Synthetic logic characterizations of meanings extracted from large corpora

Alex Djalali and Christopher Potts
Stanford Linguistics

Workshop on Semantics for Textual Inference
LSA Institute, University of Colorado, August 9-10, 2011
Overview

Goals

- Establish new connections between Bill MacCartney’s NatLog system and linguistic theory
- Understand Natlog’s logical underpinnings
- Use the logic to systematize the heterogenous information we have about word meanings

Plan

1. Rethinking NatLog as a logical system (a sequent calculus)
2. Completeness via representation (answering the question, What models does the logic characterize?)
3. Instantiate the semantics using large corpora
4. Evaluate on a novel corpus of indirect question–answer pairs
Two conceptions of semantic theory

- Meaning as model-theoretic denotation
- Meaning as relations between forms
Jerrold Katz, *Semantic Theory*: Meaning as relations between forms
Two conceptions of semantic theory

Jerrold Katz, *Semantic Theory: Meaning as relations between forms*

- “The arbitrariness of the distinction between form and matter reveals itself [. . .]”
Two conceptions of semantic theory

Jerrold Katz, *Semantic Theory: Meaning as relations between forms*

- “The arbitrariness of the distinction between form and matter reveals itself [...]”
- “makes no distinction between what is logical and what is not”
Two conceptions of semantic theory

Jerrold Katz, *Semantic Theory*: Meaning as relations between forms

- “The arbitrariness of the distinction between form and matter reveals itself […]”
- “makes no distinction between what is logical and what is not”
- What is meaning? broken down:
  - What is synonymy?
  - What is antonymy?
  - What is superordination?
  - What is semantic ambiguity?
  - What is semantic truth (analyticity, metalinguistic truth, etc.)?
  - What is a possible answer to a question?
  - …
Two conceptions of semantic theory

David Lewis, ‘General semantics’: Meaning as denotation

“Semantic interpretation by means of them [semantic markers] amounts merely to a translation algorithm from the object language to the auxiliary language Markerese.”
Two conceptions of semantic theory

David Lewis, ‘General semantics’: Meaning as denotation

“Semantic interpretation by means of them [semantic markers] amounts merely to a translation algorithm from the object language to the auxiliary language Markerese. But we can know the Markerese translation of an English sentence without knowing the first thing about the meaning of the English sentence: namely, the conditions under which it would be true.
Two conceptions of semantic theory

David Lewis, ‘General semantics’: Meaning as denotation

“Semantic interpretation by means of them [semantic markers] amounts merely to a translation algorithm from the object language to the auxiliary language Markerese. But we can know the Markerese translation of an English sentence without knowing the first thing about the meaning of the English sentence: namely, the conditions under which it would be true. Semantics with no treatment of truth conditions is not semantics. [. . . ]
Two conceptions of semantic theory

David Lewis, ‘General semantics’: Meaning as denotation

“Semantic interpretation by means of them [semantic markers] amounts merely to a translation algorithm from the object language to the auxiliary language Markerese. But we can know the Markerese translation of an English sentence without knowing the first thing about the meaning of the English sentence: namely, the conditions under which it would be true. Semantics with no treatment of truth conditions is not semantics. […] My proposals are in the tradition of referential, or model-theoretic, semantics descended from Frege, Tarski, Carnap (in his later works), and recent work of Kripke and others on semantic foundations in intensional logic.”
Bill MacCartney’s natural logic


Bill MacCartney’s natural logic

1. Ask not what a phrase means, but how it relates to others.

   *dog*
   - is entailed by *poodle*
   - excludes *tree*
   - is consistent with *hungry*
   ...  

   *dance without pants*
   - entails *move without jeans*
   - excludes *tango in chinos*
   - is consistent with *tango*
   ...  

2. Seamless blending of logical and non-logical operators: everything appears synthetic (as opposed to analytic).

3. Following Popper: “synthetic statements in general are placed, by the entailment relation, in the open interval between self-contradiction and tautology”.
IBM’s Watson

“so you’re associating words with other words, and then you can associate those with other words …”
Propositional Synthetic Logic

- Propositional Synthetic Logic (PSL) is a singly-typed version of MacCartney’s natural logic.
- The logic is a theory of the lexicon.
- We will shortly extend the logic with types and composition rules, but our meta-logical results are only for PSL.

Example (A simple PSL proof)

\[
\Gamma \vdash \text{short} \mid \text{tall} \quad \Gamma \vdash \text{tall} \wedge \text{tall} \\
\hline
\Gamma \vdash \text{short} \sqsubseteq \text{tall}
\]
Syntax

Definition (Syntax of $\mathcal{L}$)

Let $\Phi$ be a countable set of proposition letters, which we refer to as the set of proper terms. Then,

1. If $\varphi$ is a proper term, then so is $\bar{\varphi}$;
2. If $\varphi$ and $\psi$ are proper terms, then

$$\varphi \equiv \psi, \quad \varphi \sqsubset \psi, \quad \varphi \sqsupset \psi,$$
$$\varphi ^ \psi, \quad \varphi \mid \psi, \quad \varphi \sim \psi$$

are synthetic terms. Nothing else is a term of $\mathcal{L}$.

