Modeling the Induced Action Alternation and the Caused-Motion Construction with Tree Adjoining Grammar (TAG) and Semantic Frames

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Abstract

The induced action alternation and the caused-motion construction are two phenomena that allow English verbs to be interpreted as motion-causing events. This is possible when a verb is used with a direct object and a directional phrase, even when the verb does not lexically signify causativity or motion, as in "Sylvia laughed Mary off the stage". While participation in the induced action alternation is a lexical property of certain verbs, the caused-motion construction is not anchored in the lexicon. We model both phenomena with XMG-2 and use the TuLiPA parser to create compositional semantic frames for example sentences. We show how such frames represent the key differences between these two phenomena at the syntax-semantics interface, and how TAG can be used to derive distinct analyses for them.

1 Introduction

Verbs and their semantics generally play an important role in determining the semantics of English sentences. In many cases, the meaning of an event-denoting sentence can be derived by identifying the verb's syntactic arguments and assigning them to specific participant slots in the verb's semantic frame, thus creating a frame that represents the meaning of the whole sentence. However, the presence or absence of slot fillers is not the only way in which the semantics of a verb depends on its syntactic environment. The induced action alternation and the caused-motion construction are examples of phenomena in which certain syntactic structures can enrich the semantics of the observed verbs in a systematic way.

In this paper, we discuss the overlap of possible syntactic structures licensed by these two phenomena, draw attention to differences in the way they assign semantic frames to sentences, and present a TAG model written in XMG-2 that can parse input sentences and derive their semantics correctly. While participation in the induced action alternation is a lexical property of certain verbs and thus has to be specified for each participating verb in our grammar, the caused-motion construction can apply to all verbs that fulfill the constraints imposed by the construction, and is thus not anchored in the lexicon.

We use XMG-2 to model the constraints on frame unification that are required to generate the different frames licensed by the phenomena. We explore the phenomena from a perspective focused on modeling their key differences, and leave the implementation of edge cases to future work (see Section 5). This work contributes to research on verb alternations and constructions by showing how similar meanings can be generated by them, while pointing out important differences in the results and the underlying processes. This is also a step towards a better understanding of the alternation and the construction in the context of practical applications like semantic role labeling, where sentences involving the phenomena need to be analysed correctly in order to successfully model their meaning.

To our knowledge, this is the first work to deal with these two phenomena in a TAG setting.

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2 The Induced Action Alternation and the Caused-Motion Construction

This paper is concerned with differences between two phenomena at the syntax-semantics interface that license causative interpretations by different means. While verb alternations apply to specific sets of verbs in a language and allow these verbs to express their semantic arguments in particular syntactic forms (Levin, 1993), constructions are "form-meaning correspondences that exist *independently of particular verbs*" (Goldberg, 1995, emphasis added).

The induced action alternation (Levin, 1993) is a verb alternation that allows participating verbs to occur either intransitively or transitively, where the transitive use introduces a cause to the event (examples taken from Levin, 1993, p. 31):

(1) a. Sylvia jumped the horse over the fence.
b. The horse jumped over the fence.

Sentence (1-a) can be paraphrased as "Sylvia caused the horse to jump over the fence". Here, the verb *jump* describes the action or behavior of the syntactic object, whereas in sentence (1-b), it describes the action or behavior of the syntactic subject.

When an English verb does not participate in the induced-action alternation, it may still be used to express a causative meaning. The caused-motion construction (Goldberg, 1995) allows sentences like the following to be interpreted:

(2) Sylvia hit the horse into the barn.

Sentence (2) can be paraphrased as "Sylvia hit the horse, and thereby caused the horse to move into the barn". Here, the verb *hit* describes the action of the syntactic subject, and the directional phrase *into the barn* describes a motion of the syntactic object that results from the action of the syntactic subject.

The caused-motion construction can also be used with intransitive verbs and verbs that do not lexically encode motion. Combining a verb with a direct object and a directional phrase can result in a caused-motion reading that is independent of the lexical meaning of the verb, as in (3), which can be paraphrased as "By laughing, Sylvia caused Mary to move off the stage".

(3) Sylvia laughed Mary off the stage.

