# Synthetic logic characterizations of meanings extracted from large corpora

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Stanford Linguistics

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# Overview

## Goals

- Establish robust connections between MacCartney's NatLog and linguistic theory
- Understand Natlog's logical underpinnings

## 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. Redefining the semantics using large corpora, focusing on
   - Sentiment
   - Veridicality

# Two conceptions of semantic theory

- Meaning as model-theoretic denotation
- Meaning as relations between forms

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"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."

# Two conceptions of semantic theory

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# 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?
  - . . .

# Bill MacCartney's natural logic

Bill MacCartney and Christopher D. Manning. 2007. Natural logic for textual inference. In Proceedings of the ACL-PASCAL Workshop on Textual Entailment and Paraphrasing.

Bill MacCartney and Christopher D. Manning. 2008. Modeling semantic containment and exclusion in natural language inference. Proceedings COLING 2008.

Bill MacCartney. 2009. *Natural Language Inference*. PhD thesis, Stanford University.

Bill MacCartney and Christopher D. Manning. 2009. An extended model of natural logic. In Proceedings of ACL.

# 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 . . . "

1. Rethinking NatLog as a logical system (a sequent calculus)

# Natural language ‘proofs’

$$\dfrac{\Gamma \vdash \text{John is short} \mid \text{John is tall} \qquad \dfrac{}{\Gamma \vdash \text{John is tall} \wedge \overline{\text{John is tall}}}\ \wedge_1}{\Gamma \vdash \text{John is short} \sqsubset \overline{\text{John is tall}}}\ \mid, \wedge$$

# Syntax

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

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

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

$$\varphi \equiv \psi, \quad \varphi \sqsubset \psi, \quad \varphi \sqsupset \psi,$$
$$\varphi \,^\wedge\, \psi, \quad \varphi \,|\, \psi, \quad \varphi \smile \psi$$

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

# Synthetic terms

## MacCartney Relations

1. *Equivalence* ($\equiv$);
2. *Strict Forward Entailment* ($\sqsubset$);
3. *Strict Reverse Entailment* ($\sqsupset$);
4. *Negation* ($^\wedge$);
5. *Alternation* ($|$);
6. *Cover* ($\smile$).

- John is a Frenchman | John is a Dutchman
- Every beagle runs $\sqsubset$ Some beagle moves
- John is tall $^\wedge$ $\overline{\text{John is tall}}$

# Models

## Definition (Synthetic Models)

Let a synthetic model $\mathbb{M}$ be the pair $\langle D, [\![\cdot]\!]\rangle$, where

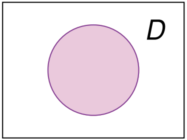
1. $D$ is a non-empty set
2. $[\![\cdot]\!]$ is an interpretation function taking proper terms $\varphi$ to their denotations in $D$ such that
   1. $[\![\overline{\varphi}]\!] = D - [\![\varphi]\!]$ such that
   2. $$[\![\varphi]\!] \neq \begin{cases} \varnothing & \text{or} \\ D & \end{cases}$$

# Semantics

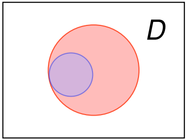
## Definition (Tarski-Style Truth Conditions)

$$
\begin{aligned}
\mathbb{M} \models \varphi \equiv \psi \quad &\Leftrightarrow \quad [\![\varphi]\!] = [\![\psi]\!] \\
\mathbb{M} \models \varphi \sqsubset \psi \quad &\Leftrightarrow \quad [\![\varphi]\!] \subset [\![\psi]\!] \\
\mathbb{M} \models \varphi \sqsupset \psi \quad &\Leftrightarrow \quad [\![\varphi]\!] \supset [\![\psi]\!] \\
\mathbb{M} \models \varphi \,^\wedge\, \psi \quad &\Leftrightarrow \quad ([\![\varphi]\!] \cap [\![\psi]\!] = \varnothing) \wedge ([\![\varphi]\!] \cup [\![\psi]\!] = D) \\
\mathbb{M} \models \varphi \,|\, \psi \quad &\Leftrightarrow \quad ([\![\varphi]\!] \cap [\![\psi]\!] = \varnothing) \wedge ([\![\varphi]\!] \cup [\![\psi]\!] \neq D) \\
\mathbb{M} \models \varphi \smile \psi \quad &\Leftrightarrow \quad ([\![\varphi]\!] \cap [\![\psi]\!] \neq \varnothing) \wedge ([\![\varphi]\!] \cup [\![\psi]\!] = D)
\end{aligned}
$$

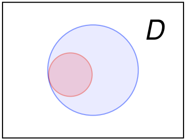
# Graphical representation of the MacCartney relations



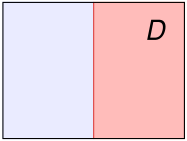

$\varphi \equiv \psi$
*equivalence*
couch ≡ sofa



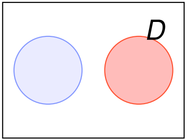

$\varphi \sqsubset \psi$
*forward entailment*
crow ⊏ bird



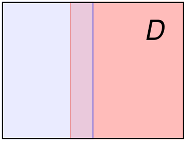

$\varphi \sqsupset \psi$
*reverse entailment*
bird ⊐ crow




$\varphi \;^\wedge\; \psi$
*negation*
man ^ non-man




$\varphi \mid \psi$
*alternation*
cat | dog




$\varphi \smile \psi$
*cover*
animal ‿ non-human

# Mutual Exclusivity of the MacCartney Relations

**Theorem 1**

If $\mathbb{M}$ is a synthetic model then

$$\mathbb{M} \models \varphi \mathcal{R} \psi \Rightarrow \mathbb{M} \not\models \varphi \mathcal{S} \psi$$

for $\mathcal{R} \neq \mathcal{S}$.

