Events and Relative Clauses

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Outline

Theme

(Polynomial) Event Semantics

Obtaining entailments by ‘pure logic’

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(Polynomial) Event Semantics

Obtaining entailments by ‘pure logic’

FraCaS

Textual inference problem set

Problem

There was an Italian who became the world's greatest tenor.

FraCaS 001

Dearth of analyses of relative clauses in Event Semantics

More Interesting Example

(1) Every European has the right to live in Europe.

(2) Every European is a person.

(3) Every person who has the right to live in Europe can travel freely within Europe.

(4) Every European can travel freely within Europe.

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To remind

The goal is to determine if the last sentence in a problem (sentence (4) in our case) is entailed from the others

Even More Interesting Example

There was one auditor who signed all the reports.

There is a car that John and Bill own.

And More. . .

(5) Smith wrote to a representative every week.

(6) There is a representative that Smith wrote to every week.

FraCaS 308

Answer: undefined

And More. . .

(5) Smith wrote to a representative every week.

(6) There is a representative that Smith wrote to every week.

FraCaS 308

Answer: undefined
The only example of scoping ambiguity in FraCaS

And More. . .

two students who skipped three classes

every student who skipped no classes

a student who didn't skip all classes

Not in FraCas, but very common

Outline

Sentences and Denotations

John has the right to live in Europe

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE} : \text{event set}$$
$$[\![\text{John}]\!] = \mathsf{john} : \text{individual}$$

Sentences and Denotations

John has the right to live in Europe

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE} : \text{event set}$$
$$[\![\text{John}]\!] = \mathsf{john} : \text{individual}$$

$$[\![[_{\text{NP}-\text{SUBJ}}\ \text{John}]]\!] = \mathsf{subj}'/\,\mathsf{john}$$
$$= \{e|(e, \mathsf{john}) \in \mathsf{subj}'\} = \{e|ag(e) = \mathsf{john}\}$$

Sentences and Denotations

John has the right to live in Europe

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE} : \text{event set}$$
$$[\![\text{John}]\!] = \mathsf{john} : \text{individual}$$

$$[\![[_{\text{NP}-\text{SUBJ}}\ \text{John}]]\!] = \mathsf{subj}'/\,\mathsf{john}$$
$$= \{e|(e, \mathsf{john}) \in \mathsf{subj}'\} = \{e|ag(e) = \mathsf{john}\}$$

$$[\![\text{John has the right to live in Europe}]\!] = \mathsf{subj}'/\,\mathsf{john} \cap \mathsf{RTLE}$$

Sentences and Denotations

John has the right to live in Europe

$$[\![\text{John has the right to live in Europe}]\!] = \mathsf{subj}'/\,\mathsf{john} \cap \mathsf{RTLE}$$

Sentence denotation

- Events *witnessing* the truth of the sentence
- Formula: Query 'the world record' for such events

Coordination

John and Bill have the right to live in Europe

$[\![\text{John and Bill}]\!] =$

Coordination

John and Bill have the right to live in Europe

$[\![\text{John and Bill}]\!] = \mathsf{john} \otimes \mathsf{bill} : \text{polyindividual}$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill}]\!] = \mathsf{john} \otimes \mathsf{bill} : \text{polyindividual}$$
$$[\![[_{\text{NP}-\text{SUBJ}}\ \text{John and Bill}]]\!] = \mathsf{subj}'/\,\mathsf{john} \otimes \mathsf{bill} : \text{polyconcept}$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill}]\!] = \mathsf{john} \otimes \mathsf{bill} : \text{polyindividual}$$
$$[\![[_{\text{NP}-\text{SUBJ}}\ \text{John and Bill}]]\!] = \mathsf{subj}'/\,\mathsf{john} \otimes \mathsf{bill} : \text{polyconcept}$$
$$[\![\text{has the right to live in Europe}]\!] =$$
$$\mathsf{RTLE} : \text{event set}, \mathit{isa}\ \text{polyconcept}$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill}]\!] = \mathsf{john} \otimes \mathsf{bill} : \text{polyindividual}$$
$$[\![[_{\text{NP}-\text{SUBJ}}\ \text{John and Bill}]]\!] = \mathsf{subj}'/\,\mathsf{john} \otimes \mathsf{bill} : \text{polyconcept}$$
$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE} : \text{event set}, \mathit{isa}\ \text{polyconcept}$$