In sentences involving the induced action alternation, the verb describes the action or behavior of the syntactic object. In contrast to this, sentences involving the caused-motion construction express the behavior of the syntactic subject in the verb, and the motion of the syntactic object in the directional phrase (often realized in the form of a PP, as in "off the stage", or an adverb, as in "away").

This paper is concerned with a type of sentence structure that is licensed by both phenomena. In both cases, the verb can occur together with a direct object and a directional phrase. When the verb in a sentence participates in the alternation, it is interpreted analogously to (1-a). If this reading is not available, the sentence can be interpreted analogously to (2) and (3). Constraints on the construction have been discussed in the literature, for instance in Goldberg (1995); Goldberg and Jackendoff (2004); Oyón (2007); Cervel (2009). Crucially, participation in the alternation is a lexical property of certain verbs, while the construction can productively apply to any verb, as long as that verb fulfills the constraints imposed by the construction. This means that sentences like (1-a) can also be interpreted in the caused-motion reading. We discuss the available analyses for sentences like this in the course of the paper.

One possible test for the distinction between the alternation and the construction is their behavior when the direct object and/or the directional phrase are deleted. For verbs in the induced action alternation, like *jump*, each of the sentences (4-a) - (4-c) is felicitous and interpretable, while non-alternating verbs only allow structures like (4-d) if they are intransitive (like *laugh*) and/or (4-e) if they are transitive (like *hit*). (4-f) is infelicitous for verbs that do not lexically encode motion or directedness. Note that (4-a) and (4-c) express that it is Sylvia who moves over the fence, whereas the horse is the moving entity in (4-b).

(4) a. Sylvia jumped.
b. Sylvia jumped the horse.
c. Sylvia jumped over the fence.
d. Sylvia laughed. / *Sylvia hit.
e. *Sylvia laughed Mary. / Sylvia hit Mary.
f. *Sylvia laughed off the stage.

3 Modeling with XMG-2

We present an XMG-2 model that can be used to derive the available readings of sentences like those discussed above. XMG (eXtensible MetaGrammar, Crabbé et al. 2013) is a system for designing metagrammars that can be compiled into natural-language grammars. We use XMG-2 (Petitjean et al., 2016) to create a TAG fragment (Tree Adjoining Grammar, Joshi and Schabes 1997) that encodes the syntax and semantics of the sentence types discussed here. How XMG-2 generates compositional semantic frames is laid out in Lichte and Petitjean (2015). After compiling the metagrammar, we use TuLiPA (an open-source parsing environment by Kallmeyer et al., 2008) to parse input sentences and generate their frames (Arps and Petitjean, 2018).

The semantic frames for a sentence are generated based on the frames of the lexical items in the sentence and the unification constraints encoded in the metagrammar. This is inspired by Kallmeyer and Osswald (2014), who present a model for directed motion expressions and the dative alternation.

We aim for a grammar fragment that allows and disallows sentences according to the judgments given for the examples in (4). We achieve this by specifying the semantic frames for the lexical items that are involved and providing different mechanisms for the derivation of compositional semantic frames. We mark each lexical item in our grammar with the syntactic environments in which it can occur. The syntactic trees assign frames to input sentences. This allows us to parse not only the causative sentences, but also more basic cases, like “Sylvia laughed” or “The horse jumped over the fence”, in accordance with the judgments in (4).

Fig. 1 presents the semantic frames we assume for the sentences (1-a) and (3).[1] Both phenomena add a causative reading to a sentence whose verb does not lexically express causativity.

$$
\begin{bmatrix}
\textit{causation} & \\
\textsc{cause} & \begin{bmatrix} \textit{activity} & \\ \textsc{actor} & \textit{Sylvia} \end{bmatrix} \\
\textsc{effect} & \begin{bmatrix} \textit{translocation} & \\ \textsc{mover} & \textit{the horse} \\ \textsc{manner} & \textit{jumping} \\ \textsc{path} & \textit{over the fence} \end{bmatrix}
\end{bmatrix}
\quad
\begin{bmatrix}
\textit{causation} & \\
\textsc{cause} & \begin{bmatrix} \textit{activity} & \\ \textsc{actor} & \textit{Sylvia} \\ \textsc{manner} & \textit{laughing} \end{bmatrix} \\
\textsc{effect} & \begin{bmatrix} \textit{translocation} & \\ \textsc{mover} & \textit{Mary} \\ \textsc{path} & \textit{off the stage} \end{bmatrix}
\end{bmatrix}
$$

Figure 1: Event frames for (1-a) Sylvia jumped the horse over the fence (left, induced action alternation) and (3) Sylvia laughed Mary off the stage (right, caused-motion construction).

