Towards Compositional Semantics and Inference System for Telicity

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Overview

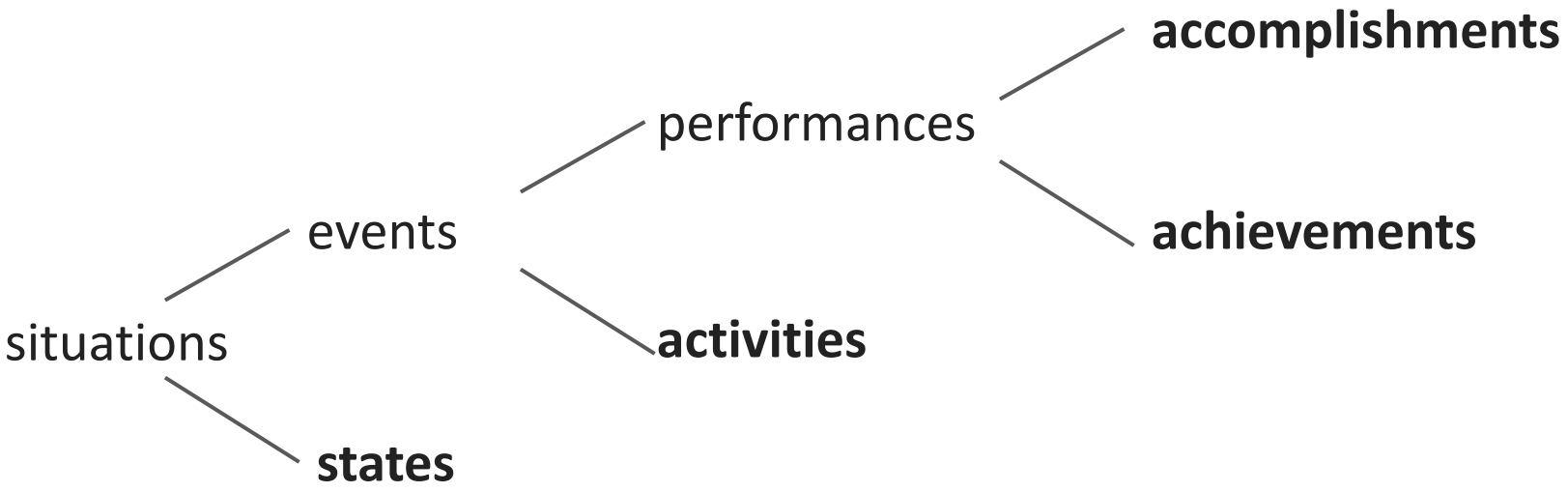
- Aspectual class of verbs: key role in tense and aspect
- Previous work on aspectual class of verbs:
  - Theoretical Linguistics[Vendler1957][Mourelatos1978][Dowty1979][Krifka1998]
  - Computational Linguistics[Friedrich and Palmer2014][Kober+2020]

Question: How to handle inference with aspectuality in computational linguistics?

➡ provide a hybrid approach of **distributional semantics** and **event semantics**