Examples

- Frenchman $|$ Dutchman
- run $\sqsubseteq$ move
- tall $\wedge$ tall
Models

Definition (Synthetic models)

Let a synthetic model \( M \) be the pair \( \langle D, \llbracket \cdot \rrbracket \rangle \), where

1. \( D \) is a non-empty set
2. \( \llbracket \cdot \rrbracket \) is an interpretation function taking proper terms \( \varphi \) to their denotations in \( D \) such that
   a. \( \llbracket \overline{\varphi} \rrbracket = D - \llbracket \varphi \rrbracket \) such that
   b. \( \llbracket \varphi \rrbracket \neq \emptyset \) or \( \llbracket \varphi \rrbracket = D \)
## Semantics

### Definition (Tarski-style truth conditions)

- \( M \models \varphi \equiv \psi \iff \llbracket \varphi \rrbracket = \llbracket \psi \rrbracket \)
- \( M \models \varphi \sqsubseteq \psi \iff \llbracket \varphi \rrbracket \subseteq \llbracket \psi \rrbracket \)
- \( M \models \varphi \sqsupset \psi \iff \llbracket \varphi \rrbracket \supset \llbracket \psi \rrbracket \)
- \( M \models \varphi \wedge \psi \iff (\llbracket \varphi \rrbracket \cap \llbracket \psi \rrbracket = \emptyset) \land (\llbracket \varphi \rrbracket \cup \llbracket \psi \rrbracket = D) \)
- \( M \models \varphi \mid \psi \iff (\llbracket \varphi \rrbracket \cap \llbracket \psi \rrbracket = \emptyset) \land (\llbracket \varphi \rrbracket \cup \llbracket \psi \rrbracket \neq D) \)
- \( M \models \varphi \dashv \psi \iff (\llbracket \varphi \rrbracket \cap \llbracket \psi \rrbracket \neq \emptyset) \land (\llbracket \varphi \rrbracket \cup \llbracket \psi \rrbracket = D) \)
Graphical representation of the semantics

\[ \phi \equiv \psi \]

\textit{equivalence}

\textit{couch} \equiv \textit{sofa}

\[ \phi \sqsubseteq \psi \]

\textit{forward entailment}

\textit{crow} \sqsubseteq \textit{bird}

\[ \phi \sqsupseteq \psi \]

\textit{reverse entailment}

\textit{bird} \sqsupseteq \textit{crow}

\[ \phi \wedge \psi \]

\textit{negation}

\textit{man} \wedge \textit{non-man}

\[ \phi | \psi \]

\textit{alternation}

\textit{cat} | \textit{dog}

\[ \phi \dashv \psi \]

\textit{cover}

\textit{animal} \dashv \textit{non-human}
Mutual exclusivity of the relations

**Theorem**

*If \( \mathcal{M} \) is a synthetic model then*

\[
\mathcal{M} \models \varphi_R \psi \Rightarrow \mathcal{M} \not\models \varphi_S \psi
\]

*for \( R \neq S \).*
Entailment

**Definition (Synthetic entailment)**

Let $\Gamma$ be a set of synthetic terms. $\Gamma$ entails $\varphi \mathcal{R} \psi$ written, $\Gamma \models \varphi \mathcal{R} \psi$, if, and only if

$$M \models \Gamma \Rightarrow M \models \varphi \mathcal{R} \psi$$
Propositional Synthetic Logic proof calculus

- A sequent calculus for reasoning with PSL
- A logical perspective on (the lexical parts of) MacCartney’s procedural, matrix-based reasoning
### MacCartney rules

<table>
<thead>
<tr>
<th>$\mathcal{R}, \mathcal{S}$</th>
<th>$\equiv$</th>
<th>$\Gamma$</th>
<th>$\psi$</th>
<th>$\Gamma$</th>
<th>$\psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\equiv$</td>
<td>$\equiv$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td></td>
</tr>
<tr>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td></td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
</tr>
<tr>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
<td>$\psi$</td>
<td>$\Gamma$</td>
</tr>
</tbody>
</table>

### M-rules

$$
\frac{\Gamma \vdash \varphi R \psi \quad \Gamma \vdash \psi S \chi}{\Gamma \vdash \varphi T \chi}
$$
### MacCartney rules

| $\mathcal{R}, S$ | $\equiv$ | $\sqsubseteq$ | $\sqsupseteq$ | $\wedge$ | $|$ | $\supseteq$ |
|-----------------|--------|-------------|-------------|--------|-----|--------|
| $\equiv$        | $\equiv$| $\sqsubseteq$ | $\sqsupseteq$| $\wedge$| $|$ | $\supseteq$ | $\equiv$|
| $\sqsubseteq$   | $\sqsubseteq$| $\sqsubseteq$| $\cdot$| $|$ | $\cdot$ | $\cdot$ | $\cdot$ |
| $\sqsupseteq$   | $\cdot$| $\sqsupseteq$| $\equiv$| $\sqsubseteq$| $\cdot$| $\cdot$| $\cdot$ |
| $\wedge$        | $\cdot$| $\wedge$| $\cdot$| $\cdot$| $\cdot$| $\cdot$| $\cdot$ |
| $|$              | $|$| $|$| $|$| $|$| $|$| $|$| $|$ |
| $\supseteq$     | $\supseteq$| $\supseteq$| $\cdot$| $\cdot$| $\cdot$| $\cdot$| $\cdot$ |

### $M$-rules: Instantiated with $\sqsubseteq, \sqsubseteq$

$$
\Gamma \vdash \varphi \sqsubseteq \psi \quad \Gamma \vdash \psi \sqsubseteq \chi
\quad \frac{}{\Gamma \vdash \varphi \sqsubseteq \chi} \quad \sqsubseteq, \sqsubseteq
$$
### MacCartney rules