# 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

$$\mathbb{M} \models \Gamma \Rightarrow \mathbb{M} \models \varphi\mathcal{R}\psi$$

1. The synthetic proof calculus

# MacCartney rules

| $\mathcal{R}, \mathcal{S}$ | $\equiv$ | $\sqsubset$ | $\sqsupset$ | $\wedge$ | $\mid$ | $\smile$ |
|---|---|---|---|---|---|---|
| $\equiv$ | $\equiv$ | $\sqsubset$ | $\sqsupset$ | $\wedge$ | $\mid$ | $\smile$ |
| $\sqsubset$ | $\sqsubset$ | $\sqsubset$ | $\cdot$ | $\mid$ | $\mid$ | $\cdot$ |
| $\sqsupset$ | $\sqsupset$ | $\cdot$ | $\sqsupset$ | $\smile$ | $\cdot$ | $\smile$ |
| $\wedge$ | $\wedge$ | $\smile$ | $\mid$ | $\equiv$ | $\sqsupset$ | $\sqsubset$ |
| $\mid$ | $\mid$ | $\cdot$ | $\mid$ | $\sqsubset$ | $\cdot$ | $\sqsubset$ |
| $\smile$ | $\smile$ | $\smile$ | $\cdot$ | $\sqsupset$ | $\sqsupset$ | $\cdot$ |

## *M*-rules

$$\frac{\Gamma \vdash \varphi \mathcal{R} \psi \qquad \Gamma \vdash \psi \mathcal{S} \chi}{\Gamma \vdash \varphi \mathcal{T} \chi}\ \mathcal{R}, \mathcal{S}$$

# MacCartney Rules

| $\mathcal{R}, \mathcal{S}$ | $\equiv$ | $\sqsubset$ | $\sqsupset$ | $\wedge$ | $\mid$ | $\smile$ |
|---|---|---|---|---|---|---|
| $\equiv$ | $\equiv$ | $\sqsubset$ | $\sqsupset$ | $\wedge$ | $\mid$ | $\smile$ |
| $\sqsubset$ | $\sqsubset$ | $\sqsubset$ | $\cdot$ | $\mid$ | $\mid$ | $\cdot$ |
| $\sqsupset$ | $\sqsupset$ | $\cdot$ | $\sqsupset$ | $\smile$ | $\cdot$ | $\smile$ |
| $\wedge$ | $\wedge$ | $\smile$ | $\mid$ | $\equiv$ | $\sqsupset$ | $\sqsubset$ |
| $\mid$ | $\mid$ | $\cdot$ | $\mid$ | $\sqsubset$ | $\cdot$ | $\sqsubset$ |
| $\smile$ | $\smile$ | $\smile$ | $\cdot$ | $\sqsupset$ | $\sqsupset$ | $\cdot$ |

***M*-rules: $\sqsubset, \sqsubset$**

$$\frac{\Gamma \vdash \varphi \sqsubset \psi \qquad \Gamma \vdash \psi \sqsubset \chi}{\Gamma \vdash \varphi \sqsubset \chi}\ {\scriptstyle \sqsubset, \sqsubset}$$

# Additional proof rules

## *D*-rules

$$\frac{}{\Gamma \vdash \varphi \equiv \varphi}\equiv_1 \qquad \frac{\Gamma \vdash \varphi \equiv \psi}{\Gamma \vdash \psi \equiv \varphi}\equiv_2 \qquad \frac{}{\Gamma \vdash \varphi \wedge \overline{\varphi}}\wedge_1 \qquad \frac{\Gamma \vdash \varphi \wedge \psi}{\Gamma \vdash \psi \wedge \varphi}\wedge_2$$

$$\frac{\Gamma \vdash \varphi \sqsubset \psi}{\Gamma \vdash \psi \sqsubset \varphi}\sqsubset_1 \qquad \frac{\Gamma \vdash \varphi \sqsupset \psi}{\Gamma \vdash \psi \sqsubset \varphi}\sqsupset_1 \qquad \frac{\Gamma \vdash \varphi \mid \psi}{\Gamma \vdash \psi \mid \varphi}|_1 \qquad \frac{\Gamma \vdash \varphi \smile \psi}{\Gamma \vdash \psi \smile \varphi}\smile_1$$

## Reflexivity

$$\frac{\varphi \mathcal{R} \psi \in \Gamma}{\Gamma \vdash \varphi \mathcal{R} \psi}\text{Refl}$$

# Proofs involving complementation

## Theorem 2 (Complementation)

1. $\Gamma \vdash \varphi \equiv \psi \Leftrightarrow \Gamma \vdash \varphi \,^\wedge\, \overline{\psi}$
2. $\Gamma \vdash \varphi \,^\wedge\, \psi \Leftrightarrow \Gamma \vdash \varphi \equiv \overline{\psi}$
3. $\Gamma \vdash \varphi \equiv \overline{\overline{\varphi}}$ (*double negation*)
4. $\Gamma \vdash \varphi \sqsubset \psi \Leftrightarrow \Gamma \vdash \overline{\psi} \sqsubset \overline{\varphi}$ (*contraposition*)
5. $\Gamma \vdash \varphi \sqsupset \psi \Leftrightarrow \Gamma \vdash \overline{\varphi} \sqsubset \overline{\psi}$
6. $\Gamma \vdash \varphi \,|\, \psi \Leftrightarrow \Gamma \vdash \varphi \sqsubset \overline{\psi}$
7. $\Gamma \vdash \varphi \smile \psi \Leftrightarrow \Gamma \vdash \varphi \sqsupset \overline{\psi}$

# Natural language inference

**Theorem 2.6**

$\Gamma \vdash \varphi \mid \psi \Rightarrow \Gamma \vdash \varphi \sqsubset \overline{\psi}$

***M*-rule: |, ^**

$$\frac{\Gamma \vdash \varphi \mid \psi \qquad \Gamma \vdash \psi \wedge \chi}{\Gamma \vdash \varphi \sqsubset \chi} \mid, \wedge$$