Aspectual class of verbs

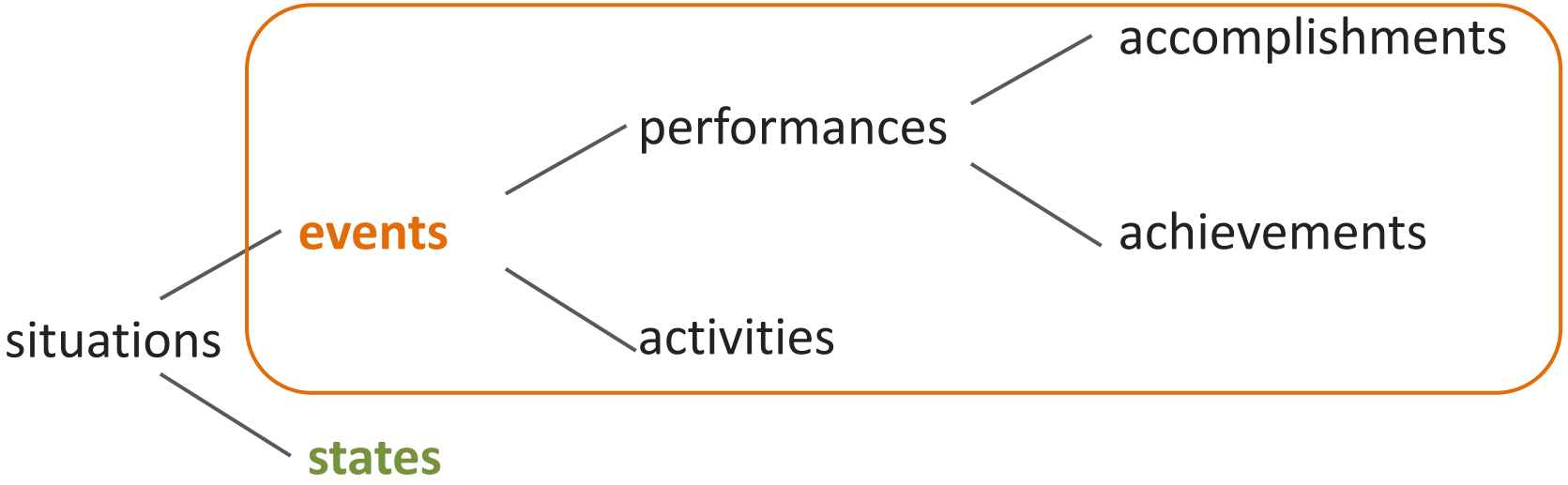
- semantic property of verbs that plays a key role in interpreting temporal structure[Moens and Steedman1988]
- typically categorized into 4 types[Vendler1957][Mourelatos1978][Bach1986]



Aspectual class of verbs: Event vs. States

- semantic property of verbs that plays a key role in interpreting temporal structure[Moens and Steedman1988]
- typically categorized into 4 types[Vendler1957][Mourelatos1978][Bach1986]
- main distinction 1:

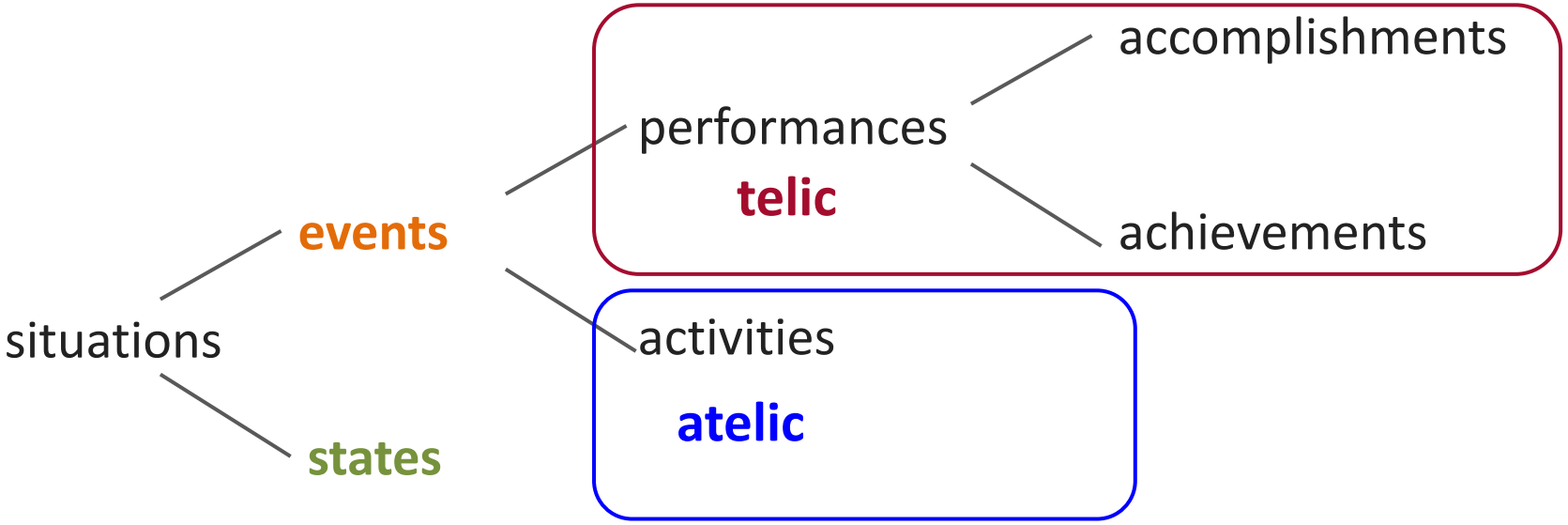
  events (e.g., run, draw a circle) vs. **states** (e.g., know, love)