<table>
<thead>
<tr>
<th>( R, S )</th>
<th>( \equiv )</th>
<th>( \sqsubseteq )</th>
<th>( \sqsupseteq )</th>
<th>( \land )</th>
<th>( \lor )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \equiv )</td>
<td>( \equiv )</td>
<td>( \sqsubseteq )</td>
<td>( \sqsupseteq )</td>
<td>( \land )</td>
<td>( \lor )</td>
</tr>
<tr>
<td>( \sqsubseteq )</td>
<td>( \sqsubseteq )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
</tr>
<tr>
<td>( \sqsupseteq )</td>
<td>( \cdot )</td>
<td>( \sqsubseteq )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
</tr>
<tr>
<td>( \lor )</td>
<td>( \lor )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
</tr>
<tr>
<td>( \land )</td>
<td>( \land )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
</tr>
<tr>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
<td>( \cdot )</td>
</tr>
</tbody>
</table>

**M-rules: Instantiated with \( \sqsubseteq, \lor \)**

\[
\Gamma \vdash \varphi \sqsubseteq \psi \quad \Gamma \vdash \psi \lor \chi \\
\therefore \Gamma \vdash \varphi \lor \chi \quad \sqsubseteq, \lor
\]
Additional proof rules

**Definition (D-rules)**

\[
\begin{align*}
\Gamma &\vdash \varphi \equiv \varphi & \equiv_1 \\
\Gamma &\vdash \psi \equiv \varphi & \equiv_2 \\
\Gamma &\vdash \varphi \sqsubseteq \psi & \sqsubseteq_1 \\
\Gamma &\vdash \psi \sqsubseteq \varphi & \sqsubseteq_1 \\
\Gamma &\vdash \varphi \models \psi & \models_1 \\
\Gamma &\vdash \psi \models \varphi & \models_1 \\
\Gamma &\vdash \varphi \vdash \psi & \vdash_1 \\
\Gamma &\vdash \psi \vdash \varphi & \vdash_1 \\
\end{align*}
\]

**Definition (Reflexivity)**

\[
\begin{align*}
\varphi R \psi & \in \Gamma \\
\Gamma &\vdash \varphi R \psi & \text{Refl}
\end{align*}
\]
Proofs involving complementation

**Theorem (Complementation)**

1. \( \Gamma \vdash \varphi \equiv \psi \iff \Gamma \vdash \varphi \land \neg \psi \)
2. \( \Gamma \vdash \varphi \land \psi \iff \Gamma \vdash \varphi \equiv \neg \psi \)
3. \( \Gamma \vdash \varphi \equiv \neg \varphi \) (double negation)
4. \( \Gamma \vdash \varphi \sqsupset \psi \iff \Gamma \vdash \neg \psi \sqsubset \neg \varphi \) (contraposition)
5. \( \Gamma \vdash \varphi \sqsubseteq \psi \iff \Gamma \vdash \neg \varphi \sqsubseteq \neg \psi \)
6. \( \Gamma \vdash \varphi \mid \psi \iff \Gamma \vdash \varphi \sqsubset \neg \psi \)
7. \( \Gamma \vdash \varphi \triangledown \psi \iff \Gamma \vdash \varphi \sqsupset \neg \psi \)
## Natural language inference

### Definition (M-rule: $|$, $^\wedge$)

\[
\frac{\Gamma \vdash \varphi | \psi \quad \Gamma \vdash \psi^\wedge \chi}{\Gamma \vdash \varphi \sqsubseteq \chi} \qquad |, ^\wedge
\]

### Theorem

\[
\Gamma \vdash \varphi | \psi \Rightarrow \Gamma \vdash \varphi \sqsubseteq \overline{\psi}
\]

### Proof.

\[
\frac{\Gamma \vdash \varphi | \psi \quad \Gamma \vdash \psi^\wedge \overline{\psi}}{\Gamma \vdash \varphi \sqsubseteq \overline{\psi}} \quad |, ^\wedge
\]

\[
\frac{\Gamma \vdash \varphi | \psi \quad \Gamma \vdash \psi^\wedge \overline{\psi}}{\Gamma \vdash \varphi \sqsubseteq \overline{\psi}} \quad |, ^\wedge
\]
Natural language inference

Definition (\(M\)-rule: \(|, ^\wedge\))

\[
\begin{align*}
\Gamma & \vdash \varphi | \psi \quad \Gamma \vdash \psi ^\wedge \chi \\
\hline
\Gamma & \vdash \varphi \sqsubseteq \chi
\end{align*}
\]

Theorem

\(\Gamma \vdash cat | dog \Rightarrow \Gamma \vdash cat \sqsubseteq \underline{dog}\)

Proof.

\[
\begin{align*}
\Gamma & \vdash cat | dog \quad \Gamma \vdash dog ^\wedge \underline{dog} \\
\hline
\Gamma & \vdash cat \sqsubseteq \underline{dog}
\end{align*}
\]
Final proof rule

Definition (Explosion)

\[
\Gamma \vdash \varphi R \psi \\
\Gamma \vdash \varphi S \psi \\
\text{for } R \neq S
\]

\[
\Gamma \vdash \varphi' T \psi' \text{ for all synthetic terms } \varphi' T \psi'
\]

Exp
Consistency

Definition (Consistency)

Γ is **consistent** if, and only if \( \Gamma \models \varphi R \psi \) for some synthetic term \( \varphi R \psi \).
Theorem (Inconsistent set)

\[ \Gamma = \{ \varphi \sqsubseteq \psi, \psi \sqsupseteq \vartheta, \varphi \sim \vartheta \} \text{ is inconsistent} \]

Proof.

