The logic of infinitival complement constructions

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The goal

- To persuade you that one can do formal reasoning in natural language without translating it into a formal language, perhaps more than you thought possible.
Outline

- A brief history of “Natural Logic”
  (as van Benthem might tell it)
  Monotonicity

- Background
  Entailment vs. presupposition
  Implicative and factive constructions

- Simple and phrasal implicatives
  Two types on two-way implicatives: manage and fail
  Four types of one-way implicatives: force, prevent, be able, hesitate

- Can we implement this type of natural reasoning in GF?
  What about Type theory?
This is a story of Natural Logic as told by Johan van Benthem in a couple of lectures. The short version of this goes like this. The curvy line represents the movement of van Bentham’s finger. Natural Logic has been around over 2000 years. It started out pretty well with Aristotle and the Greeks who invented syllogisms, some two dozen valid patterns of inference in ancient Greek. In the medieval times all of this was ported into Latin and slightly improved and complicated by people like Buridan and William of Ockham. With the waning of the Middle Ages there began a lamentable decline in logic that bottoms out in the works of De Morgan in the middle of the 19th Century. But soon came the rise of modern logic first on the formal side with Frege and on the Natural Logic side with Charles Sanders Peirce. The current bloom in Natural Logic was kicked off by van Benthem and his student Sanchez in the 1990s. Among the latest advances is the work by Bill MacCartney and the recent papers by Thomas Icard and Larry Moss that build on MacCartney.
Why the nadir at De Morgan?

- **De Morgan's Laws**
  
  The negation of a conjunction is the disjunction of the two negations.
  \[ \neg(p \land q) \equiv \neg p \lor \neg q \]
  
  The negation of a disjunction is the conjunction of the two negations.
  \[ \neg(p \lor q) \equiv \neg p \land \neg q \]

- **What did de Morgan get wrong?**
  
  *Every tail of a horse is a tail of an animal.*
  
  is true in our world because every horse is an animal.
  
  *Every tail of an animal is a tail of a horse.*
  
  is false in our world because not every animal is a horse.

We credit these equivalences to De Morgan but they were already known in the Middle Ages, clearly formulated by William of Ockham and possibly others some 500 years earlier.

The tail of the horse examples came from the Medievalists. De Morgan thought that the facts had not correctly explained before. He was wrong about that. Furthermore, contrary to what de Morgan thought, under his own account both inferences come out as valid. It has been said that if you go back in time from de Morgan to Ockham in the 14th Century or forward in time to Peirce the logic gets better. Pierce gave the first correct account of the "horse's tail" puzzle in modern times, later taken up by van Benthem and Sanchez.

Sanchez says that Ockham had the right insight about that puzzle although the medieval theory of "suppositions" seems quite opaque to a modern reader. Ockham is also a pioneer of three-valued logic, and of course, the inventor of "Ockham's razor."
Every tail of a horse is a tail of a horse

- Given that every horse is an animal, why is it that substituting animal for first occurrence of horse
  
  \[\text{Every tail of an animal is a tail of a horse.}\]

  is an invalid inference but substituting animal for the second

  \[\text{Every tail of a horse is a tail of an animal.}\]

  is valid?

- Downward monotone vs. upward monotone contexts

\[
\uparrow \downarrow \downarrow \downarrow \downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
(\text{Every (tail of a horse)} \text{ (is a tail of a horse)}.)
\]

- A term in an upward monotone context can be replaced by a more general term: horse \(\subseteq\) animal.

This example was discussed by in the Middle Ages. Whatever it exactly was in modern terms, Ockham's insight had been lost by the time of Leibnitz and De Morgan, both of whom believed to have solved the problem but got it wrong. Sanchez shows that rules they give derive both the correct and incorrect inference.