Aspectual class of verbs: Telic vs. Atelic

- semantic property of verbs that plays a key role in interpreting temporal structure[Moens and Steedman1988]
- typically categorized into 4 types[Vendler1957][Mourelatos1978][Bach1986]
- main distinction 2:

  telic vs. **atelic** event (whether an event has a particular endpoint)



Imperfective Paradox[Dowty1979]

A telic event does not license entailment from its progressive form to the corresponding non-progressive form

Telic event:

T: John was writing a report ⇏ H: John wrote a report

Atelic event:

T: John was running in the park ⇒ H: John ran in the park

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Question: How to handle inference with imperfective paradox in computational linguistics?

Previous work on compositional semantics in computational linguistics

Logic-based inference systems

- First-order prover and model builder[Bos and Markert 2005]
- Tableau prover for natural logic [Abzianidze2015 and 2016]
- Higher-order logic inference[Mineshima+2015][Martinez-Gomez+2017]
- Grammatical Framework and Coq-based inference system[Bernardy and Chatzikyriakidis2017 and 2021]

Computationally realize compositional semantics studied in formal semantics by defining lexical entries

Challenge: the telicity of verbs is complex

The telicity is not just lexically determined by a verb, but interacts with other words in a sentence[Bach1986][Krifka1998]

(1a) John wrote	**atelic**
(1b) John wrote a report	**telic**
(2a) John drank some coffee	**atelic**
(2b) John drank two cups of coffee	**telic**

How to computationally handle the telicity of verbs is a non-trivial issue

Previous work on aspectual class in computational linguistics

Various machine learning approaches for classifying aspectual class:

- Linguistic indicators for lexical aspects
  [Klavans and Chodorow1992][Siegel and McKeown2000]
- Cross-lingual projections[Friedrich and Gateva2017]
- Word representations using a distributional semantic model
  [Friedrich and Palmer2014][Friedrich+2016][Kober+2020]
  About 60-85% accuracy for the classification of clause-level aspects

Neural network-based Natural Language Inference

- BERT[Devlin+2019], RoBERTa[Liu+2019]
  Neural models do not perform aspectual inference very well
  [Kober+2019]