\[
\frac{\varphi \sqsubseteq \psi \in \Gamma}{\Gamma \vdash \varphi \sqsubseteq \psi} \quad \text{Refl}
\]
\[
\frac{\Gamma \vdash \varphi \sqsubseteq \psi}{\Gamma \vdash \psi \sqsupseteq \varphi} \quad \text{\textcircled{1}}
\]
\[
\frac{\varphi \sim \vartheta \in \Gamma}{\Gamma \vdash \varphi \sim \vartheta} \quad \text{Refl}
\]
\[
\frac{\Gamma \vdash \varphi \sim \vartheta}{\Gamma \vdash \psi \sim \vartheta} \quad \text{\textcircled{2}, \textcircled{3}}
\]
\[
\frac{\psi \supseteq \vartheta \in \Gamma}{\Gamma \vdash \psi \supseteq \vartheta} \quad \text{Refl}
\]
\[
\frac{\psi \supseteq \vartheta \in \Gamma}{\Gamma \vdash \psi \supseteq \vartheta} \quad \text{Exp}
\]

\[ \square \]
Propositional Synthetic Logic completeness

\[ \Gamma \vdash \varphi R \psi \Leftrightarrow \Gamma \models \varphi R \psi \]
Soundness proof sketch

Soundness (if provable, then true)

\[ \Gamma \vdash \varphi \mathcal{R} \psi \Rightarrow \Gamma \models \varphi \mathcal{R} \psi \]

1. By induction on the height of the derivation.
2. Basic set-theoretic observations.

Example

\[ \Gamma \vdash \varphi \sqsubset \psi \quad \Gamma \vdash \psi \sqsubset \chi \]

\[ \Gamma \vdash \varphi \sqsubset \chi \quad \sqsubset, \sqsubset \]

The semantics of $\sqsubset$ is strict set-theoretic containment, which is transitive.
Adequacy proof sketch

Adequacy of the Proof Calculus

\[ \Gamma \models \varphi R \psi \Rightarrow \Gamma \vdash \varphi R \psi \iff \neg \varphi R \psi \Rightarrow \Gamma \not\models \varphi R \psi \]

contraposition

The strategy

The proof is built around a model existence lemma: we show that every consistent \( \Gamma \) has a synthetic model \( M \) such that

\[ \Gamma \vdash \varphi R \psi \iff M \models \varphi R \psi \quad \text{for all } \varphi, R, \psi \]
Model construction via representation

1. Every consistent $\Gamma$ induces an order on the set of proper terms $\Phi$.
2. That ordered set can be transformed into an orthoposet.
3. Every orthoposet can be represented as a system of sets.
4. The system of sets will function as a synthetic model for $\Gamma$.


From premise sets to orthoposets

**Definition (Orthposets)**

An **orthoposet** is a tuple \((P, \leq, 0, \neg)\) such that

1. \((P, \leq)\) is a partial order;
2. 0 is a minimal element, i.e., \(0 \leq x\) for all \(x \in P\);
3. \(x \leq y\) if, and only if \(\overline{y} \leq \overline{x}\);
4. \(\overline{x} = x\)
5. If \(x \leq y\) and \(x \leq \overline{y}\), then \(x = 0\).

**From arbitrary consistent \(\Gamma\) to orthoposet \((\Phi^*, \leq_\Gamma, 0, \neg)\)**

- \(\Phi^*\) is a set of equivalence classes under \(\equiv\);
- \(\phi \leq_\Gamma \psi \iff \Gamma \vdash \phi \equiv \psi\) or \(\Gamma \vdash \phi \sqsubseteq \psi\)
- 0 is a fresh element added not in the original language;
- \(\neg\) is the complementation operator.
Example of orthoposet construction

1. Define the relation $\leq_{\Gamma}$: $\varphi \leq_{\Gamma} \psi \iff \Gamma \vdash \varphi \equiv \psi$ or $\Gamma \vdash \varphi \sqsubseteq \psi$
2. $\leq_{\Gamma}$ induces an equivalence relation under $\equiv$
3. Let the elements of the orthoposet be those equivalence classes
4. Let the equivalence class for $\varphi$, written $[\varphi]$, be $[\varphi]$
5. Add elements 0, 1 to $\Phi$, setting $0 = 1$ and $0 < x < 1$:

\[ \Gamma = \{ \varphi \sqsubseteq \psi, \vartheta \sqsubseteq \psi, \varphi \mid \vartheta \} \]
From orthopsets to systems of sets (models)

**Definition (Points)**

A point of an orthoposet $P$ is a subset $S \subseteq P$ such that:

1. If $x \in S$ and $x \leq y$, then $y \in S$ (*$S$ is upward-closed*);
2. For all $x$, either $x \in S$ or $\overline{x} \in S$ (*$S$ is complete*), but not both (*$S$ is consistent*).
From orthopsets to systems of sets (models)

**Theorem (Representation)**

Let $P = (P, \leq, 0, -)$ be an orthoposet. There is a set $\text{points}(P)$ and a strict morphism $f$ such that

$$f : P \rightarrow \mathcal{P}(\text{points}(P))$$

by setting $f(x) = \{S \in \text{points}(P) \mid x \in S\}$
Model construction (putting the pieces together)

Recall, \((\Phi^*, \leq, 0, -)\) is an orthoposet. So,

1. Define \(g : \Phi \rightarrow \Phi^*\) such that

\[\varphi \mapsto [\varphi]_\Gamma\]

2. Set \(f : \Phi^* \rightarrow \mathcal{P}(\text{points}(\Phi^*))\) such that

\[f(x) = \{S \in \text{points}(\Phi^*) \mid x \in S\}\]