As Peirce figured out the two occurrences of horse appear in different contexts syntactically, we now call them upward monotonic (or monotone) contexts and downward monotonic (or antitone) contexts. The algorithm for computing monotonicity given by Peirce and taken up by Sanchez and van Benthem is a bit convoluted. It involves building a parse tree or a derivation tree for the sentence and making two down passes through the structure, the first pass top down, the second pass bottom up on all the branches. In the first pass you mark the nodes with + signs and - signs depending on the commanding node. In the second pass you count the number of - signs on the path above each node. If the number of - signs is even you leave the first sign as it is, if the number of - signs along the upward path is odd your reverse the polarity of the node. At the end + marks upward monotonicity and - downward monotonicity.

I am not bothering you with pluses and minuses because it all can be done in just one top-down pass.
Every tail of an animal is a tail of an animal

- A term in a downward monotonic context can be replaced by a more specific term. (horse ⊏ animal)

\[ \uparrow \downarrow \downarrow \downarrow \downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \]

(Every (tail of an animal)) (is a tail of an animal).

\[ \uparrow \downarrow \downarrow \downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \]

(Every (tail of a horse) (is a tail of an animal)).

- Every ↓ ↑: Every is downward monotonic (= antitone) on its first argument, upward monotonic (monotone) on the second

The substitution of animal by horse is valid here because every horse is an animal, but no vice versa. In MacCartney’s notation small horse ⊏ animal.

Where do these ↑ ↓ arrow’s come from? Here they come from the signature of every. Every is downward monotone on the first argument, upward monotone on the second. This is a trivial observation for us because we have a better understanding of the syntactic structure of language than the Medieval philosophers and their ancient predecessors.

If you translate the horse’s tail examples into first-order logic and proceed by some variant of Natural Deduction or sequent calculus you can of course show that one of the two inferences is valid and the other invalid but moving the problem into a formal language makes it more complicated than it is if you do monotonicity reasoning in natural language. It is a homework problem, not self-evident to a beginning logic student.
Monotonicity reasoning

- Some ↑ ↑: some small boys sang beautifully
  □ some kids sang small boys □ kids
  sang beautifully □ sang

- No ↓ ↓: no tigers attacked people
  □ no dangerous tigers attacked and killed people
  dangerous tigers □ tigers
  attacked and killed □ attacked

- With ↑: with a red umbrella □ with an umbrella

- Without ↓: without an umbrella □ without a red umbrella

These are obviously valid inferences that are based on monotonicity and lexical relations. In an upward monotonic context we can replace small boys by kids because kids is less specific. For the same reason we can replace sang beautifully by just sang. With and without have just one argument.
Beyond monotonicity

- James Dean refused to move without blue jeans.

\[ \begin{aligned}
\text{\ding{192}} & \quad \text{Dean didn’t dance without trousers.} \\
(\text{MacCartney & Manning, 2008}) & \\
\text{blue jeans} \in\text{trousers} & \\
\text{dance} \in\text{move} & \\
\text{For these edits to be correct, move must be in a downward monotonic context and blue jeans in an upward monotonic context. What justifies turning refused to didn’t?} & \\
\uparrow & \uparrow & \downarrow & \downarrow & \downarrow & \uparrow & \\
\text{James Dean refused to move without blue jeans.} & \\
\end{aligned} \]

How does monotonicity work here? From what we just said on the preceding slide, without blue jeans \(\in\) without trousers hence blue jeans should be a valid substitution for trousers, not the other way around.

It is examples like this one that motivated the two-pass up and down algorithm of Peirce for computing monotonicity. Here refuse and without mark their argument phrases with minus but the on the upward pass it is noticed that blue jeans has even number, 2, minus marks on its branch to the root of the tree. so the minus originally assigned to it is turned into a plus for upward polarity. In contrast, the minus originally assigned to move stays in place as a mark for downward monotonicity.

As I already said, this can be done more simply in one top-down pass that recognizes refuse and without are polarity reversing operators. We don’t need to first calculate polarity and then monotonicity in another pass.

This is not new, the basic idea is already in my 1971 paper on “Implicative verbs.” In modern times it is described in a 2005 paper about the implementation we did at Xerox Parc that was the inspiration for MacCartney.

