Separating Argument Structure from Logical Structure in AMR

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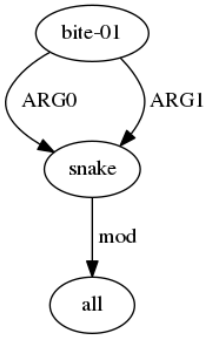
Abstract

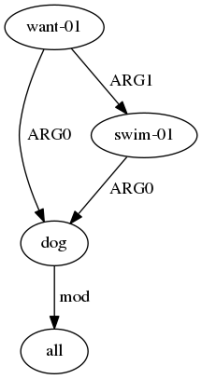
The AMR (Abstract Meaning Representation) formalism for representing meaning of natural language sentences puts emphasis on predicate-argument structure and was not designed to deal with scope and quantifiers. By extending AMR with indices for contexts and formulating constraints on these contexts, a formalism is derived that makes correct predictions for inferences involving negation and bound variables. The attractive core predicate-argument structure of AMR is preserved. The resulting framework is similar to the meaning representations of Discourse Representation Theory employed in the Parallel Meaning Bank.

1 Introduction

Abstract Meaning Representation, AMR (Langkilde and Knight, 1998), or the PENMAN notation it is based on (Kasper, 1989), puts emphasis on argument structure. In this paper I put forward a proposal to extend AMRs with a logical dimension, in order to—from a formal semantics point of view—correctly capture negation, quantification, and presuppositional phenomena. It is desirable to investigate such an extension, because (i) it would make a comparison of AMR with other semantics formalisms possible (in particular Discourse Representation Theory); (ii) it would make AMR suitable for performing logical inferences; and (iii) it would be an important step in sharing resources for semantic parsing. The aim is to do this in such a way that existing AMR-annotated corpora (Banarescu et al., 2013) can be relatively easily extended with the desired extensions.

This is not the first proposal of extending the PENMAN notation to handle scope phenomena. The need to do so was recognized by other researchers (Bos, 2016; Stabler, 2017; Lai et al., 2020). Pustejovsky et al. (2019) extend AMR with a possibility of adding explicit scope relations. This extension, however, doesn't solve a fundamental problem that AMR faces, namely viewing AMRs as directed acyclic graphs and basing their interpretation on this. Consider examples such as "every snake bit itself" or "all dogs want to swim". In the original AMR graph notation, where quantifiers are expressed as a predicate rather than taking scope, the resulting diagrams are:





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The corresponding interpretations for these sentences could be paraphrased as "every snake bit every snake" and "all dogs want all dogs to swim", which are not the meanings that the sentences express. Let's refer to this issue as the *bound variable problem*.

But there is a second, perhaps an even more pressing issue, which could be dubbed the *scope representation problem*. AMRs, in their original PENMAN format (Kasper, 1989), cannot be used directly for drawing valid inferences. Let me demonstrate why this is so. Using the simple conjunction elimination rule (if the conjunction "A and B" is true, then "A" is true, and "B" is true), and assuming that an AMR is interpreted as a conjunction of clauses, AMR will make the right predictions as long as no negation is involved (e.g., it will yield the correct inference "Mary left" from "Mary left yesterday"). But since, in AMR, negation is represented as a predicate rather than an operator that takes scope, it will make wrong predications for negated sentences (e.g., it will allow the inference "Mary left" from "Mary did not leave". This is why AMRs need some kind of reformulation before interpretation, and that is exactly what has been proposed in earlier work (Artzi et al., 2015; Bos, 2016; Stabler, 2017; Lai et al., 2020).

In this paper I seek the solution at the representational level. I think the contribution of this paper is that this extension is simpler of nature than those proposed earlier (Bos, 2016; Stabler, 2017). It bears similarities with *named graphs* for semantic representations (Crouch and Kalouli, 2018). I argue that, if we want to fix the bound variable problem and the scope representation problem, AMR requires explicit scope in their representations (Bos and Abzianidze, 2019). I propose a method to do this by keeping the underlying predicate-argument structure, and adding a second, logical layer (Section 2). In Section 3, a list of examples of extended AMRs demonstrate the approach. Some loose ends are discussed in Section 4.

