- ▶ Abstract Meaning Representation (AMR):
 - ▶ Graph-based (DAG), nodes are *concepts*, edges are *relations*.
 - ▶ Built on predicative core of a sentence.
 - ▶ Ignores syntactic differences between equivalent sentences.
 - ▶ PropBank framesets are used for concepts (entities, events, properties, states).

Introduction

(Basic) AMR is reductionistic. This is awesome for:

- ▶ Annotation (esp. by non-experts).
- ▶ Semantic parsing (smaller target space).

This is not awesome for:

- ▶ Representing and recovering fine-grained meaning.
- ▶ Automating reasoning/inference.

Introduction

- ▶ The trade-off between ease of generation/use and rich expressivity/inferentiability is at least as old as computing.
- ▶ AMR has made a choice that works well in data-driven NLP.
- ▶ However AMR can bridge this gap:
- ▶ AMR already does this in a modular way with extensions.
- ▶ Some of these extensions give afford interpretation in first-order logic:
 - ▶ Automated inference for logics is a rich area with lots of tools.
 - ▶ This is where we come in.

Motivation

"Why do we need formal methods? Can't state-of-the-art language models do this already?"

Short answer: Not really, and even if they could:

- ▶ Statistically driven techniques are unnecessarily expensive for formal inference.
- ▶ Increasing need for ability to guarantee/verify properties of software:
 - ▶ Does the software give us the right *type* of result for an input?
 - ▶ Bias in NLP.
- ▶ Machine learning (by itself) does not lend itself well to this.
- ▶ Hybrid systems and explainable AI.

Approach

- ▶ Combine two AMR extensions for richer interpretation:
 - ▶ Scope and quantification (?)
 - ▶ Tense and aspect (?)

AMR with Tense and Aspect

AMR with Scope

Modal Logic

- ▶ Propositional logic lets us form statements like $p \wedge (q \vee \neg r)$.
- ▶ Modal propositional logic extends propositional logic with an operator \diamond , read as “possible”. i.e. it is not possible that p and $\neg p$ are the case would be:

$$\neg\diamond(p \wedge \neg p)$$

- ▶ (More) formal meaning of \diamond : There is a *possible world* where p is true, and this possible world is *accesible* from the current one.
- ▶ The problem: the “current world” is an implicit notion dependent on context. Is there something more expressive?

Hybrid Logic

- ▶ Idea: take propositional modal logic, and add an operator @ , that lets us know which world we're referring to.
- ▶ p or r is possible at world i : $\text{@}_i \Diamond(p \vee r)$
- ▶ In the above proposition i is called a nominal since it *names*/uniquely picks out some world.
- ▶ Everything true at the nominal j is true at the nominal i (they name the same world): @_{ij}

Hybrid Logic Variants



First-Order Hybrid Tense Logic

FHTL Tableau Example

- (1)
- (2) $\mathbb{O}_s(\exists x)[P((\exists y)[f(x, y) = f(y, x)]) \vee \neg(\exists z)[x = z]]$
- (3) $\mathbb{O}_s P((\exists y)[f(s_1, y) = f(y, s_1)]) \vee \neg(\exists z)[s_1 = z]$
-
- (4) $\mathbb{O}_s P((\exists y)[f(s_1, y) = f(y, s_1)])$
- (5) $\mathbb{O}_s P t$
- (6) $\mathbb{O}_t(\exists y)[f(s_1, y) = f(y, s_1)]$
- (7) \dots
- $\mathbb{O}_s \neg(\exists z)[s_1 = y]$
- $\mathbb{O}_s \neg[s_1 = s_1]$
- $\mathbb{O}_s [s_1 = s_1]$
- \otimes

Model Checking Example

- ▶ Every computer will be located at a desk.

- ▶ AMR with quantification and tense:

(s / scope

```
:pred (b / be-located-at-91 :ongoing -
      :complete +
      :time (a / after
            :op1 (n / now))

      :ARG0 (c / computer)
      :ARG1 (d / desk
            :quant (e / every)))
```

```
:ARG0 d
```

```
:ARG1 c)
```

- ▶ FHTL translation:

$$@_{now}(\forall y)[\text{desk}(y) \rightarrow (\exists x)[\text{computer}(x) \wedge F(\text{be-located-at-91}(x, y))]]$$

Model Checking Example

Define a small *FHTL* model $\mathfrak{M} = (T, \mathcal{R}, (D_t)_{t \in T}, I_{nom}, (I_t)_{t \in T})$ where:

$$T = \{\text{yesterday, now, tomorrow}\}$$

$$\mathcal{R} = \{(\text{yesterday, now}), (\text{now, tomorrow}), (\text{yesterday, tomorrow})\}$$

$$I_{nom} = \{(y, \text{yesterday}), (n, \text{now}), (t, \text{tomorrow})\}$$

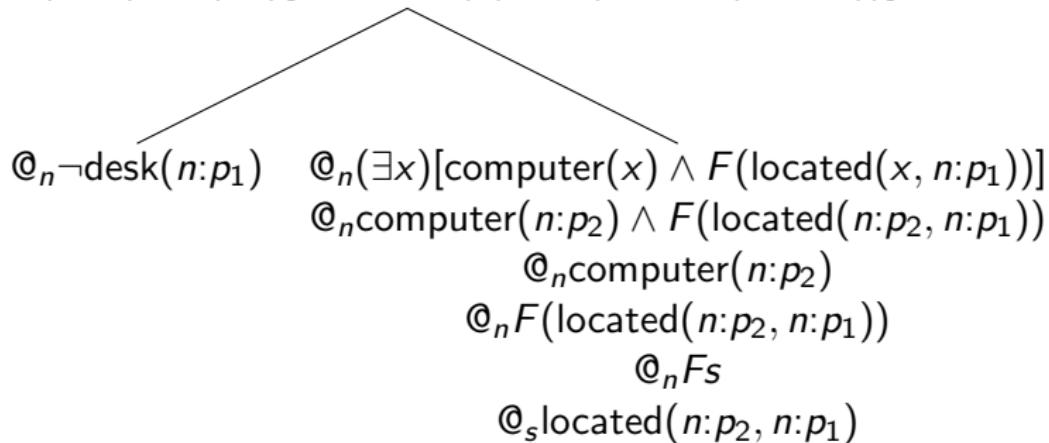
$$D_{\text{yesterday}} = \{\text{computer}_1, \text{desk}_1\}$$

$$D_{\text{now}} = \{\text{computer}_1, \text{computer}_2, \text{desk}_1, \text{desk}_2, \text{desk}_3\}$$

$$D_{\text{tomorrow}} = \{\text{computer}_1, \text{computer}_2, \text{desk}_1, \text{desk}_2\}$$

Model Checking Example

$$\begin{aligned} \textcircled{n}(\forall y)[\text{desk}(y) \rightarrow (\exists x)[\text{computer}(x) \wedge F(\text{located}(x, y))]] \\ \textcircled{n}\text{desk}(n:p_1) \rightarrow (\exists x)[\text{computer}(x) \wedge F(\text{located}(x, n:p_1))] \end{aligned}$$



Where we assign $s = t = \text{tomorrow}$, $n:p_2 = \text{computer}_1$ and $n:p_1 = \text{desk}_2$, or $n:p_2 = \text{computer}_2$ and $n:p_1 = \text{desk}_1$ we see that \mathfrak{M} satisfies the *FHTL* sentence.

Extraction

Interpretation

References I