But what about the replacement of refused by didn’t? That brings us to main topic: the logic of infinitival complement constructions.
Presupposition

- Eubulides (4th c. BCE)
  Have you lost your horns?
- Frege (1892)
  Kepler died in misery. The name ‘Kepler’ designates something.
- Russell (1905)
  The present king of France is bald. FALSE!
- Strawson (1950)
  Neither true nor false.

Although the Greek philosophers knew about presuppositions, in the modern logical literature the concept first comes up in Frege’s “Sinn und Bedeutung” paper where he argued that proper names presuppose that they designate something. If there is no Kepler, any sentence with the name Kepler is meaningless, neither true nor false. In Russell’s system, anything with the present king of France is just false. Strawson argued against Russell and agreed with Frege. But then linguists took over the notion of presupposition from philosophers and in just a few years they created a large collection of “presupposition triggers.”
Factives and implicatives

• C. & P. Kiparsky 1970 “Fact”
  Factive verbs: regret, resent, care, …
  Factive adjectives: significant, odd, exciting, strange, …
  • introduces two standard tests for distinguishing between presupposition and entailment: negation and questions.
  Is it not strange that desire should so many years outlive performance?

• L. Karttunen 1971 “Implicative Verbs”
  Two types of two-way implicatives: manage and fail
  Four types of one-way implicatives: force, prevent, be able, hesitate
  • two-way implicatives involve both entailments and presuppositions (conventional implicatures).

The late 1960s and early 1970s were an auspicious time to enter linguistics, as many of us of that vintage have found it. Many of the phenomena that were documented then for the first time are still topics that people write about. These two papers are still often quoted although they have of course been superseded by subsequent work.
Semantics of complementation

Kim said that she had scheduled a meeting.

*no commitment* to the truth of the complement clause

Kim remembered *that* she had scheduled a meeting.

*presupposes* that Kim had scheduled a meeting

Kim remembered *to* schedule a meeting.

*entails* that Kim scheduled a meeting

Syntactically there are several types of complement constructions in English: that-clauses, infinitival clauses with to, and -ing complements. Semantically there are three main types, some carry no commitment to the truth of the complement, some presuppose that the complement is true or that the complement is false, and some that entail the truth of the complement. There is also a forth type that I don’t have time to elaborate, constructions that suggest that complement is true or that is false without actually committing the speaker to it. Conversational implications they are called.
Presupposition vs. entailment

Kim remembered \textit{that} she had scheduled a meeting.
Kim did not remember \textit{that} she had scheduled a meeting.
Did Kim remember \textit{that} she had scheduled a meeting?

\texttt{presuppose} that Kim had scheduled a meeting

Kim remembered \textit{to} schedule a meeting.

\texttt{entails} that Kim scheduled a meeting
Did Kim remember to schedule a meeting?

\texttt{no entailment} (presupposes intention)

\texttt{remember that} is factive (presupposition)
\texttt{remember to} is implicative (entailment)

Presuppositions persist under negation, in questions and if-clauses, entailments do not.
Implicative constructions

Implicative constructions yield an entailment about the truth of their complement clause.

Some are simple verbs like forget to and remember to, some are phrasal construction like take the trouble to.

There are six different kinds of implicative constructions. Each of them has one the six possible implicative signatures:

$$++|-- \quad +-|-- \quad ++ \quad +-- \quad -- \quad --$$

to be explained shortly.
**Simple two-way implicatives**

<table>
<thead>
<tr>
<th>Remember to X</th>
<th>+ +</th>
<th>- -</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Kim remembered to X</td>
<td>entails</td>
<td>+ Kim Xed</td>
</tr>
<tr>
<td>- Kim did not remember to X</td>
<td>entails</td>
<td>- Kim did not X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forget to X</th>
<th>+ -</th>
<th>- +</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Kim forgot to X</td>
<td>entails</td>
<td>- Kim did not X</td>
</tr>
<tr>
<td>- Kim did not forget to X</td>
<td>entails</td>
<td>+ Kim did X</td>
</tr>
</tbody>
</table>