Hybrid approach of distributional semantics and event semantics

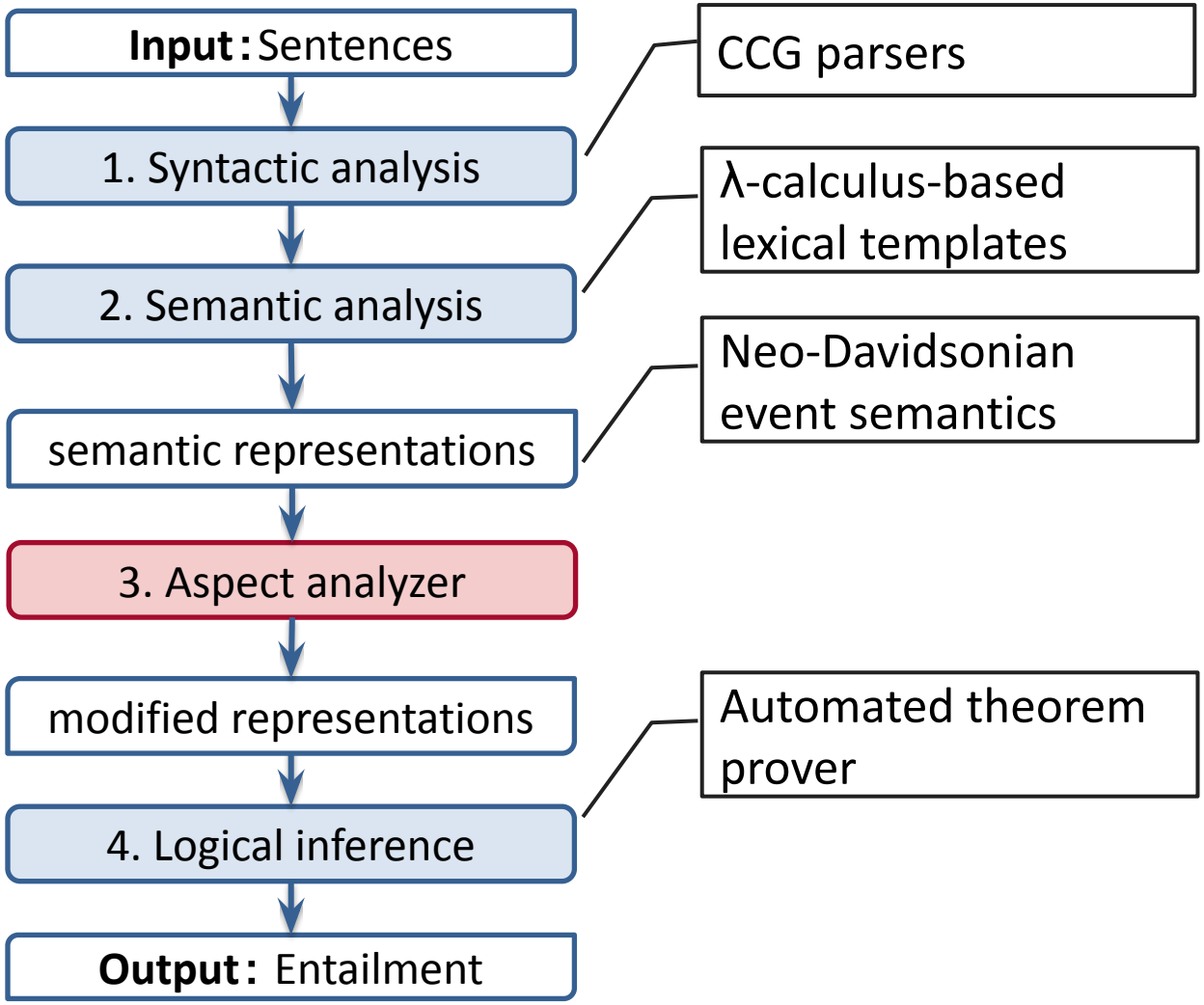
- Aim:
  1. a compositional semantics to map the aspectual class of verbs to semantic representations

  2. an inference system that performs inference with imperfective paradox

- Key idea:
  Combine **distributional semantics** with **event semantics** to handle inference with imperfective paradox

Overview of our proposed system

ccg2lambda
[Mineshima+,2015]
[Martinez-Gomez+,2016]



1. Syntactic analysis

Combinatory Categorial Grammar (CCG) [Steedman1996]

- Lexicalized grammar with clear syntax-semantics
- Robust CCG parsers trained on CCGBank[Hockenmaier and Steedman 2007]
  C&C[Clark and Curran2007], EasyCCG[Lewis and Steedman2014], depccg[Yoshikawa+2017]
- Lexical template:
  syntactic category and semantic representation for a word

Example: Some cats ran

$$\dfrac{\dfrac{\dfrac{\text{Some}}{NP/N}\quad\dfrac{\text{cats}}{N}}{NP}<\quad\dfrac{\text{ran}}{S\backslash NP}}{S}>$$

2. Semantic analysis

Neo-Davidsonian Event Semantics [Parsons1990]

- Every verb is decomposed into a predicate over events and a set of functional expressions relating the events
- **Event time** is a 1-place predicate over events **Dur(e)**
- **Temporal relation** between speech time (*st*) and reference time/ between event time and reference time[Reichenbach1956] Before/Equal/Meet/Overlap/Start/Finish/During [Allen1983]
- **Culmination point** is a 1-place predicate over events **Cul(e)**

Example: Some cats ran

$$\dfrac{\dfrac{\dfrac{\text{Some}}{NP[nb]/N} \quad \dfrac{\text{cats}}{N}}{\lambda F1F2.\exists x.(F1(x) \wedge F2(x)) \quad \lambda x.\text{cat}(x)}}{\lambda F2.\exists x.(\text{cat}(x) \wedge F2(x))}\,{<} \quad \dfrac{\dfrac{\text{ran}}{S[dcl]\backslash NP}}{\lambda Qt1.Q(\lambda x.\exists et2.(\text{run}(e) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(t1, t2) \wedge \text{Cul}(e) \wedge (\text{Subj}(e) = x)))}\,{>}$$

$$\dfrac{}{\exists x.(\text{cat}(x) \wedge \exists et2.(\text{run}(e) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2) \wedge \text{Cul}(e) \wedge (\text{Subj}(e) = x)))}$$

$$\exists x.(\text{cat}(x) \wedge \exists et2.(\text{run}(e) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2) \wedge \text{Cul}(e) \wedge (\text{Subj}(e) = x)))$$