**Proof.**

$$\frac{\Gamma \vdash \varphi \mid \psi \qquad \dfrac{}{\Gamma \vdash \psi \wedge \overline{\psi}}\wedge_1}{\Gamma \vdash \varphi \sqsubset \overline{\psi}} \mid, \wedge$$

□

# Natural language proofs revisited

**Theorem 2.6 (Natural Language Instantiation)**

$$\Gamma \vdash \text{John is short} \mid \text{John is tall} \Rightarrow$$
$$\Gamma \vdash \text{John is short} \sqsubset \overline{\text{John is a tall}}$$

$$\frac{\Gamma \vdash \text{John is short} \mid \text{John is tall} \qquad \dfrac{}{\Gamma \vdash \text{John is tall} \wedge \overline{\text{John is tall}}}\,\wedge_1}{\Gamma \vdash \text{John is short} \sqsubset \overline{\text{John is tall}}}\,\wedge, \wedge$$

# Final proof rule

**Definition (Explosion)**

$$\frac{\Gamma \vdash \varphi \mathcal{R} \psi \qquad \Gamma \vdash \varphi \mathcal{S} \psi \qquad \text{for } \mathcal{R} \neq \mathcal{S}}{\Gamma \vdash \varphi' \mathcal{T} \psi' \text{ for all synthetic terms } \varphi' \mathcal{T} \psi'} \text{Exp}$$

# Consistency

**Definition (Consistency)**

$\Gamma$ is consistent if, and only if $\Gamma \nvdash \varphi\mathcal{R}\psi$ for some synthetic term $\varphi\mathcal{R}\psi$.

# Inconsistency

## Theorem 3 (Inconsistent Set)

$\Gamma = \{\varphi \sqsubset \psi, \psi \sqsupset \vartheta, \varphi \smile \vartheta\}$ is inconsistent

## Proof.

$$\dfrac{\dfrac{\dfrac{\dfrac{\varphi \sqsubset \psi \in \Gamma}{\Gamma \vdash \varphi \sqsubset \psi}\,\text{Refl}}{\Gamma \vdash \psi \sqsupset \varphi}\,\sqsubset_1 \qquad \dfrac{\varphi \smile \vartheta \in \Gamma}{\Gamma \vdash \varphi \smile \vartheta}\,\text{Refl}}{\Gamma \vdash \psi \smile \vartheta}\,\sqsupset,\smile \qquad \dfrac{\psi \sqsupset \vartheta \in \Gamma}{\Gamma \vdash \psi \sqsupset \vartheta}\,\text{Refl}}{\text{☹}}\,\text{Exp}$$

□

# Meta-logical results

## Completeness

$$\Gamma \vdash \varphi \mathcal{R} \psi \Leftrightarrow \Gamma \models \varphi \mathcal{R} \psi$$

# Soundness proof sketch

**Soundness**

$$\Gamma \vdash \varphi \mathcal{R} \psi \Rightarrow \Gamma \models \varphi \mathcal{R} \psi$$

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

# Soundness proof sketch (cont.)

## Provability

$$\frac{\Gamma \vdash \varphi \sqsubset \psi \qquad \Gamma \vdash \psi \sqsubset \chi}{\Gamma \vdash \varphi \sqsubset \chi}\ {\sqsubset},{\sqsubset}$$

## Truth

$$\frac{\Gamma \models \varphi \sqsubset \psi \qquad \Gamma \models \psi \sqsubset \chi}{\Gamma \models \varphi \sqsubset \chi}\ {\sqsubset},{\sqsubset}$$

- Recall that the semantics of strict forward entailment is strict set-theoretic containment.
- Strict set-theoretic containment is transitive.

# Adequacy proof sketch

## Adequacy of the Proof Calculus

$$\Gamma \models \varphi \mathcal{R} \psi \Rightarrow \Gamma \vdash \varphi \mathcal{R} \psi \Leftrightarrow \underbrace{\Gamma \nvdash \varphi \mathcal{R} \psi \Rightarrow \Gamma \not\models \varphi \mathcal{R} \psi}_{\text{contraposition}}$$

1. Every consistent $\Gamma$ has a synthetic model:

$$\Gamma \vdash \varphi \mathcal{R} \psi \Leftrightarrow \mathbb{M} \models \varphi \mathcal{R} \psi$$

2. Given $\Gamma \nvdash \varphi \mathcal{R} \psi$, then:

$$\mathbb{M} \not\models \varphi \mathcal{R} \psi$$

3. By (1) and (2),

$$\mathbb{M} \models \Gamma \text{ but } \mathbb{M} \not\models \varphi \mathcal{R} \psi$$

# Model construction via representation

- Every consistent Γ induces an order on the set of proper terms Φ;
- That ordered set can be transformed into an orthoposet;
- Every orthoposet can be represented as a system of sets;
- The system of sets will function as a synthetic model.

Cristian Calude, Peter Hertling, and Karl Svozil. 1999. Embedding quantum universes in classical ones. *Foundations of Physics* 29: 349–379.

Lawrence S. Moss. 2007. Syllogistic logic with complements. Manuscript, Indiana University.

Nel Zierler and Michael Schlessinger. 1965. Boolean embeddings of orthomodular sets and quantum and logic. *Duke Math Journal* 32: 251–262.

# Algebraic machinery

## Orthposets

An *orthoposet* is a tuple $(P, \leq, 0, -)$ 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. $\overline{\overline{x}} = x$
5. If $x \leq y$ and $x \leq \overline{y}$, then $x = 0$.