Either way, there is a presupposition that Kim intended to or was expected to X.
More simple two-way implicatives

| ++ | -- |
| +-- | -++ |

- turn out that X
- manage to X
- succeed in Xing
- deign to X
- happen to X
- dare to X

- fail to X
- neglect to X
- refrain from Xing
- avoid Xing
Example of natural reasoning

Kim almost failed to remember to eat breakfast.
  \textbf{entails} Kim didn't fail to remember to eat breakfast.
  \textbf{entails} Kim remembered to eat breakfast.
  \textbf{entails} Kim ate breakfast.

almost  ++
fail  ++ | --
remember ++ | --

CSLI                 Language and Natural Reasoning
## One-way implicatives

<table>
<thead>
<tr>
<th>++</th>
<th>+-</th>
</tr>
</thead>
<tbody>
<tr>
<td>cause NP to</td>
<td>refuse to</td>
</tr>
<tr>
<td>force NP to</td>
<td>prevent NP from</td>
</tr>
<tr>
<td>make NP to</td>
<td>keep NP from</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>--</th>
<th>-+</th>
</tr>
</thead>
<tbody>
<tr>
<td>can</td>
<td>hesitate to</td>
</tr>
<tr>
<td>be able to</td>
<td></td>
</tr>
</tbody>
</table>
One-way entailments

Kim forced Mary to speak up.  
\[ \text{entails} \] Mary spoke up.
Kim did not force Mary to speak up.  
\[ \text{no commitment} \]

Kim prevented Mary from speaking up.  
\[ \text{entails} \] Mary did not speak up.
Kim did not prevent Mary from speaking up.  
\[ \text{no commitment} \]

The negative versions of the first two sentences do not yield any entailments. \textit{Kim did not force Mary to speak up} doesn’t tell us whether she did or didn’t. The affirmative versions of the last two are also non-committal, although there is a bias of taking Mary could speak up as implicating that she did and Mary hesitated to speak up that she did not.
More one-way entailments

Mary was not able speak up. ---
  entails Mary did not speak up.
Mary was able to speak up.
  no commitment (suggests that she did – invited inference)

Mary did not hesitate to speak up. ++
  entails Mary spoke up.
Mary hesitated to speak up.
  no commitment

The negative versions of the first two sentences do not yield any entailments. Kim did not force Mary to speak up doesn't tell us whether she did or didn't. The affirmative versions of the last two are also non-committal, although there is a bias of taking Mary could speak up as implicating that she did and Mary hesitated to speak up that she did not.
### Simple and phrasal implicatives

<table>
<thead>
<tr>
<th>Simple Implicative</th>
<th>Phrasal Implicative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim did not attempt to hide her feelings.</td>
<td>Kim made no attempt to hide her feelings.</td>
</tr>
<tr>
<td>Jim did not dare to speak to her.</td>
<td>Jim did not have the guts to speak to her.</td>
</tr>
<tr>
<td>Ed did not bother to come.</td>
<td>Ed did not take the trouble to come.</td>
</tr>
</tbody>
</table>

There are only a few dozen simple two-way implicative verbs in English but there are hundreds of verb-noun VP constructions that are semantically similar to one of the six simple kinds of implicative verbs.
Phrasal two-way implicatives

++ | --

have the courage, wisdom
Julie had the chutzpah to ask the meter maid for a quarter.
I didn’t have the courage to tell her that I loved her.

meet an obligation
We clearly fulfilled the obligation to pass a balanced budget.
Strausser hasn’t met his responsibility to make improvements.

take the effort, asset, opportunity
She took the trouble to iron all the clothes.
I just didn’t take the time to care for myself.

Phrasal implicatives are composed of a transitive verb such as have, make, take and use, and a noun phrase headed by a noun such as attempt, effort and opportunity that can take infinitival complements. The “implicative signature” of such a phrase depends both on the type of verb and the type of the noun.
I used the money to buy shoes and food.

Randy didn’t use the opportunity to toot his own horn.

I wasted the money to buy a game that I cannot play.

I’m glad I didn’t waste 90 minutes to see this film.

Mr. Spitzer wasted the opportunity to drive a harder bargain.