3. Let \([\cdot \cdot]\) be defined as the \textit{composition} of \(f\) and \(g\) \((f \cdot g)\).
Model existence

Lemma

\[ M \models \varphi R \psi \iff \Gamma \vdash \varphi R \psi \]

Proof.

\[
\begin{align*}
\Gamma \vdash \varphi \equiv \psi & \iff g(\varphi) = g(\psi) \\
& \iff f(g(\varphi)) = f(g(\psi)) \\
& \iff \llbracket \varphi \rrbracket = \llbracket \psi \rrbracket \\
& \iff M \models \varphi \equiv \psi
\end{align*}
\]

\[
\begin{align*}
\Gamma \vdash \varphi \sqsubset \psi & \iff g(\varphi) \lhd g(\psi) \\
& \iff f(g(\varphi)) \subset f(g(\psi)) \\
& \iff \llbracket \varphi \rrbracket \subset \llbracket \psi \rrbracket \\
& \iff M \models \varphi \sqsubset \psi
\end{align*}
\]
Semantic composition

- We have so far looked only at lexical reasoning, or reasoning within a single type domain.
- We now extend the system, more informally, with a theory of semantic composition.
Projectivity

Every pair of like-typed lexical items has an associated projectivity signature mapping synthetic logic relations into same.

Example (Negation, both inserted and deleted)

Project(\textit{not, not}) = \text{Project}(\epsilon, \textit{not}) = \begin{pmatrix}
\square & \leftrightarrow & \square \\
\square & \leftrightarrow & \square \\
\equiv & \leftrightarrow & \equiv \\
\wedge & \leftrightarrow & \wedge
\end{pmatrix}

Project(\textit{not, }\epsilon) = \text{identity}

- MacCartney motivates numerous projectivity signatures, for one- and two-place operators, as well as default signatures for inserting and deleting phrases.
- Thomas Icard is currently exploring the formal properties of the linguistically useful signatures.
**Definition (Semantic composition)**

The rule for computing the value of the mother based on its daughter:

\[ R \bowtie \text{Project}(\alpha, \beta)(S) \quad \text{or} \quad \text{Project}(\alpha, \beta)(S) \bowtie R \]

\[ \alpha R \beta \quad \delta S \gamma \]

where \( A \bowtie B \) abbreviates the proof

\[
\Gamma \vdash \varphi A \psi \\
\Gamma \vdash \psi B \chi \\
\frac{}{\Gamma \vdash \varphi C \chi}
\]

**Table: Semantic Composition**

<table>
<thead>
<tr>
<th>( R, S )</th>
<th>( \equiv )</th>
<th>( \land )</th>
<th>( \lor )</th>
<th>( \lnot )</th>
<th>( \rightarrow )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \equiv )</td>
<td>( \equiv )</td>
<td>( \land )</td>
<td>( \lor )</td>
<td>( \lnot )</td>
<td>( \rightarrow )</td>
</tr>
<tr>
<td>( \land )</td>
<td>( \equiv )</td>
<td>( \lnot )</td>
<td>( \rightarrow )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \lor )</td>
<td>( \equiv )</td>
<td>( \rightarrow )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \lnot )</td>
<td>( \equiv )</td>
<td>( \rightarrow )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \rightarrow )</td>
<td>( \equiv )</td>
<td>( \rightarrow )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example: negation

Example (Insertion)

\[
\begin{bmatrix}
\equiv & \mapsto & \equiv \\
\equiv & \mapsto & \equiv \\
\wedge & \mapsto & \wedge \\
\end{bmatrix}
\]

Project(\(\varepsilon, \text{not}\))

\[
\begin{bmatrix}
\equiv & \mapsto & \equiv \\
\equiv & \mapsto & \equiv \\
\wedge & \mapsto & \wedge \\
\end{bmatrix}
\]

move \not\rightarrow not run

\[
\varepsilon \land \text{not move} \rightarrow \text{run}
\]

Example (Deletion)

Project(\(\text{not}, \varepsilon\)) = identity

\[
\begin{bmatrix}
\equiv & \mapsto & \equiv \\
\equiv & \mapsto & \equiv \\
\wedge & \mapsto & \wedge \\
\end{bmatrix}
\]

not move | run

\[
\not\varepsilon \land \text{move} \not\rightarrow \text{run}
\]
Lexical meanings

- Instantiating the lexicon using multiple resources
- Balancing high precision (WordNet and hand-built lexicons) with broad coverage (data gathered from the Web)
- Using Synthetic Logic to characterize this information and reason in terms of it
WordNet (roughly as in MacCartney’s work)

\[
\begin{align*}
\text{if } \text{WordNet}(\varphi, \psi) &= \text{antonym} & \text{then } \varphi \mid \psi \\
\text{else if } \text{WordNet}(\varphi, \psi) &\in \{ \text{entailment, (instance) hypernym, member|substance|part meronym} \} & \text{then } \varphi \sqsubseteq \psi \\
\text{else if } \text{WordNet}(\varphi, \psi) &\in \{ \text{cause, (instance) hyponym, member|substance|part holonym} \} & \text{then } \varphi \sqsupset \psi \\
\text{else if } \text{WordNet}(\varphi, \psi) &\in \{ \text{also see, similar to, synonym, derivationally related, pertainym} \} & \text{then } \varphi \equiv \psi \\
\text{else } \varphi \not\equiv \psi
\end{align*}
\]
### Overview of WordNet coverage