In (1-a), the manner in which Sylvia causes the horse to jump over the fence is not explicitly stated. This is reflected in the CAUSE subframe on the left in Fig. 1, where no MANNER attribute is given. The alternation observed here can only apply to a specific subset of English verbs. Therefore, we include in our grammar a dedicated tree for this sentence structure that is associated with a causation frame, and allow alternating verbs, like *jump*, to anchor that tree. Note that a verb’s participation in the alternation must be made explicit in the grammar fragment for this analysis to be derived.

[1]Our representation of the meanings of “over” and “off” is simplified due to space and time limitations.

In (3), Sylvia's action is specified by the verb, *laugh*. Here, the manner in which Mary leaves the stage (running, walking, jumping, etc.) is not explicitly stated. This is reflected in the EFFECT subframe, which does not contain a MANNER attribute. Because the caused-motion construction exists independently of individual verbs, we let verbs like *laugh* or *hit* anchor regular intransitive/transitive trees; the tree for the caused-motion construction is a possible shape these trees can take, provided the syntactic structure is compatible. Furthermore, the participants in a given sentence must be semantically compatible with the slots of the causative frame, e.g., the ACTOR must be an agentive entity, and the MOVER must be an entity that can be caused to move. We do not impose any restrictions as to whether the MOVER has to belong to a type that can move by itself (like a horse), or a type that cannot move by itself (like a ball).

To design a metagrammar that can generate causation frames as in Fig. 1, we implement the following modules: (i) The **morph** file contains a morphological lexicon that connects word forms to the lemmas they belong to. We need this to parse inflected word forms, such as *jumped*. (ii) The **lemma** file contains a lexicon that connects known lemmas to their lexical frames. These are the "building blocks" that will be used to derive frames for full sentences. (iii) The **frame** file defines the type hierarchy and the frames that encode the lexical meaning of the lemmas, e.g. for the verb *jump*. (iv) Finally, the **syntax** file defines the syntactic trees for sentences. Where new frames arise compositionally from the syntactic structure, due to a verb alternation or a construction, the definition of that tree includes the appropriate frame and specifies which syntactic arguments will be used to fill the slots of the semantic frame. For a more detailed description of how these modules interact during parsing, see Arps and Petitjean (2018).

The trees that are generated for our input sentences during parsing assign different semantic frames to the sentences, depending on whether the verb in question participates in the induced action alternation. If it does, the frame will resemble the left side of Fig. 1; if not, it will resemble the right side.

Since the caused-motion construction is productive, it is conceivable that a conflict between these analyses may arise. This would be the case when a verb that participates in the induced action alternation is used in a way meant to realize the frame on the right of Fig. 1, not the one on the left. When parsing such a sentence, the frame for the induced action reading will be derived as expected. The frame for the caused-motion reading, where the verb is understood as applying to the syntactic subject, may however be available as an alternative interpretation. For instance, one might construe a situation in which Sylvia is jumping up and down in a way that scares the horse, causing it to move over the fence; in this case, the sentence (1-a) may be read as an example of the caused-motion construction.

This is why we allow all sentences that involve compatible lexical items to generate the semantic frame for the caused-motion construction. By explicitly marking verbs that participate in the induced action alternation, we ensure that TuLiPA will generate both analyses wherever appropriate.

3.1 Grammar Excerpts

As mentioned above, our grammar fragment consists of a **morph** file, a **lemma** file, a **frame** file and a **syntax** file. Examples from the files are presented in this section. The full grammar is available at `https://github.com/ojahnn/caused-motion-xmg`.