3. Aspect analyzer

Our aspect analyzer is composed of three components:

3-1. Event extraction

Extract subformulas related to events from semantic representations

3-2. Event classification

Classify aspectual class of extracted events

3-3. Semantic recomposition

According to the predicted aspectual class, compose semantic representations again

Example demonstration (Telic event)

1. 2. Obtain tentative semantic representations via syntactic and semantic analysis

- In this step, we do not represent whether the event includes a culmination point

Telic event:

T1: John was writing a report ⇏ H1: John wrote a report

Semantic representation of T1:

$$\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{During}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2))))$$

Semantic representation of H1:

$$\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2))))$$

3-1. Event extraction

Extract a set of predicates related to events

- extract a set of predicates involving event variables
- extract a set of predicates which are accusative/dative cases of events

Telic event:

T1: John was writing a report ⇏ H1: John wrote a report

Semantic representation of H1:

$$\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2))))$$

Then, extract surface forms related to a set of predicates from an original sentence:

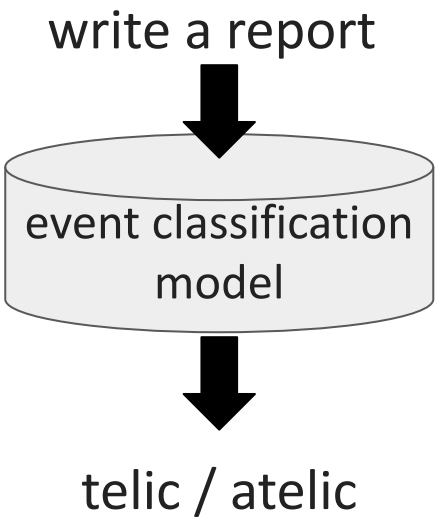
➡ write a report

3-2. Event classification

Classify the aspectual class (telic/atelic) of the extracted event phrase by a distributional semantic model and annotate **aspectual class tags**

- Previous work[Kobers+,2020] has reported that the accuracy with a verb phrase (local context) information is better than the accuracy with only a verb/sentence

Classify the aspectual class:



e.g., sequence classification using BERT[Devlin+2019]

Annotate aspectual class tags:

TEL
John wrote a report

ATE
John wrote

3-3. Semantic recomposition

According to the annotated aspectual class tag, compose semantic representations again

- In this step, we represent whether or not the event includes a culmination point
- The predicate Cul(e) is added only if the Part-of-speech tag is VBD (verb past tense) and the aspectual class tag is TEL (telic)

Lexical template examples

```
category: (S|NP)|NP
semantics: \E Q1 Q2 K t1. Q2(\x.True, \x.Q1(\y.True, \y.exists e t2.(E(e) &
Equal(t2,Dur(e)) & Before(t1,t2) & (Subj(e) = x) & (Acc(e) = y) & K(e,t2)),t1),t1)
pos: VBD
atag: TEL
```