$$[\![\text{John and Bill have the right to live in Europe}]\!] = \mathsf{subj}'/\,(\mathsf{john} \otimes \mathsf{bill}) \sqcap \mathsf{RTLE}$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill have the right to live in Europe}]\!]$$
$$= \mathsf{subj}'/\,(\mathsf{john} \otimes \mathsf{bill}) \;\sqcap\; \mathsf{RTLE}$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill have the right to live in Europe}]\!]$$
$$= \mathsf{subj}'/\,(\mathsf{john} \otimes \mathsf{bill}) \;\sqcap\; \mathsf{RTLE}$$
$$= ((\mathsf{subj}'/\,\mathsf{john}) \otimes (\mathsf{subj}'/\,\mathsf{bill})) \;\sqcap\; \mathsf{RTLE}$$

Coordination

John and Bill have the right to live in Europe

$$
\begin{aligned}
&[\![\text{John and Bill have the right to live in Europe}]\!] \\
&= \mathsf{subj}'/\,(\mathsf{john} \otimes \mathsf{bill}) \;\sqcap\; \mathsf{RTLE} \\
&= ((\mathsf{subj}'/\,\mathsf{john}) \otimes (\mathsf{subj}'/\,\mathsf{bill})) \;\sqcap\; \mathsf{RTLE} \\
&= (\mathsf{subj}'/\,\mathsf{john} \;\cap\; \mathsf{RTLE}) \otimes (\mathsf{subj}'/\,\mathsf{bill} \;\cap\; \mathsf{RTLE})
\end{aligned}
$$

Coordination

John and Bill have the right to live in Europe

$$
\begin{aligned}
&[\![\text{John and Bill have the right to live in Europe}]\!] \\
&= \mathsf{subj}'/\,(\mathsf{john} \otimes \mathsf{bill}) \;\sqcap\; \mathsf{RTLE} \\
&= ((\mathsf{subj}'/\,\mathsf{john}) \otimes (\mathsf{subj}'/\,\mathsf{bill})) \;\sqcap\; \mathsf{RTLE} \\
&= (\mathsf{subj}'/\,\mathsf{john} \;\cap\; \mathsf{RTLE}) \otimes (\mathsf{subj}'/\,\mathsf{bill} \;\cap\; \mathsf{RTLE}) \\
&= [\![\text{John has the RTLE and Bill has the RTLE}]\!]
\end{aligned}
$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill have the right to live in Europe}]\!]$$
$$= (\mathsf{subj}'/\,\mathsf{john} \;\cap\; \mathsf{RTLE}) \otimes (\mathsf{subj}'/\,\mathsf{bill} \;\cap\; \mathsf{RTLE})$$

Laws of $\otimes$

$\bot \otimes x = \bot$ $\qquad$ $x \otimes \bot = \bot$, from which follows

$$x \otimes y \neq \bot \Longrightarrow x \neq \bot$$

Coordination

John and Bill have the right to live in Europe

$$[\![\text{John and Bill have the right to live in Europe}]\!]$$
$$= (\mathsf{subj}'/\,\mathsf{john} \;\cap\; \mathsf{RTLE}) \otimes (\mathsf{subj}'/\,\mathsf{bill} \;\cap\; \mathsf{RTLE})$$

Laws of $\otimes$

$\bot \otimes x = \bot$ $\qquad$ $x \otimes \bot = \bot$, from which follows

$$x \otimes y \neq \bot \Longrightarrow x \neq \bot$$

John and Bill have the right to live in Europe
$\Longrightarrow$ John has the right to live in Europe

Entailment by 'pure logic'