3.1.1 The `frame` File

The **frame** file contains a type hierarchy and the lexical frames for the frame-evoking items in our grammar. Since we are concerned with a grammar fragment for a specific set of phenomena, we use a small set of types and specify only a small number of attribute constraints.

Lexical frames for proper names, such as *Sylvia*, include the specification that the frame is of type `person`, as well as the corresponding value for the `name` attribute. Non-human agentive entities, such as *horse*, are given the type `actor`, as well as an attribute `kind` that describes them further. Similarly, non-animate entities such as *fence* are given the type `physical-entity`, with a `kind` attribute that describes them further. These are greatly simplified frame structures because our focus here is on the behavior of verbs and their influence on the structure of the derived event frames.

In our grammar fragment, we use directional phrases in the form of a set of prepositions. Since the semantic structure of prepositions like *over* is nontrivial, we opt for a simplified frame structure here, too. The prepositions in our grammar fragment are of type `path` and are described further by the value of their `trajectory` attribute. Because trajectories are typically understood in relation to a landmark, a `landmark` attribute is added when a PP is parsed (see e.g. Fig. 4).

Finally, the lexical frames for the verbs in our grammar fragment are given the type `activity` and distinguished further by the value of their `manner` attribute.

The frame hierarchy and type constraints, as well as examples for the kinds of frames mentioned above, are given in Fig. 2.

```
frame-types = {activity, physical_object, person, name,
      actor, mover, causation, manner, translocation,
      landmark, path, trajectory, kind}

frame-constraints = {
      physical_object -> kind: +,
      activity -> actor: +,
      person ->  name: + }
```

```
class FrameSylvia
declare ?X0
{   <frame>{
    ?X0[person,
        name: Sylvia]
 }; <iface>{
     [i=?X0]
}}
```

```
class FrameFence
export ?X0
declare ?X0
{   <frame>{
    ?X0[physical_object,
        kind: fence]
 }; <iface>{
     [i=?X0]
 }}
```

```
class FrameOver
export ?X0
declare ?X0
{   <frame>{
     ?X0[path,
         trajectory: over]
 }; <iface>{
     [i=?X0]
 }}
```

```
class FrameLaugh
export ?X0
declare ?X0
{   <frame>{
     ?X0[activity,
      manner: laughing]
 }; <iface>{
     [e=?X0]
 }}
```

Figure 2: Excerpts from the frame file. Type hierarchy and frame constraints (top left); frame for a proper name (top right); frame for a physical object (bottom left); frame for a preposition (bottom middle); frame for a verb (bottom right). The `iface` feature allows unification of lexical and compositional frames.

3.1.2 The `lemma` and `syntax` Files

Our **lemma** file specifies the sentence trees that can be anchored by each verb. For instance, the verb *laugh* can anchor intransitive sentences, which are covered by the tree named `n0V` in our **syntax** file. The verb *dance* can anchor intransitive sentences with or without directional phrases, so we connect it to the `n0V` tree as well as the `n0Vpp` tree, which is for verbs that lexically express motion.

The set of trees that can be anchored by the verb *jump* is where the induced action alternation comes into play. The verb can be used intransitively with or without a directional phrase; but unlike *laugh* or *dance*, it can also be used with a direct object and a directional phrase to trigger the induced action alternation. We encode this by letting this verb anchor the `n0V` and `n0Vpp` trees, as well as a special tree, `n0Vn1pp_actioninducing`. This is necessary because verbs in the alternation express their semantic arguments in different syntactic slots, compared to sentences with non-alternating verbs. The effect of the `n0Vn1pp_actioninducing` tree is that the verb frame defined in the frame file is “wrapped” in a causative frame that assigns the syntactic arguments to their semantic slots, as given in Fig. 1.

The caused-motion construction is triggered whenever a verb like *laugh* or *hit*, which cannot anchor the `n0Vn1pp_actioninducing` tree, is observed in the same syntactic environment (with a direct object and a directional phrase).[2] These cases are served by one of the possible realizations of the `n0V` tree, which is called `alphanx0Vnx1pp_motioncausing`. Its effect is to “wrap” the verb frame into a new, constructionally generated `causation` frame. Sentences that involve these verbs, but do not have the

[2]Note that some verbs, such as *imagine* or *prefer*, should not be assigned an `actor` attribute and can thus easily be excluded from anchoring this tree by way of additional type constraints in the frame file.

syntactic structure that triggers the caused-motion construction, are realized by the other realization of the `n0V` tree, `alphanx0V`.