2 Method

The idea is to extend the AMR with logical structure, obtaining a scoped representation AMR$^+$ with two dimensions: one level comprising predicate-argument structure (the original AMR, minus polarity attributes), and one level consisting of the logical structure (information about logical operators such as negation and the scope they take). This is achieved by viewing an AMR as a recursive structure, rather than interpreting it as a graph, and performing two operations on them:

1. assign an index to each (sub-)AMR;

2. add structural constraints to the AMR via the indices.

AMRs can be seen as a recursive structure by viewing every slash within an AMR as a sub-AMR (Bos, 2016). If a (sub-)AMR contains relations, those relations will introduce nested AMRs. (A constant is also an AMR, following this view.) An AMR (and all its sub-AMRs) will be labeled by decorating the slashes with indices (indices will be indicated by numbers enclosed in square brackets).

Every AMR is augmented by a set of scoping constraints on the labels. This way, a sub-AMR can be viewed as describing a "context". The constraints state how the contexts relate to each other. They can be declared as the same contexts (=), a negated context ($\neg$), a conditional context ($\Rightarrow$), or a presuppositional context ($<$). Colons are used to denote inclusion, i.e., $l : C$ states that context l contains condition C.

Note that these labels are similar in spirit to those used in underspecification formalisms as proposed in the early 1990s (Reyle, 1993; Copestake et al., 1995; Bos, 1996). The treatment of presuppositions is inspired by semantic formalism extending Discourse Representation Theory (Van der Sandt, 1992; Geurts, 1999; Venhuizen et al., 2013; Venhuizen et al., 2018).

3 Results

Below I illustrate the idea with several canonical examples involving existential and universal quantification, definite descriptions, proper names, and, of course, negation.

3.1 Existential Quantification

Consider the AMR for "a dog scared a cat" with a transitive verb and two indefinite noun phrases in PENMAN notation:

```
(e / scare-01
   :ARG0 (x / dog)
   :ARG1 (y / cat))
```

Within this AMR we can identify three sub-AMRs. We index and constrain them and arrive at the following AMR$^+$:

```
(e /1/ scare-01
    :ARG0 (x /2/ dog)
    :ARG1 (y /3/ cat)) {1 = 2, 1 = 3}
```

Here, there is just one context shared by all three sub-AMRs, as one would expect with existential quantification: scope does not play a pivotal role here. As equivalent alternative, the following simplified, constraint-free AMR$^+$ can be obtained after eliminating the identity constraints:

```
(e /1/ scare-01
    :ARG0 (x /1/ dog)
    :ARG1 (y /1/ cat)) {}
```

3.2 Definite Descriptions and Proper Names

A sentence like "the bear growled" contains a definite description triggering an existential presupposition. Presuppositions yield new contexts:

```
(e /1/ growl-01
    :ARG0 (x /2/ bear)) {2<1}
```

In other words, the definite article triggers a presupposition that there is a bear (the AMR with index 2) with respect to context provided by the AMR indexed as 1. Proper names can be handled similarly, as the AMR$^+$ for the sentence "Fido barked" shows (the existence of a dog named "Fido" is a presupposition for the barking event):

```
(e /1/ bark-01
    :ARG0 (x /2/ dog
              :Name "Fido")) {2<1}
```

3.3 Negation

Negation introduces a new (negated) context in AMR$^+$. This makes the `:polarity-` relation in AMR obsolete. As negation is always part of another context in some cases a context needs to be coerced (second and third example below, see also Section 4.1). Consider the representations for "a woman didn't smile", "the woman didn't smile", and "no woman smiled":

```
(e /1/ smile-01
    :ARG0 (x /2/ woman)) {2:¬1}

(e /1/ smile-01
    :ARG0 (x /3/ woman)) {3<1,2:¬1}

(e /1/ smile.v.01
    :Agent (x /1/ woman)) {2:¬1}
```

3.4 Universal Quantification

Universal quantification introduces a conditional context in AMR$^+$. Below are examples for quantifiers in subject position, object position, subject and object position, and a quantification with a bound variable. Note that the *mod*-relation used in AMR becomes obsolete.