# An orthoposet

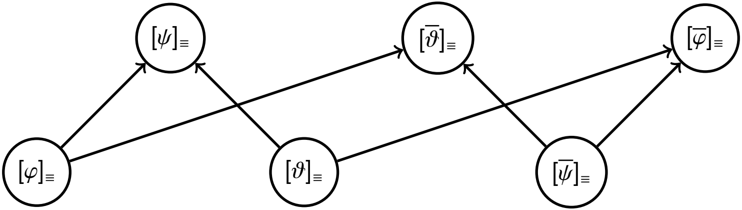
Consider the following premise set:

$$\Gamma = \{\varphi \sqsubset \psi, \vartheta \sqsubset \psi, \varphi \mid \vartheta\}$$

- Define the relation:

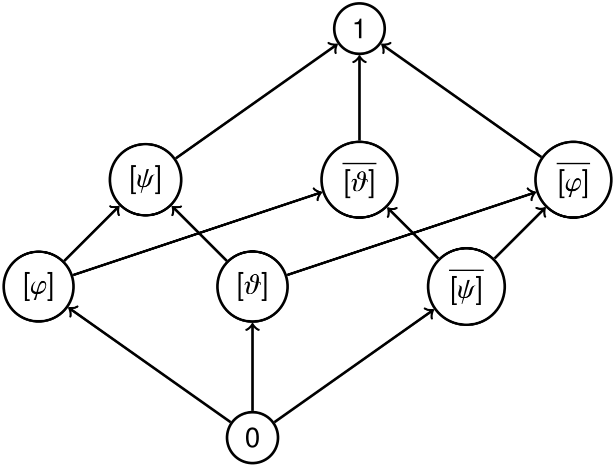
$$\varphi \leq_\Gamma \psi \Leftrightarrow \Gamma \vdash \varphi \equiv \psi \text{ or } \Gamma \vdash \varphi \sqsubset \psi$$

- $\leq_\Gamma$ induces an equivalence relation under $\equiv$
- Let the elements of the orthoposet be those equivalence classes and set $[\overline{\varphi}] = \overline{[\varphi]}$



# An orthoposet (cont.)

- Add elements 0, 1 to $\Phi$, setting $\overline{0} = 1$ and $0 < x < 1$:



# Forming an orthoposet from a premise set

For arbitrary, consistent $\Gamma$, we can form an orthoposet:

$$(\Phi^*, \leq_\Gamma, 0, -)$$

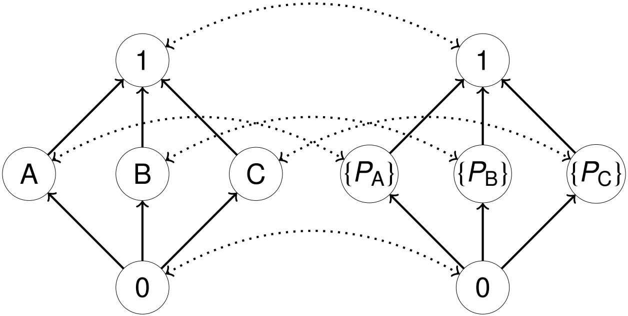
- $\Phi^*$ is a set of equivalence classes under $\equiv$;
- $\leq_\Gamma$ is the order defined above;
- 0 is a fresh element added not in the original language;
- $-$ is the complementation operator.

# Representation

## Theorem

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

$$f : P \to S$$



# Points (or a poor man's ultra-filter)

## Points

A *point* of a orthoposet is a subset $S \subseteq P$ with the following properties:

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*).

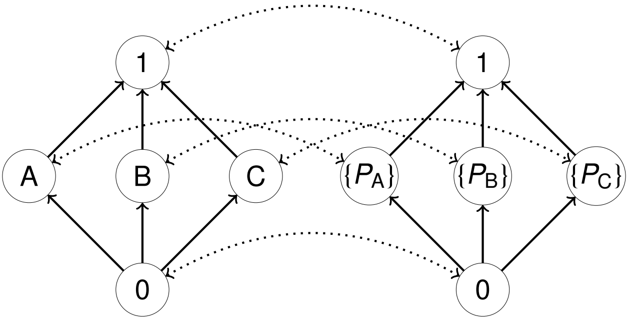
# Representation

## Theorem

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

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

by setting $f(x) = \{S \in \text{point}(P) \mid x \in S\}$



# Model construction

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 $[\![\cdot]\!]$ be defined as the *composition* of $f$ and $g$ $(f \cdot g)$.

## Lemma

$$\mathbb{M} \models \varphi \mathcal{R} \psi \Leftrightarrow \Gamma \vdash \varphi \mathcal{R} \psi$$

## Proof.

$$\begin{aligned} \Gamma \vdash \varphi \equiv \psi &\Leftrightarrow g(\varphi) = g(\psi) \\ &\Leftrightarrow f(g(\varphi)) = f(g(\psi)) \\ &\Leftrightarrow [\![\varphi]\!] = [\![\psi]\!] \\ &\Leftrightarrow \mathbb{M} \models \varphi \equiv \psi \end{aligned}$$

$$\begin{aligned} \Gamma \vdash \varphi \sqsubset \psi &\Leftrightarrow g(\varphi) <_\Gamma g(\psi) \\ &\Leftrightarrow f(g(\varphi)) \subset f(g(\psi)) \\ &\Leftrightarrow [\![\varphi]\!] \subset [\![\psi]\!] \\ &\Leftrightarrow \mathbb{M} \models \varphi \sqsubset \psi \end{aligned}$$

□

**Theorem 2.1**

$$\Gamma \vdash \varphi \equiv \psi \Leftrightarrow \Gamma \vdash \varphi \mathbin{^\wedge} \overline{\psi}$$

**Proof.**

$$\begin{aligned}\Gamma \vdash \varphi \mathbin{^\wedge} \psi &\Leftrightarrow \Gamma \vdash \varphi \equiv \overline{\psi} \\ &\Leftrightarrow [\![\varphi]\!] = [\![\overline{\psi}]\!] \\ &\Leftrightarrow ([\![\varphi]\!] \cap [\![\psi]\!]) \wedge ([\![\varphi]\!] \cup [\![\psi]\!] = D) \\ &\Leftrightarrow \mathbb{M} \models \varphi \mathbin{^\wedge} \psi\end{aligned}$$