All other words in our grammar fragment are also connected to appropriate elementary trees. This allows phrases like NPs and PPs to be derived from the corresponding token sequences, and the NPs and PPs can then be adjoined or substituted into the sentence trees described above.

Fig. 3 displays some example trees and shows that the construction can be applied to any activity verb in our grammar that can anchor simple intransitive trees, while the induced action frame can only be derived for those verbs that are lexically specified to anchor the corresponding tree.

```
class n0V
{ alphanx0V[] | alphanx0Vn1pp_motioncausing[] }
```

```
class n0Vpp
import Subject[] directedverb[]
declare ?X ?Y ?F
{<iface>{[cat=v, e=?F]};
 <frame>{?F[translocation,
            actor:?X,
            mover:?X,
            path:?Y]}
}
```

```
class alphanx0V
import Subject[] BareVerbProjection[]
declare ?F ?X
{<iface>{[cat=v, e=?F]};
 <frame>{?F[activity,
            actor:?X]}
}
```

```
class alphanx0Vn1pp_actioninducing
import Subject[] actioninducingverb[]
{<iface>{[cat=v, e=?G]};
 <frame>{[causation,
          cause:
              [activity,
               actor:?X],
          effect:
              ?G[translocation,
                 mover:?Z,
                 actor:?Z,
                 path:?Y]
  ]}}
```

```
class alphanx0Vn1pp_motioncausing
import Subject[] motioncausingverb[]
{<iface>{[e=?G]};
 <frame>{[causation,
          cause:
              ?G[activity,
                 actor:?X],
          effect:
              [translocation,
               mover:?Z,
               path:?Y]
  ]}}
```

Figure 3: Excerpts from the syntax file. The `n0V` tree has two realizations (top row). Trees with frames for intransitive sentences with PP (middle left) and without PP (middle right); trees with frames for transitive sentences with PP in alternation and construction reading (bottom left, bottom right). The `iface` feature allows unification of derived frame and lexical frames. The imported trees carry exclusively syntactic information.

4 Parsing With TuLiPA

Once the metagrammar is compiled, we use TuLiPA to check whether the sentences are correctly analyzed as specified in Fig. 1. When processing one of the input sentences, TuLiPA will look up the correct lemma for each observed word form; select possible lexical frames for the given lemmas; derive possible syntactic trees for the sentence; and generate a frame that represents the meaning of the full sentence. For sentences with a direct object and a directional PP, a causation frame will be generated, with the subframes for cause and effect filled as appropriate for the observed verb.

Fig. 4 shows one analysis generated by TuLiPA for the input sentence (1-a). The sentence licenses two different frames, since both readings are possible. The alternative reading is shown in Fig. 5.