"Everyone smiled."

```
(e /1/ smile-01
    :ARG0 (x /2/ person.n.01)) {3:2=>1}
```

"A dog scared every cat."

```
(e /1/ scare-01
    :ARG0 (x /3/ dog)
    :ARG1 (y /2/ cat)) {3:2=>1}
```

"Every dog scared every cat."

```
(e /1/ scare-01
    :ARG0 (x /2/ dog.n.01)
    :ARG1 (y /3/ cat)) {5:3=>4,4:2=>1}
```

"Every student revised their paper."

```
(e /1/ revise-01
    :ARG0 (x /2/ student)
    :ARG1 (y /3/ paper
               :poss x)) {2=3,3<1,4:2=>1}
```

3.5 From AMR to DRS

The AMR$^+$ representations share characteristics with the Discourse Representation Structure (DRS) introduced in Discourse Representation Theory, DRT for short (Kamp and Reyle, 1993). It is important to compare AMR$^+$ with DRS for various reasons. DRT is a well-studied formalism with a model-theoretic component. If we are able to show that the representations are equivalent then this has positive consequences for AMR, as all inferential properties supplied by DRT could be transferred to AMR.

As a matter of fact, there is a rather straightforward way of converting labelled AMRs to DRS in the style of the Parallel Meaning Bank (Abzianidze et al., 2017). This conversion comprises three main steps (τ is the translation function, $\oplus$ is a DRS-merge operation, and v is a function mapping an AMR to its main variable):

1. Replace each sub-AMR by a DRS. This DRS contains exactly one discourse referent, a one-place predicate, and zero or more two-place relations. The first argument of the two-place relation is the main variable of the sub-AMR; the second argument of the two-place relation is the main variable of the sub-AMR. So given an AMR$^+$ (x/i/C :R_1 A_1 ... R_n A_n), the corresponding DRS is τ(i) = $\boxed{\text{x} \mid \text{C'(x) R'}_1\text{(x,v(A}_1\text{)) ... R'}_n\text{(x,v(A}_n\text{))}}$.

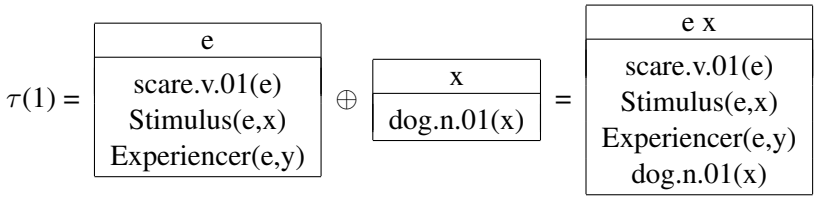
2. Merge all DRSs that are indexed with the same index. A merge of two DRSs ($\oplus$) consists of taking the unions of their respective domains and conditions. Assign an empty DRS $\boxed{\ \ \mid\ \ }$ to inferred contexts.

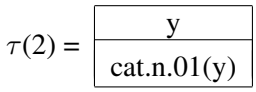
3. Construct the final DRS by following the structure expressed by the constraints. For instance, 3:2=>1 is translated as $\tau(3) \oplus \boxed{\ \ \mid \tau(2) \Rightarrow \tau(1)}$, and 1:¬2 is translated as $\tau(1) \oplus \boxed{\ \ \mid \neg\, \tau(2)}$.

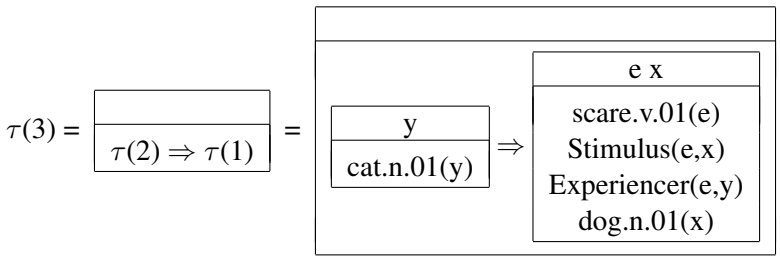
Here are two examples that illustrate this translation, converting AMR predicates to PMB WordNet synsets, and AMR PropBank relations to PMB VerbNet roles:

"A dog scared every cat."

```
(e /1/ scare-01
    :ARG0 (x /1/ dog)
    :ARG1 (y /2/ cat)) {3:2=>1}
```

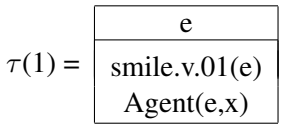


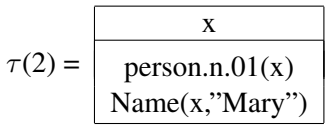


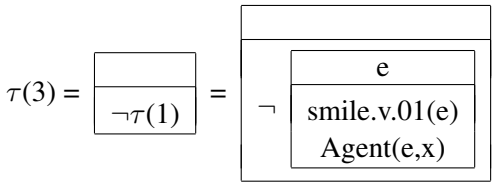


”Mary didn’t smile.”

```
(e /1/ smile-01
    :ARG0 (x /2/ person.n.01
                 :Name "Mary")) {2<3,3:¬1}
```







In terms of expressive power, AMR$^+$ is equivalent with the dialect of DRS employed in the Parallel Meaning Bank (Abzianidze et al., 2017), where relations cannot have arity larger than two. In general, DRS is a more expressive meaning representation language.