Quantification

$$[\![\text{Every European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/\bigotimes_{\mathsf{i}\in\mathsf{European}}\mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/\mathcal{A}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{A}\,\mathsf{subj}'/\mathsf{European}) \sqcap \mathsf{RTLE}$$

Quantification

$$[\![\text{Every European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/ \bigotimes_{\mathsf{i} \in \mathsf{European}} \mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/ \mathcal{A}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{A}\,\mathsf{subj}'/ \mathsf{European}) \sqcap \mathsf{RTLE}$$

$$[\![\mathrm{A}_N \text{ European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/ \bigsqcup_{\mathsf{i} \in \mathsf{European}} \mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/ \mathcal{E}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{E}\,\mathsf{subj}'/ \mathsf{European}) \sqcap \mathsf{RTLE}$$

Quantification

$$[\![\text{Every European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/ \bigotimes_{\mathsf{i} \in \mathsf{European}} \mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/ \mathcal{A}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{A}\,\mathsf{subj}'/ \mathsf{European}) \sqcap \mathsf{RTLE}$$

$$[\![\text{A}_N \text{ European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/ \bigsqcup_{\mathsf{i} \in \mathsf{European}} \mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/ \mathcal{E}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{E}\,\mathsf{subj}'/ \mathsf{European}) \sqcap \mathsf{RTLE}$$

$$[\![\text{A}_W \text{ European has the right to live in Europe}]\!]$$

$$= (\mathsf{subj}'/ \bigoplus_{\mathsf{i} \in \mathsf{European}} \mathsf{i}) \sqcap \mathsf{RTLE}$$

$$\stackrel{\text{def}}{=} (\mathsf{subj}'/ \mathcal{I}\mathsf{European}) \sqcap \mathsf{RTLE} = (\mathcal{I}\,\mathsf{subj}'/ \mathsf{European}) \sqcap \mathsf{RTLE}$$

Outline

Subject Relative Clauses

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE}$$

$$[\![\text{who has the right to live in Europe}]\!] = \{ag(e) \mid e \in \mathsf{RTLE}\}$$

Subject Relative Clauses

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE}$$

$$\begin{gathered}[\![\text{who has the right to live in Europe}]\!] \\ = \{ag(e) \mid e \in \mathsf{RTLE}\} \\ = \{i \mid e \in \mathsf{RTLE}\,, (e, i) \in \mathsf{subj}'\}\end{gathered}$$

Subject Relative Clauses

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE}$$

$$\begin{gathered}[\![\text{who has the right to live in Europe}]\!] \\ = \{ag(e) \mid e \in \mathsf{RTLE}\} \\ = \{i \mid e \in \mathsf{RTLE}\,, (e,i) \in \mathsf{subj}'\} \\ = \{i \in \mathrm{dom}(\mathsf{subj}') \mid \mathsf{subj}'/\, i \cap \mathsf{RTLE} \neq \varnothing\}\end{gathered}$$

Subject Relative Clauses

$$[\![\text{has the right to live in Europe}]\!] = \mathsf{RTLE}$$

$$\begin{gathered}
[\![\text{who has the right to live in Europe}]\!] \\
= \{ag(e) \mid e \in \mathsf{RTLE}\} \\
= \{i \mid e \in \mathsf{RTLE}\,, (e,i) \in \mathsf{subj}'\} \\
= \{i \in \mathrm{dom}(\mathsf{subj}') \mid \mathsf{subj}'/\, i \cap \mathsf{RTLE} \neq \varnothing\} \\
= \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}
\end{gathered}$$

More Interesting Example

(7) Every European has the right to live in Europe.

(8) Every European is a person.

(9) Every person who has the right to live in Europe can travel freely within Europe.

(10) Every European can travel freely within Europe.