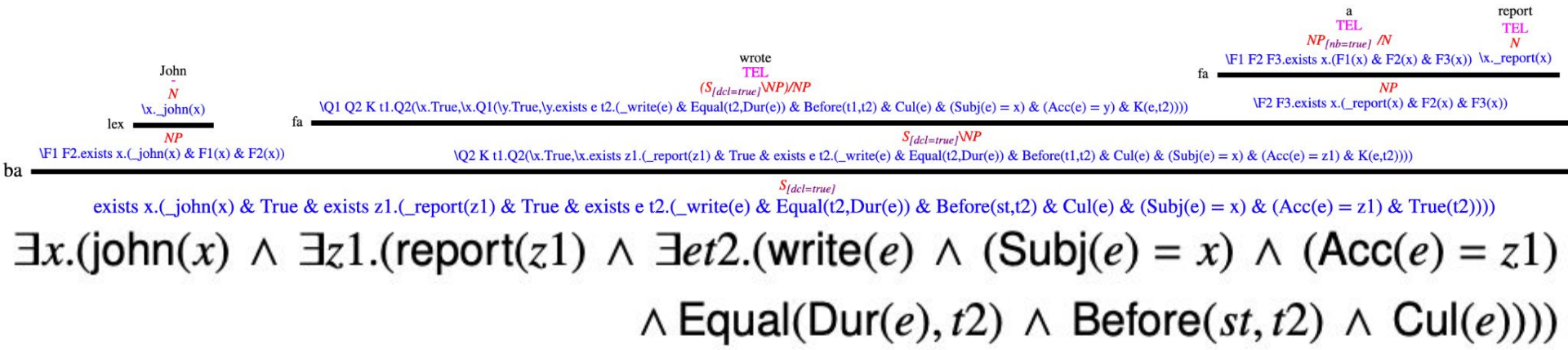
```
category: (S|NP)|NP
semantics: \E Q1 Q2 K t1. Q2(\x.True, \x.Q1(\y.True, \y.exists e t2.(E(e) &
Equal(t2,Dur(e)) & Before(t1,t2) & Cul(e) & (Subj(e) = x) & (Acc(e) = y) &
K(e,t2)),t1),t1)
pos: VBD
atag: ATE
```

3-3. Semantic recomposition: example

According to the annotated aspectual class tag, compose semantic representations again

- In this step, we represent whether or not the event includes a culmination point

Telic event: John wrote a report
TEL



$$\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2) \wedge \text{Cul}(e))))$$

4. Logical inference

- Convert semantic representations to typed First-Order forms[Sutcliffe2017]
- Try to prove the entailment relation by using the theorem prover Vampire
- Use axioms for First-Order Theory of Allen's Interval Algebra [Allen1983][Grüninger and Li,2017]

Telic event:

T: John <u>was writing a report</u> ↛ H: John <u>wrote a report</u>

TEL **TEL**

- We solve imperfective paradox by the existence of the predicate **Cul(e)**

T: $\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2))))$

↛ H: $\exists x.(\text{john}(x) \wedge \exists z1.(\text{report}(z1) \wedge \exists et2.(\text{write}(e) \wedge (\text{Subj}(e) = x) \wedge (\text{Acc}(e) = z1) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge \text{Before}(st, t2) \wedge \text{Cul}(e))))$

(*st*: speech time)

4. Logical inference

- Convert semantic representations to tptp format[Sutcliffe2017]
- Try to prove the entailment relation by using the theorem prover Vampire
- Use axioms for First-Order Theory of Allen's Interval Algebra
  [Allen1983][Grüninger and Li,2017]

Atelic event:

T: John was writing → H: John wrote

ATE **ATE**

- We solve imperfective paradox by the existence of the predicate **Cul(e)**

T: $\exists x.(\text{john}(x) \wedge \exists et2.(\text{write}(e) \wedge \text{During}(\text{Dur}(e), t2) \wedge (\text{Subj}(e) = x) \wedge \text{Before}(st, t2)))$

H: $\exists x.(\text{john}(x) \wedge \exists et2.(\text{write}(e) \wedge \text{Equal}(\text{Dur}(e), t2) \wedge (\text{Subj}(e) = x) \wedge \text{Before}(st, t2)))$

(st: speech time)

Discussion

Quantized property and cumulative property for representing the telicity of objects and events[Krifka1998][Zucchi&White2001][Rothstein2004]

- More fine-grained analysis for the telicity
- When we consider implementing Krifka's analysis computationally, distributional semantics should be also applicable to distinguish whether a predicate is quantized or cumulative

John drank a **quantity** of milk	**atelic**
John drank a **cup** of milk	**telic**
John drank a **cup** of milk **every day**	**habitual**

Conclusion and Future Work

- Aim:
  1. a compositional semantics to map the aspectual class of verbs to semantic representations
  2. an inference system that performs aspectual inference

- Key idea:
  - Combine **distributional semantics** with **event semantics**
  - Provide an aspect analyzer to represent the telicity of events

- Future work:
  - Cover various temporal and aspectual examples (e.g., temporal adverbials, habituality, states which are negative events)
  - Create a temporal and aspectual inference dataset and evaluate the proposed system

Thanks for listening!

Acknowledgements and References 1

Acknowledgements

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