□

3. Redefining the semantics using large corpora, focusing on
   - Sentiment
   - Veridicality

# Answers and inferences

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

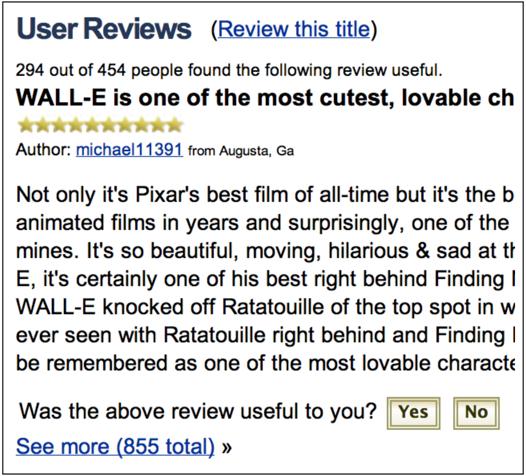
- What is meaning? broken down:
  - What is synonymy?
  - What is antonymy?
  - What is superordination?
  - What is semantic ambiguity?
  - What is semantic truth (analyticity, metalinguistic truth, etc.)?
  - What is a possible answer to a question?
  - …

**Example**

A: Was the vacation enjoyable?

B: It was memorable.

# IMDB user-supplied reviews

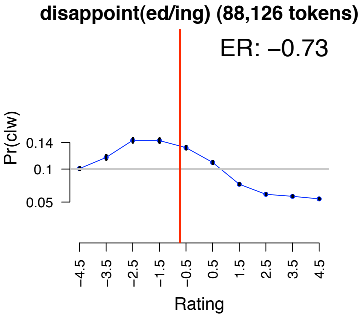


# IMDB user-supplied reviews

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

# Counting and visualizing: IMDB

| A<br>$R$ | B<br>Count | C<br>Total | D<br>$\Pr(w\|c)$ | E<br>$\Pr(c\|w)$ |
|---|---|---|---|---|
| −4.5 | 8,557 | 25,395,214 | 0.0003 | 0.10 |
| −3.5 | 4,627 | 11,755,132 | 0.0004 | 0.12 |
| −2.5 | 6,726 | 13,995,838 | 0.0005 | 0.14 |
| −1.5 | 7,171 | 14,963,866 | 0.0008 | 0.14 |
| −0.5 | 9,039 | 20,390,515 | 0.0004 | 0.13 |
| +0.5 | 10,101 | 27,420,036 | 0.0004 | 0.11 |
| +1.5 | 10,362 | 40,192,077 | 0.0003 | 0.08 |
| +2.5 | 10,064 | 48,723,444 | 0.0002 | 0.06 |
| +3.5 | 7,909 | 40,277,743 | 0.0002 | 0.06 |
| +4.5 | 13,570 | 73,948,447 | 0.0002 | 0.05 |




$$\Pr(w|c) \stackrel{def}{=} \text{Count}(w,c)/\text{Total}(c)$$

$$\text{ER}(w) \stackrel{def}{=} \sum_{c \in R} c \cdot \Pr(c)$$

$$\Pr(c|w) \stackrel{def}{=} \frac{\Pr(w|c)}{\sum_{x \in R} \Pr(w|x)}$$

# Scalars

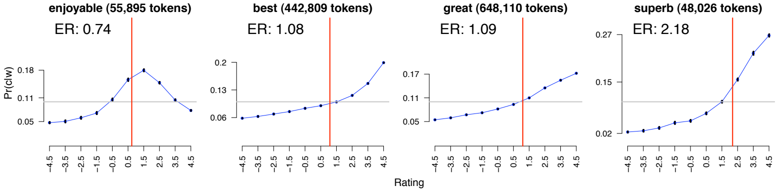



Figure: Positive

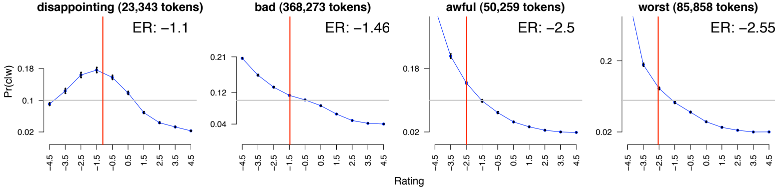



Figure: Negative

# Semantics

## Definition (Lexical meanings)

$$[\![\alpha]\!] = \begin{cases} [\mathrm{ER}(\alpha), +4.5] & \text{if} \quad \mathrm{ER}(\alpha) \geqslant 0 \\ [-4.5, \mathrm{ER}(\alpha)] & \text{if} \quad \mathrm{ER}(\alpha) < 0 \end{cases}$$

## Definition (Negation)

$$[\![\textbf{neg}\ \alpha]\!] = \begin{cases} (\mathrm{ER}(\alpha), +4.5] & \text{if} \quad \mathrm{ER}(\alpha) < 0 \\ [-4.5, \mathrm{ER}(\alpha)) & \text{if} \quad \mathrm{ER}(\alpha) \geqslant 0 \end{cases}$$

## Definition (Lexical relations)

$$\begin{array}{lll} \alpha \equiv \beta & \text{iff} & [\![\alpha]\!] \approx [\![\beta]\!] \\ \alpha \sqsubset \beta & \text{iff} & [\![\alpha]\!] \subset [\![\beta]\!] \\ \alpha \sqsupset \beta & \text{iff} & [\![\alpha]\!] \supset [\![\beta]\!] \\ \alpha \mid \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] = \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] \neq [-4.5, +4.5] \\ \alpha \mathbin{^\wedge} \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] = \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] = [-4.5, +4.5] \\ \alpha \smile \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] \neq \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] = [-4.5, +4.5] \end{array}$$

# Application: Indirect question–answer pairs

Marie-Catherine de Marneffe

Scott Grimm

Chris Manning

Marie-Catherine de Marneffe, Scott Grimm & Christopher Potts. 2009. Not a simple yes or no: Uncertainty in indirect answers. Proceedings of SIGDIAL 10.