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>n</th>
<th>r</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>hypernyms</td>
<td>0</td>
<td>74389</td>
<td>0</td>
<td>13208</td>
</tr>
<tr>
<td>instance hypernyms</td>
<td>0</td>
<td>7730</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>hyponyms</td>
<td>0</td>
<td>16693</td>
<td>0</td>
<td>3315</td>
</tr>
<tr>
<td>instance hyponyms</td>
<td>0</td>
<td>945</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>member holonyms</td>
<td>0</td>
<td>12201</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>substance holonyms</td>
<td>0</td>
<td>551</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>part holonyms</td>
<td>0</td>
<td>7859</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>member meronyms</td>
<td>0</td>
<td>5553</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>substance meronyms</td>
<td>0</td>
<td>666</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>part meronyms</td>
<td>0</td>
<td>3699</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>attributes</td>
<td>620</td>
<td>320</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>entailments</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>390</td>
</tr>
<tr>
<td>causes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>218</td>
</tr>
<tr>
<td>also sees</td>
<td>1333</td>
<td>0</td>
<td>0</td>
<td>325</td>
</tr>
<tr>
<td>verb groups</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1498</td>
</tr>
<tr>
<td>similar tos</td>
<td>13205</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>antonyms</td>
<td>3872</td>
<td>2120</td>
<td>707</td>
<td>1069</td>
</tr>
<tr>
<td>derivationally related</td>
<td>10531</td>
<td>26758</td>
<td>1</td>
<td>13102</td>
</tr>
<tr>
<td>pertainyms</td>
<td>4665</td>
<td>0</td>
<td>3220</td>
<td>0</td>
</tr>
</tbody>
</table>
IMDB user-supplied reviews

**User Reviews**  (Review this title)

294 out of 454 people found the following review useful.

**WALL-E is one of the most cutest, lovable ch**

.Author: michael11391 from Augusta, Ga

Not only it's Pixar's best film of all-time but it's the best animated films in years and surprisingly, one of the mines. It's so beautiful, moving, hilarious & sad at the same time. WALL-E, it's certainly one of his best right behind Finding Nemo. WALL-E knocked off Ratatouille of the top spot in whatever sense with Ratatouille right behind and Finding Nemo will be remembered as one of the most lovable characters of all-time.

Was the above review useful to you?  [Yes]  [No]

See more (855 total) »
## IMDB user-supplied reviews

<table>
<thead>
<tr>
<th>Rating</th>
<th>Reviews</th>
<th>Words</th>
<th>Vocabulary</th>
<th>Mean words/review</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>124,587 (9%)</td>
<td>25,395,214</td>
<td>172,346</td>
<td>203.84</td>
</tr>
<tr>
<td>2</td>
<td>51,390 (4%)</td>
<td>11,755,132</td>
<td>119,245</td>
<td>228.74</td>
</tr>
<tr>
<td>3</td>
<td>58,051 (4%)</td>
<td>13,995,838</td>
<td>132,002</td>
<td>241.10</td>
</tr>
<tr>
<td>4</td>
<td>59,781 (4%)</td>
<td>14,963,866</td>
<td>138,355</td>
<td>250.31</td>
</tr>
<tr>
<td>5</td>
<td>80,487 (6%)</td>
<td>20,390,515</td>
<td>164,476</td>
<td>253.34</td>
</tr>
<tr>
<td>6</td>
<td>106,145 (8%)</td>
<td>27,420,036</td>
<td>194,195</td>
<td>258.33</td>
</tr>
<tr>
<td>7</td>
<td>157,005 (12%)</td>
<td>40,192,077</td>
<td>240,876</td>
<td>255.99</td>
</tr>
<tr>
<td>8</td>
<td>195,378 (14%)</td>
<td>48,723,444</td>
<td>267,901</td>
<td>249.38</td>
</tr>
<tr>
<td>9</td>
<td>170,531 (13%)</td>
<td>40,277,743</td>
<td>236,249</td>
<td>236.19</td>
</tr>
<tr>
<td>10</td>
<td>358,441 (26%)</td>
<td>73,948,447</td>
<td>330,784</td>
<td>206.31</td>
</tr>
<tr>
<td>Total</td>
<td>1,361,796</td>
<td>317,062,312</td>
<td>800,743</td>
<td>232.83</td>
</tr>
</tbody>
</table>
Counting and visualizing: IMDB

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Count</td>
<td>Total</td>
<td>Pr(w</td>
</tr>
<tr>
<td>1</td>
<td>17256</td>
<td>25395214</td>
<td>0.00068</td>
</tr>
<tr>
<td>2</td>
<td>5875</td>
<td>11755132</td>
<td>0.00050</td>
</tr>
<tr>
<td>3</td>
<td>4851</td>
<td>13995838</td>
<td>0.00035</td>
</tr>
<tr>
<td>4</td>
<td>3744</td>
<td>14963866</td>
<td>0.00025</td>
</tr>
<tr>
<td>5</td>
<td>3938</td>
<td>20390515</td>
<td>0.00019</td>
</tr>
<tr>
<td>6</td>
<td>3755</td>
<td>27420036</td>
<td>0.00014</td>
</tr>
<tr>
<td>7</td>
<td>3709</td>
<td>40192077</td>
<td>0.00009</td>
</tr>
<tr>
<td>8</td>
<td>3581</td>
<td>48723444</td>
<td>0.00007</td>
</tr>
<tr>
<td>9</td>
<td>2773</td>
<td>40277743</td>
<td>0.00007</td>
</tr>
<tr>
<td>10</td>
<td>4810</td>
<td>73948447</td>
<td>0.00007</td>
</tr>
</tbody>
</table>

Pr(terrible, a) = \text{logit}^{-1}(7.06 + -0.29 * \text{category})