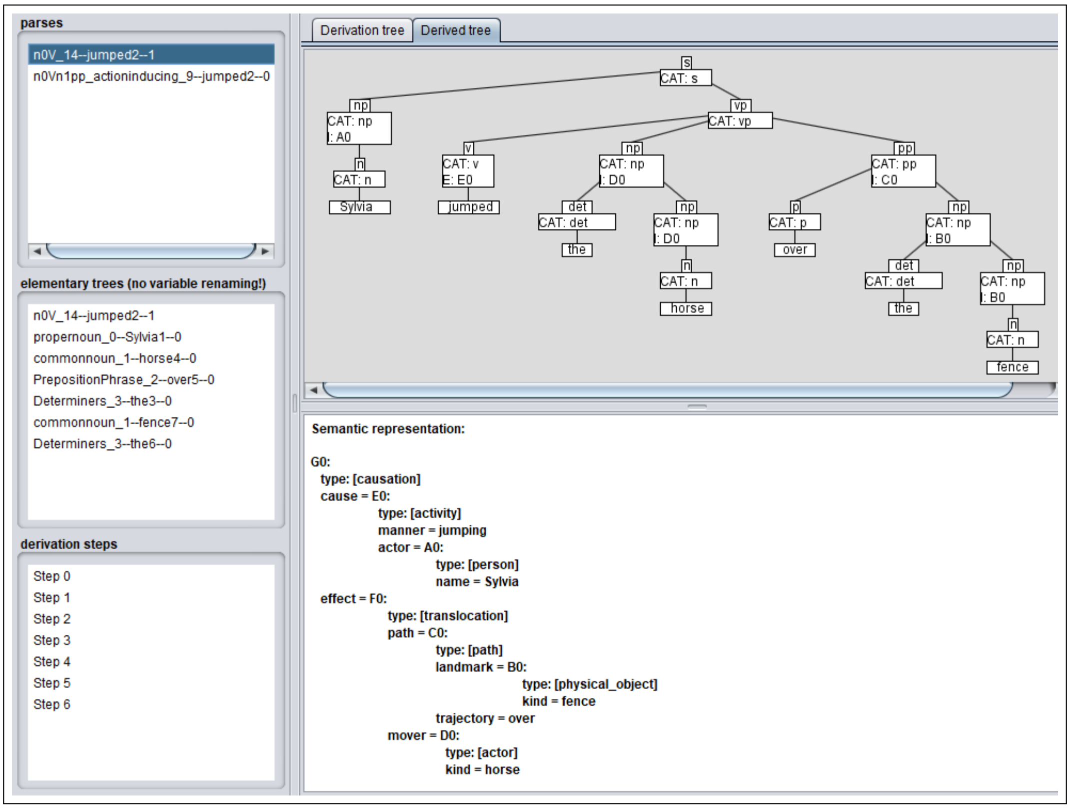

Figure 4: First TuLiPA output for sentence (1-a): Caused-motion reading. This analysis generates the frame associated with the paraphrase "By jumping, Sylvia caused the horse to move over the fence".