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

Data from CNN interview shows. Automatic and manual techniques to pull out at least a sample of the dialogues in which

- the question contains a scalar predicate
- the answer contains a scalar predicate or a numerical term

| Modification in answer | Count |
|---|---|
| Other adjective | 125 |
| Adverb - same adjective | 55 |
| Negation - same adjective | 21 |
| Omitted adjective | 4 |
| Total | 205 |

# IQAP corpus

Data from CNN interview shows. Automatic and manual techniques to pull out at least a sample of the dialogues in which

- the question contains a scalar predicate
- the answer contains a scalar predicate or a numerical term

| Modification in answer | Count |
|---|---|
| Other adjective | 125 |
| Adverb - same adjective | 55 |
| Negation - same adjective | 21 |
| Omitted adjective | 4 |
| Total | 205 |

A: Is it good?

B: It's noteworthy.

# IQAP corpus

Data from CNN interview shows. Automatic and manual techniques to pull out at least a sample of the dialogues in which

- the question contains a scalar predicate
- the answer contains a scalar predicate or a numerical term

| Modification in answer | Count |
| --- | --- |
| Other adjective | 125 |
| Adverb - same adjective | 55 |
| Negation - same adjective | 21 |
| Omitted adjective | 4 |
| Total | 205 |

A: Is it good?

B: It's impressively good.

# IQAP corpus

Data from CNN interview shows. Automatic and manual techniques to pull out at least a sample of the dialogues in which

- the question contains a scalar predicate
- the answer contains a scalar predicate or a numerical term

| Modification in answer | Count |
|---|---|
| Other adjective | 125 |
| Adverb - same adjective | 55 |
| Negation - same adjective | 21 |
| Omitted adjective | 4 |
| Total | 205 |

A: Is it good?

B: It’s not good.

# IQAP corpus

Data from CNN interview shows. Automatic and manual techniques to pull out at least a sample of the dialogues in which

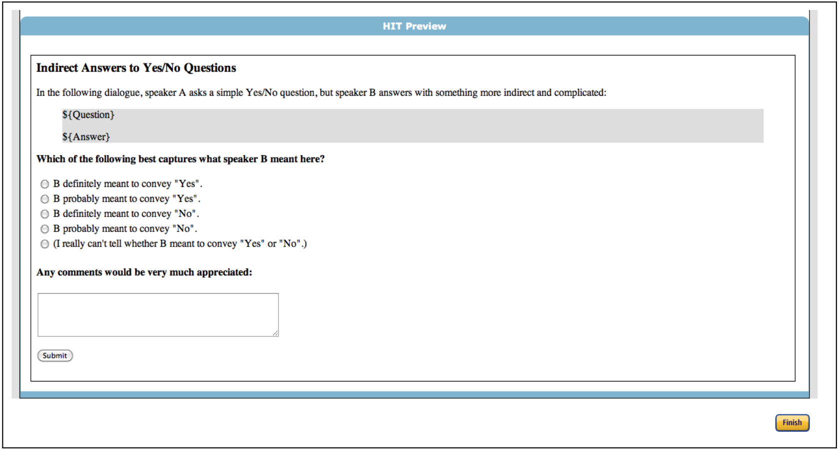
- the question contains a scalar predicate
- the answer contains a scalar predicate or a numerical term

| Modification in answer | Count |
|---|---|
| Other adjective | 125 |
| Adverb - same adjective | 55 |
| Negation - same adjective | 21 |
| Omitted adjective | 4 |
| Total | 205 |

A: Is that a huge gap in the system?

B: It is a gap.

# Annotations



HIT Preview

**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:

${Question}

${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".
- (I really can't tell whether B meant to convey "Yes" or "No".)

**Any comments would be very much appreciated:**

Submit

Finish

# Annotations

30 annotators per IQAP
120 annotators
Median items done: 28
Mean items done: 56.5

Figure: The faces of Mechanical Turk.

A: Was a it a good ad?

B: It was memorable.

| | |
|---|---|
| definite yes | 12 |
| probable yes | 15 |
| uncertain | 3 |
| probably no | 0 |
| definite no | 0 |

⇒

| | |
|---|---|
| yes | 15 |
| uncertain | 3 |
| no | 0 |

# Procedure

## Definition (de Marneffe, Manning, Potts)

Let $D$ be a dialogue consisting of (i) a polar question whose main predication is a based on scalar predicate $P_Q$ and (ii) an indirect answer whose main predication is based on scalar predicate $P_A$.

1. if $P_A$ or $P_Q$ is missing from our data, infer 'Uncertain';
2. else if ER($P_Q$) and ER($P_A$) have different signs, infer 'No';
3. else if abs(ER($P_Q$)) $\leqslant$ abs(ER($P_A$)), infer 'Yes';
4. else infer 'No'.
5. In the presence of downward monotone expressions, map 'Yes' to 'No', 'No' to 'Yes', and 'Uncertain' to 'Uncertain'.

# Procedure

## Definition (de Marneffe, Manning, Potts)

Let $D$ be a dialogue consisting of (i) a polar question whose main predication is a based on scalar predicate $P_Q$ and (ii) an indirect answer whose main predication is based on scalar predicate $P_A$.

1. if $P_A$ or $P_Q$ is missing from our data, infer ‘Uncertain’;
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4. else infer ‘No’.
5. In the presence of downward monotone expressions, map ‘Yes’ to ‘No’, ‘No’ to ‘Yes’, and ‘Uncertain’ to ‘Uncertain’.

