Combining Formal and Distributional Models of Temporal and Intensional Semantics

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Inference with Temporal Semantics

Mike is visiting Baltimore
⇒ Mike has arrived in Baltimore
⇒ Mike will leave Baltimore
⇏ Mike has left Baltimore
Inference with Temporal Semantics

Mike is visiting Baltimore
⇒ Mike has arrived in Baltimore
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Temporal information can be expressed by both function words and content words
Proposal

- Hand built lexicon for function words
- *Symbolic* content word interpretations from distributional semantics
- CCG for compositional semantics
Combining Distributional and Logical Semantics

1. visit

2. arrive in reach

3. leave exit depart
Combining Distributional and Logical Semantics

\[
\begin{align*}
\text{visit} & \vdash \lambda x \lambda y \lambda e . \text{rel1}(x, y, e) \\
\text{arrive in} & \vdash \lambda x \lambda y \lambda e . \text{rel2}(x, y, e) \\
\text{reach} & \vdash \lambda x \lambda y \lambda e . \text{rel2}(x, y, e) \\
\text{leave} & \vdash \lambda x \lambda y \lambda e . \text{rel3}(x, y, e)
\end{align*}
\]
Combining Distributional and Logical Semantics

Mike reached Baltimore

(S\NP)/NP

\(\lambda y \lambda x \lambda e \cdot \text{rel2}(x, y, e)\)

Baltimore

NP

\(\lambda e \cdot \text{rel2}(\text{mike}, \text{baltimore}, e)\)
Combining Distributional and Logical Semantics

Mike arrived in Baltimore

\[ \text{rel2}(mike, baltimore, e) \]

\[ \Rightarrow \]

Mike reached Baltimore

\[ \text{rel2}(mike, baltimore, e) \]
Combining Distributional and Logical Semantics

Mike
NP
mike

(S\NP)/(S\NP)

λpλxλe. ¬p(x,e)

reach
(S\NP)/NP

λyλxλe . rel2(x, y, e)

Baltimore
NP
baltimore

S\NP

λxλe . rel2(x, baltimore)

S\NP

λxλe . ¬rel2(x, baltimore, e)

S

λe . ¬rel2(mike, baltimore, e)
Combining Distributional and Logical Semantics

Mike didn’t arrive in Baltimore

\neg \text{rel2}(mike, baltimore)

Mike didn’t reach Baltimore

\neg \text{rel2}(mike, baltimore)
Combining Distributional and Logical Semantics

Simple clustering is not enough

- Models words as either synonyms or unrelated

- Many lexical semantic relations: temporal, causal, hypernyms, etc.
Temporal Semantics

1. visit

2. arrive in
   reach

3. leave
   exit
   depart
Learn graph structures capturing relations between events
Similar to Scaria et al. (2013)
Temporal Semantics

arrive in \( \vdash \lambda x \lambda y \lambda e . \rel2(x,y,e) \)
reach \( \vdash \lambda x \lambda y \lambda e . \rel2(x,y,e) \)
leave \( \vdash \lambda x \lambda y \lambda e . \rel3(x,y,e) \)
Temporal Semantics

\[ \vdash \lambda x \lambda y \lambda e . \text{rel1}(x,y,e) \land \exists e' [\text{rel2}(x,y,e') \land \text{before}(e,e')] \land \exists e'' [\text{rel3}(x,y,e'') \land \text{after}(e,e'')] \]
Hand-build lexical entries for auxiliary verbs, using same temporal relations:

- **has**: \( \vdash \lambda p \lambda x \lambda e . \text{before}(r, e) \land p(x, e) \)
- **will**: \( \vdash \lambda p \lambda x \lambda e . \text{after}(r, e) \land p(x, e) \)
- **is**: \( \vdash \lambda p \lambda x \lambda e . \text{during}(r, e) \land p(x, e) \)
- **used**: \( \vdash \lambda p \lambda x \lambda e . \text{before}(r, e) \land p(x, e) \land \neg \exists e'[\text{during}(r, e) \land p(x, e')] \)
Temporal Semantics

Mike (S\NP)/(S\NP) will (S\NP)/NP leave (S\NP)/NP Baltimore NP

mike \(\lambda x \lambda y \lambda e \cdot p(x,e) \land \text{after}(r,e)\)

λyλxλe . rel3(x,y,e)

λxλe . rel3(x, baltimore)

λxλe . rel3(x, baltimore, e) \land \text{after}(r,e)

λe . rel3(mike, baltimore, e) \land \text{after}(r,e)
Mike is visiting Baltimore

\( \exists e[\text{rel1}(mike, \text{baltimore}, e) \land \text{during}(r,e)] \land \exists e'[\text{rel2}(mike, \text{baltimore}, e') \land \text{before}(e,e')] \land \exists e''[\text{rel3}(mike, \text{baltimore}, e) \land \text{after}(e'',e)] \)
Mike is visiting Baltimore

\[\exists e[rel1(mike, baltimore, e) \land during(r,e)]\]
\[\land \exists e'[rel2(mike, baltimore, e') \land before(e,e')] \land \exists e''[rel3(mike, baltimore, e) \land after(e'',e)]\]

\[\Rightarrow\]

Mike will leave Baltimore

\[\exists e[rel3(mike, baltimore, e) \land after(r,e)]\]
Intensional Semantics

Mike set out for Baltimore

⇒ Mike tried to reach Baltimore
⇒ Mike headed to Baltimore
⇔ Mike reached Baltimore
Intensional Semantics

Mike failed to reach Baltimore

⇒ Mike tried to reach Baltimore
⇒ Mike headed to Baltimore
⇒ Mike didn’t reach Baltimore
Temporal Semantics

- initiated by
- terminated by
- visit
- arrive in
- reach
- leave
- exit
- depart

Graph:
- Node 1: "visit"
- Node 2: "arrive in reach"
- Node 3: "leave exit depart"
Intensional Semantics

4 set out for head to

2 arrive in reach

1 initiated by

visit

3 terminated by

leave exit depart
\[ \text{set out for } \vdash \lambda x \lambda y \lambda e. \ rel_4(x, y, e) \land \Diamond \exists e'[\ rel_2(x, y, e') \land \text{goal}(e, e')] \]
Intensional Semantics

\textbf{try} \vdash \lambda p \lambda x \lambda e. \exists e'[\text{goal}(e, e') \land \diamond p(x, e')]
Intensional Semantics

**try** \( \vdash \lambda p \lambda x \lambda e. \exists e'[\text{goal}(e, e') \land \diamond p(x, e')] \)

**fail** \( \vdash \lambda p \lambda x \lambda e. \exists e'[\text{goal}(e, e') \land \diamond p(x, e')] \land \neg \exists e''[\text{goal}(e, e'') \land p(x, e'')] \)
Intensional Semantics

Mike set out for Baltimore

\[\exists e[rel^4(x, y, e) \land \Box \exists e'[rel^2(mike, baltimore, e') \land goal(e, e')]\]

⇒ Mike tried to reach Baltimore

\[\Diamond \exists e'[rel^2(mike, baltimore, e') \land goal(e, e')]\]
Conclusions

- Many inferences rely on complex interaction of formal and lexical semantics.
- Recent work gives us the tools to incorporate more linguistics into computational semantics.