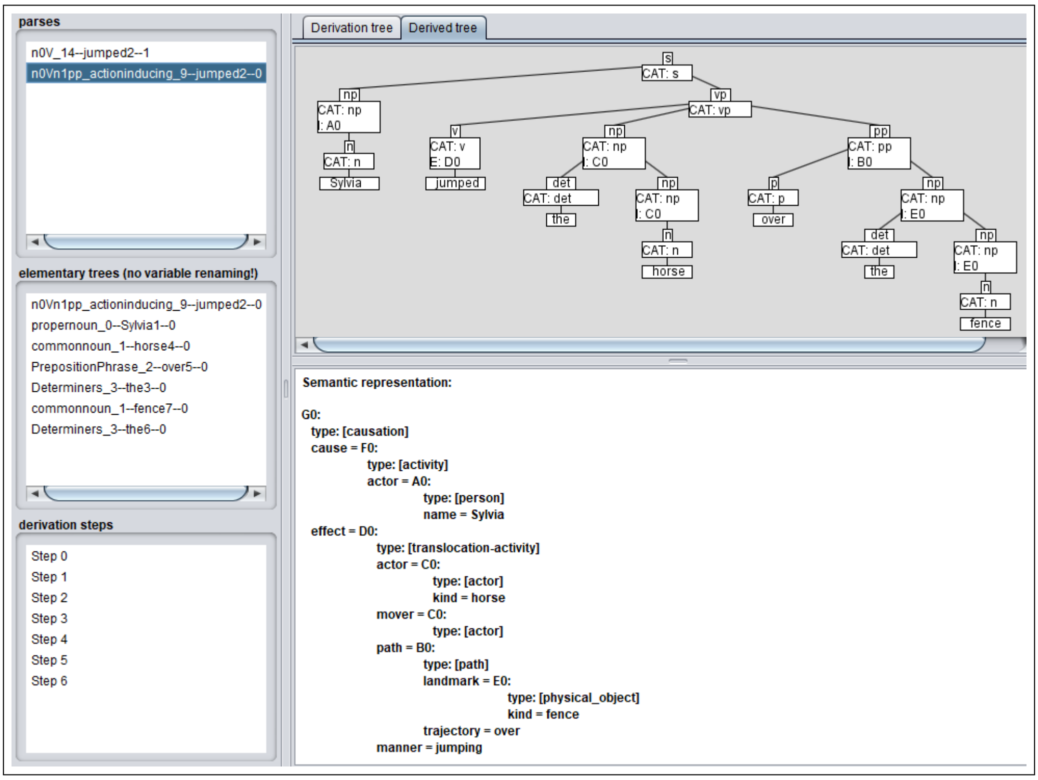

Figure 5: Second TuLiPA output for sentence (1-a): Induced-action reading. This analysis generates the same syntactic tree as shown in Fig. 4, but assigns a different frame to the sentence. This is the case because "jump" is marked in our grammar as participating in the induced action alternation.

5 Conclusion

The induced action alternation and the caused-motion construction are two different ways to use English verbs in a causative way, even when they do not lexically encode causation. We discuss the semantic frames that arise from different syntactic environments for each of these phenomena in Section 3.

We show how the two different types of semantic frames presented in Fig. 1 can be generated for input sentences using XMG-2. We also show that our model allows TuLiPA to provide more than one analysis for sentences that can be construed as examples of *both* phenomena.

Our analysis can be extended to reflect subtle differences in the interpretations of a range of possible usages of the caused-motion construction, as well as closely related constructions. Goldberg and Jackendoff (2004) treat the caused-motion construction as a "subconstruction of the resultative" (p. 535), which also includes other patterns at the syntax-semantics interface. Sentences that employ these related constructions can have the same syntactic structures as the ones discussed in this paper, but be associated with frames that are only distantly related to the frames we discuss here. A possible topic of future work is an extension of our grammar fragment so that it can handle these partially-related cases as well.

Goldberg and Jackendoff (2004) and Cervel (2009) discuss edge cases of the resultative and caused-motion construction that follow different constraints regarding selectional preferences; metaphorical readings are also often an option. The following examples (taken from Goldberg and Jackendoff 2004) illustrate part of the range of usages licensed by the construction:

(5) a. Bill walked himself into a coma.
b. Bill followed the road into the forest.
c. Aliza wiggled her tooth loose.
d. Sara caught a plane to New York.
e. Ray flew the coastal route to Buffalo.

With some additions, the grammar fragment would be able to analyze the sentences in (5).

To parse sentences like (5-a), reflexive pronouns can be added to the grammar fragment. As this example illustrates the resultative construction, the type constraints on the construction's frame may need to be modified, since "into a coma" is not a physical translocation, but a change of state.

In (5-b), unlike the sentences discussed in previous sections, the subject is the mover (it is Bill who is moving, not the road); the derivation of a causative frame could be prevented, for instance, by blocking the verb *follow* from anchoring trees that are associated with a caused-motion meaning. This could be done by giving *follow* a type that is specified to be incompatible with the caused-motion construction. Then, a different tree can be defined in the syntax file such that the frames derived for sentences like this are not causation frames.

Sentence (5-c) requires a refinement of the constraints that currently only allow directional phrases: For now, the grammar handles prepositional phrases, but it can easily be extended to also allow adverbs like *loose*. Like sentence (5-a), this sentence also expresses a change-of-state meaning, and the frame for this kind of sentence should be generated accordingly.

Sentences (5-d) and (5-e) seem to block the constructional interpretation we discuss above, because the prepositional phrases are part of the respective NPs, instead of being part of the VP.[3] The grammar needs to be extended to recognize such syntactic structures, so that frames similar to the one for sentence (5-b) can be created.

While further work is needed to enable the grammar fragment to parse these kinds of sentences, we have shown that TAG is well-suited to represent the two phenomena at the syntax-semantics interface that we have discussed. The XMG-2 framework allows us to neatly separate lexical meaning from constructional meaning. It can also provide more than one analysis if necessary; this is the case, for instance, when a sentence can be construed as exemplifying both the alternation and the construction.

[3] Sentence (5-e) seems to allow analyses that are analogous to either that of sentence (5-b) or that of sentence (5-e), so both syntactic trees and both frames should be made available to TuLiPa.

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