## Definition (Synthetic logic)

$$P_Q \; R \; P_A \begin{cases} \text{Yes} & \text{if } R \in \{\equiv, \sqsupset\} \\ \text{No} & \text{if } R \in \{\sqsubset, |, {}^\wedge\} \\ \text{Uncertain} & \text{otherwise} \end{cases}$$

# Examples

## Definition (Synthetic logic)

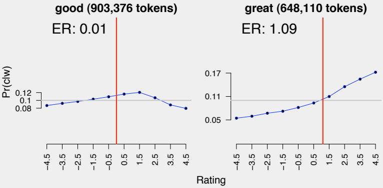
$$P_Q \; R \; P_A \begin{cases} \text{Yes} & \text{if } R \in \{\equiv, \sqsupset\} \\ \text{No} & \text{if } R \in \{\sqsubset, |, ^\wedge\} \\ \text{Uncertain} & \text{otherwise} \end{cases}$$

## Larry King Live

A: Was a it a good ad?

B: It was a great ad.

*good* ⊐ *great* ('yes')



# Examples

## Definition (Synthetic logic)

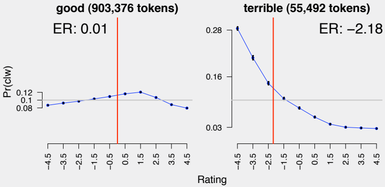
$$P_Q \; R \; P_A \begin{cases} \text{Yes} & \text{if } R \in \{\equiv, \sqsupset\} \\ \text{No} & \text{if } R \in \{\sqsubset, |, ^\wedge\} \\ \text{Uncertain} & \text{otherwise} \end{cases}$$

## Lou Dobbs Tonight

A: Do you think that's a good idea?

B: It's a terrible idea.

*good* | *terrible* ('no')



# Examples

## Definition (Synthetic logic)

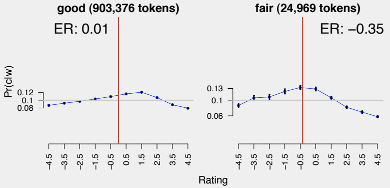
$$P_Q \; R \; P_A \begin{cases} \text{Yes} & \text{if } R \in \{\equiv, \sqsupset\} \\ \text{No} & \text{if } R \in \{\sqsubset, |, \wedge\} \\ \text{Uncertain} & \text{otherwise} \end{cases}$$

## Late Edition

A: Does he have a good chance of making it?

B: The chances are fair, I'd say.

*good* | *fair* ('no')



# Examples

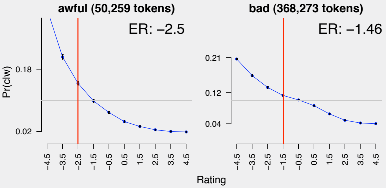
## Definition (Synthetic logic)

$$P_Q \; R \; P_A \begin{cases} \text{Yes} & \text{if } R \in \{\equiv, \sqsupset\} \\ \text{No} & \text{if } R \in \{\sqsubset, |, ^\wedge\} \\ \text{Uncertain} & \text{otherwise} \end{cases}$$

## Negation

A: Was the movie awful?

B: The movie was not bad.




$$\frac{\text{awful} \sqsubset \text{bad} \qquad \text{bad} \,|\, \overline{\text{bad}}}{\text{awful} \sqsubset \overline{\text{bad}}} \; \sqsubset, |$$

# Results

| Modification in answer | Count | Precision | Recall |
| --- | --- | --- | --- |
| Other adjective | 125 | 60 | 60 |
| Adverb - same adjective | 55 | 95 | 95 |
| Negation - same adjective | 21 | 100 | 100 |
| Omitted adjective | 4 | 100 | 100 |

Table: Summary of precision and recall (%) by type.

| Response | Precision | Recall | F1 |
| --- | --- | --- | --- |
| Yes | 87 | 76 | 81 |
| No | 57 | 71 | 63 |

Table: Precision, recall, and F1 (%) per response category. There were just two examples whose dominant response from the Turkers was 'Uncertain', so we have left that category out of the results.

3. Redefining the semantics using large corpora, focusing on
   - Sentiment
   - Veridicality

# FactBank

Freely available from the LDC. Extends TimeBank 1.2 and a fragment of the AQUAINT TimeML Corpus.

- Veridicality annotations on events relative to each participant involved in the discourse
- 208 documents from newswire and broadcast news reports
- 9,472 event descriptions

Saurí, Roser. 2008. A Factuality Profiler for Eventualities in Text. PhD thesis, Brandeis.

Saurí, Roser and James Pustejovsky. 2009. FactBank: A corpus annotated with event factuality. Language Resources and Evaluation 43.

# FactBank

**Example**

Some experts now predict Anheuser's entry into the fray **means** near-term earnings trouble for all the industry players.

1. Veridicality(means, experts) = PR+
2. Veridicality(means, author) = Uu

**Example**

Recently, analysts have said Sun also is **vulnerable** to competition from International Business Machines Corp., which plans to introduce a group of workstations early next year, and Next Inc.

1. Veridicality(vulnerable, analysts) = CT+
2. Veridicality(vulnerable, author) = Uu

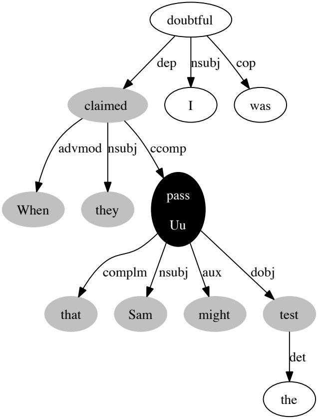
# FactBank

| Value | Definition | Count |
|---|---|---|
| CT+ | According to the source, it is certainly the case that X | 7,749 (57.6%) |
| PR+ | According to the source, it is probably the case that X | 363 (2.7%) |
| PS+ | According to the source, it is possibly the case that X | 226 (1.7%) |
| CT- | According to the source, it is certainly not the case that X | 433 (3.2%) |
| PR- | According to the source it is probably not the case that X | 56 (0.4%) |
| PS- | According to the source it is possibly not the case that X | 14 (0.1%) |
| CTu | The source knows whether it is the case that X or that not X | 12 (0.1%) |
| Uu | The source does not know what the factual status of the event is, or does not commit to it | 4,607 (34.2%) |
| | | 13,460 |

Table: FactBank annotation scheme.