4 Discussion

In this section I discuss some loose ends that emerged when designing AMR$^+$: the issue of inferred labels, annotation work required to implement the approach, and the conversion to triples.

4.1 Inferred Labels

In the current proposal, negation and conditionals introduce new indices, that do not appear in the predicate-argument level of the AMR. These are necessary to ensure a well-formed logical structure. But they are (perhaps) not intuitive, and therefore harder to annotate by coders. It would be useful to investigate whether these labels can be inferred, in such a way that constraints with colons (for negation and conditionals) could be simplified. In what direction could this go? First note that inferred contexts are needed in cases of negation (and conditionals). In DRT, a negation is formed recursively, where the negation material (represented as a DRS) is embedded into the wider context (again, represented as a DRS). But when there is nothing available in the wider context, the corresponding DRS will be empty (and as a result, there won’t be a corresponding labelled AMR). As we proposed in Section 3.3, we infer

an index to meet the requirements of a well-formed logical structure. Instead, we can adopt a short-hand notation for such cases, i.e., $\{\neg j\}$ meaning $\{i : \neg j\}$, and $\{j \Rightarrow k\}$ meaning $\{i : j \Rightarrow k\}$. But in general, conditionals would require an equivalent notation in terms of negation, so $\{\neg j, j : \neg k\}$ as short for $\{i : \neg j, j : \neg k\}$, which is logically equivalent to $\{i : j \Rightarrow k\}$. This would cover all cases in Section 3.4.

4.2 Annotation Work

Existing AMR annotations can be monotonically extended: all "slashes" that occur in AMRs need to be indexed, and constraints need to be added. Given an annotated AMR corpus (Banarescu et al., 2013), this can be done semi-automatically: first add indices automatically (by replacing "/" by "/1/"). Then manually correct cases of negation (search for ":polarity -"), universal quantification, and definite descriptions, for a sample of the corpus. Finally, use machine learning to annotate the rest (or hire or persuade human annotators to do the job). The polarity and mod relations can be optionally removed from the AMRs. An interesting question concerns the use of existing parsing models developed for AMR (Artzi et al., 2015; Van Noord and Bos, 2017; Damonte et al., 2017). How can these be extended to deal with the extended AMRs as proposed in this paper? As the original AMR is not affected, a sensible approach would be one in a modular fashion, where datasets consisting of AMRs paired with AMR$^+$s could be used as training material.

4.3 Triple Format of Logical Structure

AMRs are converted to sets of triples for evaluation purposes. Therefore, a sensible question to ask is how the logical constraints in this proposal are converted to triples. There are two new types of triple instances. The indexed sub-AMRs all introduce a membership triple (with the edge named IN) linking an instance with a scope index. Secondly, each scoping constraint introduces one or more "structural" triples. Constraints that involve two indices introduce a single triple. Constraints that involve three indices introduce two triples. Here is an example:

"Nobody smiled."
`(e /1/ smile-01`
`:ARG0 (x /2/ person))` {4:2=>3,3:¬1}

This will introduce the membership triples < e , IN , 1 > and < x , IN , 2 >, the triple for negation < 3 , NOT , 1 >, and the triples for the implication < 4 , IF , 2 >, and < 2 , THEN , 3 >. As a consequence, standard tools for AMR evaluation (Cai and Knight, 2013) can be used, or extended to more fine-grained scores (Damonte et al., 2017).

5 Conclusion and Future Work

The original AMR notation can be extended by a layer of logical structure that gives correct interpretation of linguistic phenomena that require scope or quantification. The resulting framework bears strong similarities with Discourse Representation Theory as implemented in the Parallel Meaning Bank, and it deals with the *bound variable problem* and the *scope representation problem*. So what's next? Let's get an AMR corpus annotated with logical structure!

Acknowledgements

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