(terrible,a) -- 54292 tokens

Coef. = -0.29 (p < 0.001)
Scalars

(Pr(w|c) values rescaled to Pr(c|w) to facilitate comparison.)
Duds

\( (\text{aardvark}, \text{n}) \) -- 20 tokens

Coef. = 0.03 (\( p = 0.686 \))

\( (\text{possible}, \text{a}) \) -- 52521 tokens

Coef. = -0.02 (\( p = 0.139 \))

\( (\text{governmental}, \text{a}) \) -- 443 tokens

Coef. = 0.05 (\( p = 0.014 \))

\( (\text{direct}, \text{v}) \) -- 80251 tokens

Coef. = 0 (\( p = 0.558 \))
Scalar semantics

**Definition (coef)**

\[ \text{coef}(\varphi)^{\text{def}} \text{ the coefficient estimate for Category} \]

**Definition (imdb}_x\rangle\]

\[ \text{imdb}_x(\varphi)^{\text{def}} = \begin{cases} \text{coef}(\varphi) & \text{if } p \leq x \\ \text{undefined} & \text{otherwise} \end{cases} \]

**Definition (Scalar relations)**

\[
\begin{align*}
&\text{if } \text{sign}(\text{imdb}_x(\varphi)) \neq \text{sign}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \mid \psi \\
&\text{else if } \text{imdb}_x(\varphi) \approx \text{imdb}_x(\psi) \quad \text{then } \varphi \equiv \psi \\
&\text{else if } \text{abs}(\text{imdb}_x(\varphi)) > \text{abs}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \sqsubset \psi \\
&\text{else if } \text{abs}(\text{imdb}_x(\varphi)) < \text{abs}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \sqsupset \psi
\end{align*}
\]
Lexical semantics

\[
\begin{align*}
\text{if } & \text{WordNet}(\varphi, \psi) = \text{antonym} \quad \text{then } \varphi \mid \psi \\
\text{else if } & \text{WordNet}(\varphi, \psi) \in \{ \text{entailment, (instance) hypernym, member|substance|part meronym} \} \quad \text{then } \varphi \sqsubset \psi \\
\text{else if } & \text{WordNet}(\varphi, \psi) \in \{ \text{cause, (instance) hyponym, member|substance|part holonym} \} \quad \text{then } \varphi \sqsupset \psi \\
\text{else if } & \text{WordNet}(\varphi, \psi) \in \{ \text{also see, similar to, synonym, derivationally related, pertainym} \} \quad \text{then } \varphi \equiv \psi \\
\text{else if } & \text{coef}(\varphi) \text{ and } \text{coef}(\psi) \text{ are defined} \quad \text{then} \\
\text{if } & \text{sign}(\text{imdb}_x(\varphi)) \neq \text{sign}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \mid \psi \\
\text{else if } & \text{imdb}_x(\varphi) \approx \text{imdb}_x(\psi) \quad \text{then } \varphi \equiv \psi \\
\text{else if } & \text{abs}(\text{imdb}_x(\varphi)) > \text{abs}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \sqsubset \psi \\
\text{else if } & \text{abs}(\text{imdb}_x(\varphi)) < \text{abs}(\text{imdb}_x(\psi)) \quad \text{then } \varphi \sqsupset \psi \\
\text{else } & \varphi \not\equiv \psi
\end{align*}
\]
Hand-built supplementary lexicon

- Our method doesn’t learn sensible meanings for most pairs of closed-class lexical items, so we specify those relations by hand.
- Our method doesn’t learn projectivity signatures, so we write those by hand (mostly taking them from MacCartney’s work).
Indirect question–answer pairs experiment

- A new corpus
- A new experiment, akin to MacCartney’s but with more intermingling of semantics and pragmatics
- A: Does the system work?
  B: It’s instructive.
**Answers and inferences**

Jerrold Katz, *Semantic Theory*: Meaning as relations between forms

- **What is meaning?** broken down:
  - What is synonymy?
  - What is antonymy?
  - What is superordination?
  - What is semantic ambiguity?
  - What is semantic truth (analyticity, metalinguistic truth, etc.)?
  - What is a possible answer to a question?
  - ...

**Example**

A: Was the vacation enjoyable?
B: It was memorable.
Collaborators


Marie-Catherine de Marneffe, Christopher D. Manning & Christopher Potts. 2010. Was it good? It was provocative. Learning the meaning of scalar adjectives. Proceedings of ACL 48.
## IQAP corpus

<table>
<thead>
<tr>
<th>Source</th>
<th>Dev. set</th>
<th>Eval. set</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNN show transcripts</td>
<td>40</td>
<td>17</td>
</tr>
<tr>
<td>From Julia Hirschberg’s (1985) thesis</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>The Switchboard Dialog Act Corpus</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>Yahoo Answers Corpus</td>
<td>58</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>150</strong></td>
<td><strong>65</strong></td>
</tr>
</tbody>
</table>

Available at compprag.christopherpotts.net/iqap.html
Annotations

**Indirect Answers to Yes/No Questions**

In the following dialogue, speaker A asks a simple Yes/No question, but speaker B answers with something more indirect and complicated:

A: `{Question}`
B: `{Answer}`

Which of the following best captures what speaker B meant here?

- B definitely meant to convey "Yes".
- B probably meant to convey "Yes".
- B definitely meant to convey "No".
- B probably meant to convey "No".

30 annotations per IQAP:

A: Have you mailed that letter yet?
B: I haven’t proofread it.