She didn’t waste the chance to smile back at him.

The Avatar failed his duty to bring peace to a broken world.

Orlando didn’t neglect his duty to escort the dead.

Notice that wasting an asset and wasting an opportunity are quite different.
Phrasal one-way implicatives

+-
  lack opportunity
  She lost the chance to qualify for the final.

--
  have ability
  The defendant had no ability to pay the fine.
make effort
  I have made no effort to check the accuracy of this blog.

++
  show hesitation
  She did not have any hesitation to don the role of a seductress.
  Fonseka displayed no reluctance to carry out his orders.

All the examples of the use of phrasal implicatives in this presentation have been collected from Google searches on the Web. Viewed in their full context it is clear that the intended interpretation matches the indicated implicative signature.
Most of these verb classes you can find on WordNet but what is it that the verbs in the MEET class have in common? Nothing much except that they acquire the same implicative signature, ++|--, when combined with the OBLIGATION class nouns such as duty, mission, obligation.
<table>
<thead>
<tr>
<th>Noun families</th>
<th>ability, means, oomph, power</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABILITY</td>
<td>ability, means, oomph, power</td>
</tr>
<tr>
<td>ASSET</td>
<td>asset, fortune, money, time</td>
</tr>
<tr>
<td>COURAGE</td>
<td>audacity, chutzpah, courage, endurance, guts, impudence, nerve, stamina</td>
</tr>
<tr>
<td>EFFORT</td>
<td>attempt, effort, initiative, trouble</td>
</tr>
<tr>
<td>HESITATION</td>
<td>hesitation, qualms, reluctance, scruples</td>
</tr>
<tr>
<td>OBLIGATION</td>
<td>duty, mission, obligation</td>
</tr>
<tr>
<td>OPPORTUNITY</td>
<td>chance, opportunity, occasion</td>
</tr>
<tr>
<td>WISDOM</td>
<td>expend, exploit, use, utilize</td>
</tr>
</tbody>
</table>

We should add more families to this table. For example, promise yields a ++ | -- signature with some but not all of the verbs in the MEET class: fulfill a promise vs. do a promise that doesn't have the implicative sense that keep a promise does.
<table>
<thead>
<tr>
<th>VERB FAMILY</th>
<th>NOUN FAMILY</th>
<th>IMPLICATIVE SIGNATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAVE</td>
<td>ABILITY / OPPORTUNITY</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>COURAGE/WISDOM</td>
<td>++</td>
</tr>
<tr>
<td>LACK</td>
<td>ABILITY / OPPORTUNITY</td>
<td>+--</td>
</tr>
<tr>
<td>MAKE</td>
<td>EFFORT</td>
<td>--</td>
</tr>
<tr>
<td>MEET</td>
<td>OBLIGATION</td>
<td>++</td>
</tr>
<tr>
<td>FAIL</td>
<td>OBLIGATION</td>
<td>+--</td>
</tr>
<tr>
<td>SHOW</td>
<td>HESITATION</td>
<td>++</td>
</tr>
<tr>
<td>TAKE</td>
<td>ASSET / EFFORT</td>
<td>++</td>
</tr>
<tr>
<td>USE</td>
<td>ASSET / OPPORTUNITY</td>
<td>++</td>
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<tr>
<td>WASTE</td>
<td>ASSET</td>
<td>++</td>
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<td></td>
<td>OPPORTUNITY</td>
<td>++</td>
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</table>

This table summarizes the findings for some of the most common verbs that appear in phrasal implicative constructions and the semantic types of nouns they collocate with. This table yields hundreds of possible combinations, not all of them attested or encountered by any one speaker. However, speaker of English should mostly agree on the implicative signatures in this table even on constructions they have not heard before. Some experiments on Amazon Mechanical Turk are planned to test this out.
Summary

- One can do reasoning in natural language without translating it into a formal language, perhaps more than you thought possible.
- My hope is that most of the ways to do that can be implemented in GF to enhance the capabilities it already has.
- How would this come out in type theory?
References

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