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Subject Relative Clauses: Entailment

$$[\![\text{Every European has the right to live in Europe.}]\!] = \bigotimes_{i \in \mathsf{European}} [\![i \text{ has the right to live in Europe}]\!]$$

$$[\![\text{who has the right to live in Europe}]\!] = \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

Every European has the right to live in Europe.
$\Longrightarrow \mathsf{European} \subseteq [\![\text{who has the right to live in Europe}]\!]$

Another Look at Relative Clauses

$$[\![\text{who has the right to live in Europe}]\!]$$
$$= \{i \in \text{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

$$[\![\text{person who has the right to live in Europe}]\!]$$
$$= \mathsf{Person} \cap \{i \in \text{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

Another Look at Relative Clauses

$$[\![\text{who has the right to live in Europe}]\!]$$
$$= \{i \in \text{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

$$[\![\text{person who has the right to live in Europe}]\!]$$
$$= \mathsf{Person} \cap \{i \in \text{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$
$$= \{i \mid i \in \mathsf{Person} \wedge [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

Another Look at Relative Clauses

$$[\![\text{who has the right to live in Europe}]\!]$$
$$= \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

$$[\![\text{person who has the right to live in Europe}]\!]$$
$$= \mathsf{Person} \cap \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$
$$= \{i \mid i \in \mathsf{Person} \wedge [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$
$$\stackrel{\text{def}}{=} \mathbf{subjs}\left(\bigoplus_{i \in \mathsf{Person}} [\![i \text{ has the right to live in Europe}]\!]\right)$$

Another Look at Relative Clauses

$$[\![\text{who has the right to live in Europe}]\!]$$
$$= \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}$$

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$$\stackrel{\text{def}}{=} \mathbf{subjs}\left(\bigoplus_{i \in \mathsf{Person}} [\![i \text{ has the right to live in Europe}]\!]\right)$$
$$= \mathbf{subjs}[\![(\bigoplus_{i \in \mathsf{Person}} i) \text{ has the right to live in Europe}]\!]$$

Another Look at Relative Clauses

$$
\begin{aligned}
&[\![\text{who has the right to live in Europe}]\!] \\
&= \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\}
\end{aligned}
$$

$$
\begin{aligned}
&[\![\text{person who has the right to live in Europe}]\!] \\
&= \mathsf{Person} \cap \{i \in \mathrm{dom}(\mathsf{subj}') \mid [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\} \\
&= \{i \mid i \in \mathsf{Person} \wedge [\![i \text{ has the right to live in Europe}]\!] \neq \varnothing\} \\
&\stackrel{\text{def}}{=} \mathbf{subjs}\left(\textstyle\bigoplus_{i \in \mathsf{Person}} [\![i \text{ has the right to live in Europe}]\!]\right) \\
&= \mathbf{subjs}[\![(\textstyle\bigoplus_{i \in \mathsf{Person}} i) \text{ has the right to live in Europe}]\!] \\
&= \mathbf{subjs}[\![\mathrm{A}_W \text{ person has the right to live in Europe}]\!]
\end{aligned}
$$

Another Look at Relative Clauses

$$[\![\text{Every person who has the rtlE can travel freely within Europe.}]\!] = \mathcal{A}(\mathbf{subjs}[\![\text{A}_W \text{ who has the rtlE}]\!]) \sqcap [\![\text{can travel freely within Europe.}]\!]$$

Database join

of "A person has the right to live in Europe." with "can travel freely within Europe" on agent

(Approximate)paraphrase

Some people have the right to live in Europe. Every *one of them* can travel freely within Europe.

Quantified Relative Clauses

$$[\![\text{that Smith wrote to every week}]\!]$$
$$= \{i \in \mathrm{dom}(\mathsf{ob1}') \mid [\![\text{Smith wrote to } i \text{ every week}]\!] \neq \bot\}$$

$$[\![\text{representative that Smith wrote to every week}]\!]$$
$$= \mathbf{ob1s}([\![\text{Smith wrote to } \mathrm{a}_W \text{ representative every week}]\!])$$

Quantified Relative Clauses

Smith wrote to a representative every week.

There is a representative that Smith wrote to every week.

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Outline

Conclusions

Dealing with all the challenges listed at the beginning

(see the paper)

Future Work

- Mechanical implementation of entailment
- More challenges
  It builds up muscles people thought didn't exist
  the land he had created and lived in