<table>
<thead>
<tr>
<th></th>
<th>definite yes</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>probable yes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>probable no</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>definite no</td>
<td>25</td>
</tr>
</tbody>
</table>

⇒

<table>
<thead>
<tr>
<th></th>
<th>yes</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
## Entailment cases

### The answer is stronger than the question radical:

<table>
<thead>
<tr>
<th>Question</th>
<th>Statement</th>
<th>Y def</th>
<th>Y prob</th>
<th>N def</th>
<th>N prob</th>
<th>N def</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did he do a good job?</td>
<td>He did a great job.</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is it a comedy?</td>
<td>I think it’s a black comedy.</td>
<td>14</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is Cadillac an American company?</td>
<td>It’s a division of General Motors.</td>
<td>7</td>
<td>22</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Have you finished the third grade?</td>
<td>I’ve finished the fourth.</td>
<td>20</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

### The answer is stronger than the negation of the question radical:

<table>
<thead>
<tr>
<th>Question</th>
<th>Statement</th>
<th>Y def</th>
<th>Y prob</th>
<th>N def</th>
<th>N prob</th>
<th>N def</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you think that’s a good idea?</td>
<td>It’s a terrible idea.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Is Santa an only child?</td>
<td>He has a brother named Fred.</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

### The question radical is stronger than the negation of the answer:

<table>
<thead>
<tr>
<th>Question</th>
<th>Statement</th>
<th>Y def</th>
<th>Y prob</th>
<th>N def</th>
<th>N prob</th>
<th>N def</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you mailed that letter yet?</td>
<td>I haven’t proofread it.</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Did you buy a house?</td>
<td>We haven’t gotten a mortgage yet.</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
## Implicature cases

### The question radical is stronger than the answer:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you mailed that letter yet?</td>
<td>I’ve typed it.</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Did you buy a house?</td>
<td>We haven’t gotten a mortgage yet.</td>
<td>0</td>
<td>2</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Did you ever get any information on it?</td>
<td>I sent off for stuff on it.</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Is it a sin to get drunk?</td>
<td>It is a sin to drink to excess.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you need this?</td>
<td>I want it.</td>
<td>2</td>
<td>15</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

### The question radical and the answer seem to be independent:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you know how to spell it?</td>
<td>It starts with a K.</td>
<td>0</td>
<td>6</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Have you made fondue in this pot yet?</td>
<td>Not chocolate fondue.</td>
<td>1</td>
<td>19</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Do you speak Ladino?</td>
<td>I speak Spanish.</td>
<td>1</td>
<td>9</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Do you have paste?</td>
<td>We have rubber cement.</td>
<td>0</td>
<td>8</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Was he cute?</td>
<td>He wasn’t stunning.</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Have you read the third chapter?</td>
<td>I read the fourth.</td>
<td>3</td>
<td>16</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>
Answerhood

Question \equiv Answer \Rightarrow 'Yes' \quad \text{(entailed)}

Question \sqsubseteq Answer \Rightarrow 'Yes' \quad \text{(entailed)}

Question \mid Answer \Rightarrow 'No' \quad \text{(entailed)}

Question \land Answer \Rightarrow 'No' \quad \text{(entailed)}

Question \leftarrow Answer \Rightarrow 'No' \quad \text{(implicated)}

Question \sqsubseteq Answer \Rightarrow 'No' \quad \text{(implicated)}

Question \neq Answer \Rightarrow 'No' \quad \text{(implicated)}
Examples

A: Is Kenya a continent?
B: It’s a country in eastern Africa.
   [Yes: 1, No: 29]

A: Was he cute?
B: He wasn’t stunning.
   [Yes: 4, No: 26]

A: Do you need this?
B: I want it.
   [Yes: 17, No: 13]
Experiment

Limited to the development set. Hand-alignment of ‘contrast’ subtrees. Experiment code: code.google.com/p/pynatlog/

<table>
<thead>
<tr>
<th></th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Yes’</td>
<td>0.63</td>
<td>0.73</td>
</tr>
<tr>
<td>‘No’</td>
<td>0.82</td>
<td>0.74</td>
</tr>
</tbody>
</table>

**Table:** Effectiveness results for our approach. Accuracy: 0.74.

<table>
<thead>
<tr>
<th></th>
<th>precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Yes’</td>
<td>0.71</td>
<td>0.44</td>
</tr>
<tr>
<td>‘No’</td>
<td>0.66</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**Table:** Deterministic approach, no semantic composition. Accuracy: 0.67.

<table>
<thead>
<tr>
<th></th>
<th>micro-averaged precision</th>
<th>recall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Table:** MaxEnt, no composition, 10 random train/test splits. Average accuracy: 0.77. (0.8 on training data.)
Discussion

1. WordNet is high precision but low coverage: just 22% of the examples rely on WordNet, but accuracy is around 88% for them.

2. The IMDB is lower precision, but high coverage: 43% of the examples rely on IMDB, and accuracy is around 71%.

3. 82/150 examples involve comparing just one word. For these, accuracy is 68%.

4. We get a performance boost from the fact that where our algorithm fails to predict a relationship, we infer independence, i.e., a ‘No’.

5. Implicature inferences correlate with higher variability in the annotations and more use of the ‘probable’ categories. We should find a way to bring this into the model.
Conclusion

Summary

1. Developed Propositional Synthetic Logic and proved completeness
2. Extended PSL with a theory of composition (inspired by MacCarntney’s NatLog procedure)
3. Instantiated a broad-coverage lexicon using multiple sources
4. Reported on an initial experiment using a new corpus of indirect question–answer pairs

Looking ahead

- Meta-logical results for the theory of composition
- Methods for automatic alignment
- Extend the corpus to include a wider range of examples
- Bring in contextual information