# Denotations from the corpus

How do lexical items contribute to veridicality assessment?




When they claimed that Sam might pass the test, I was doubtful.

$\text{Count}(w, t) \stackrel{\textit{def}}{=}$ the number of times word $w$ appears as clausemate to an event marked with tag $t$ *from a non-author perspective*.

$$P(w|t) \stackrel{\textit{def}}{=} \frac{\text{Count}(w, t)}{\sum_x P(x|t)}$$

$$P(t|w) \stackrel{\textit{def}}{=} \frac{P(w|T)}{\sum_{t \in T} P(w|t)}$$

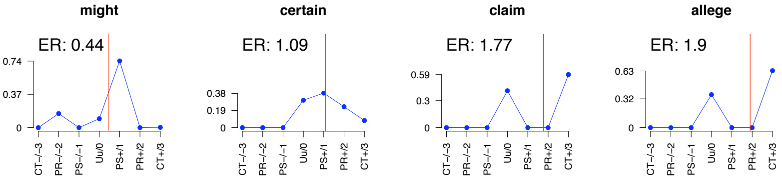
# Expected veridicality

## Definition (Tag structure)

$$T = \left\{ \begin{array}{ccccccc} & & \overset{+1}{\text{PS+}} & \Rightarrow & \overset{+2}{\text{PR+}} & \Rightarrow & \overset{+3}{\text{CT+}} \\ \underset{0}{\text{Uu}} & \begin{array}{c}\nearrow\\ \searrow\end{array} & & & & & \\ & & \underset{-1}{\text{PS}-} & \Rightarrow & \underset{-2}{\text{PR}-} & \Rightarrow & \underset{-3}{\text{CT}-} \end{array} \right\}$$

## Definition (Expected veridicality)

$$\text{EV}(w) \overset{def}{=} \sum_{t \in T} t \cdot \Pr(t|w)$$



# Semantics (same as for the sentiment corpus)

## Definition (Lexical meanings)

$$[\![\alpha]\!] = \begin{cases} [\mathrm{EV}(\alpha), +3] & \text{if } \mathrm{EV}(\alpha) \geqslant 0 \\ [-3, \mathrm{EV}(\alpha)] & \text{if } \mathrm{EV}(\alpha) < 0 \end{cases}$$

## Definition (Negation)

$$[\![\textbf{neg}\ \alpha]\!] = \begin{cases} (\mathrm{EV}(\alpha), +3] & \text{if } \mathrm{EV}(\alpha) < 0 \\ [-3, \mathrm{EV}(\alpha)) & \text{if } \mathrm{EV}(\alpha) \geqslant 0 \end{cases}$$

## Definition (Lexical relations)

$$\begin{array}{lll} \alpha \equiv \beta & \text{iff} & [\![\alpha]\!] \approx [\![\beta]\!] \\ \alpha \sqsubset \beta & \text{iff} & [\![\alpha]\!] \subset [\![\beta]\!] \\ \alpha \sqsupset \beta & \text{iff} & [\![\alpha]\!] \supset [\![\beta]\!] \\ \alpha \mid \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] = \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] \neq [-4.5, +4.5] \\ \alpha \ {}^\wedge\ \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] = \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] = [-4.5, +4.5] \\ \alpha \smile \beta & \text{iff} & [\![\alpha]\!] \cap [\![\beta]\!] \neq \emptyset \quad \& \quad [\![\alpha]\!] \cup [\![\beta]\!] = [-4.5, +4.5] \end{array}$$

# Examples

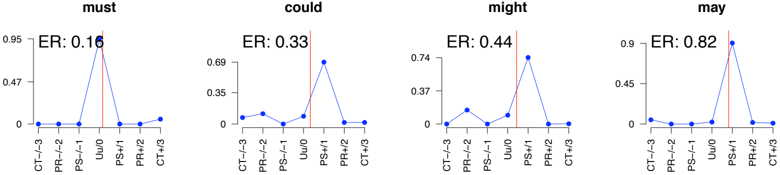



Figure: Modals ordered by ⊐. *must* anomalous?

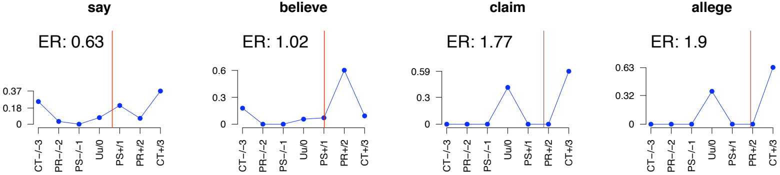



Figure: Attitude predicates ordered by ⊐.

# Examples

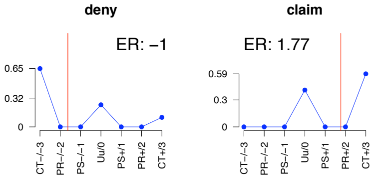



Figure: Attitude predicates in |.

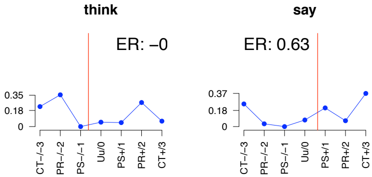



Figure: Attitude predicates in |.

# Looking ahead: Semantic composition

- We concentrated on the lexicon throughout.
- MacCartney developed a full theory of semantic composition for natural language parsetrees.
- We believe that the following rule is the right one for bringing composition and projectivity into our approach:

$$\frac{\Gamma \vdash \varphi(x) R \psi(y) \qquad \Gamma \vdash xSy \qquad \Gamma \vdash aSb}{\Gamma \vdash \varphi(a) R \psi(b)} \; S_2$$

- Moving between types domains in this way poses worthwhile new logical and empirical challenges, especially when the semantic grounding is non-traditional.