Modeling Event Implications for Compositional Semantics

Sai Qian
Maxime Amblard

Calligramme, LORIA & INRIA Nancy Grand-Est
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Outline

Ahead of Events...

- Adjectives as a very first clue:

(1) a. *John is tall, strong, handsome...*
b. *...($Handsome(Strong(Tall(J)))$)
c. $Tall(J) \wedge Strong(J) \wedge Handsome(J) \wedge \ldots$

- A bunch of adjectives (probably *infinite*) being expressed as coordination (conjunction) of predicates
- Conventional semantic representation

$$[\![tall]\!] = \lambda P \lambda x.(P(x) \wedge Tall(x))$$

- The above representation is for intersective adjectival modification

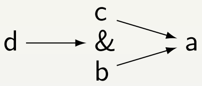
Analogy to Adjectives - Adverbs

(2) a. *Brutus stabbed Caesar.*
b. *Brutus stabbed Caesar in the back.*
c. *Brutus stabbed Caesar with a knife.*
d. *Brutus stabbed Caesar in the back with a knife.*

- **Permutation**

  Brutus stabbed Caesar in the back with a knife.
  Brutus stabbed Caesar with a knife in the back.

- **Drop**



Parallelism Between Adjectives & Adverbs

- Similarities between adjectival and adverbial quantification wrt some certain properties
  - Adjectival quantification takes **a property** (common noun), returns **a new property**: $(e \to t) \to e \to t$
  - Adverbial quantification: ???
- An implicit Event argument inside sentences
- Similar to the treatment for adjectives,

$$[\![in\_the\_back]\!] = \lambda Q \lambda e.(Q(e) \wedge in\_the\_back(e))$$

Adverbial Quantification with Events

(3)
a. $\exists e.Stab(e, B, C)$
b. $\exists e.(Stab(e, B, C) \wedge In(e, back))$
c. $\exists e.(Stab(e, B, C) \wedge With(e, knife))$
d. $\exists e.(Stab(e, B, C) \wedge In(e, back) \wedge With(e, knife))$

- Various versions of event semantic
  - Davidsonian Theory
  - Neo-Davidsonian Theory

Example

$$\exists e.(Stab(e) \wedge Subj(e, B) \wedge Obj(e, C))$$

Other Evidences

- Preceptual idioms - a perceptual verb followed by a clause missing tense

(4) a. *Sam heard Mary shoot Bill.*

- *Mary saw Brutus stab Caesar.*
- *Mary saw that Brutus stabs Caesar.*

Type Analysis

Different types for the perceptual verb "*see*"[1]:

1. sb. **sees** sb./sth.: $e \rightarrow e \rightarrow t$
2. sb. **sees** some event: $e \rightarrow v \rightarrow t$
3. sb. **sees** some fact: $e \rightarrow t \rightarrow t$

[1] "*e*" and "*t*" are the same as in other conventional semantic theory, while "*v*" stands for the type of event.

Other Evidences Continued

Corresponding Interpretations

1. $\exists e(See(e) \wedge Subj(e, M) \wedge \exists e'(Stab(e) \wedge Subj(e', B) \wedge Obj(e', C) \wedge Obj(e, e')))$
2. $\exists e(See(e) \wedge Subj(e, M) \wedge Obj(e, \exists e'(Stab(e) \wedge Subj(e', B) \wedge Obj(e', C)))$

- Explicit reference to events

(5) a. *After the singing of La Marseillaise they saluted the flag.*
b. *John arrived late. This/It annoyed Mary.*

Intuitional Clues

(6) a. *John smiles.* $\Longrightarrow$
$Smile(J)$

b. *John and Bill smile.* $\Longrightarrow$
$Smile(J\&B)$ or $Simle(J) \wedge Smile(B)$[2]

c. *John, Bill and Mike smile.* $\Longrightarrow$
$Smile(J\&B\&M)$ or
$Simle(J) \wedge Smile(B) \wedge Smile(M)$ or
$Smile(J) \wedge Smile(B\&M)$ or
......

- Intersective Reading
- Collective Reading

[2] The "&" symbol is a informal denotation for the combination of two entities.

Event in Coordination - “and”

(7) a. *John smiles.* $\Longrightarrow$
$\exists e.(Smile(e) \wedge Subj(e, \{J\}))$
b. *John and Bill smile.* $\Longrightarrow$
$\exists e.(Smile(e) \wedge Subj(e, \{J, B\}))$ or
$\exists e_1 \exists e_2.(Smile(e_1) \wedge Subj(e_1, \{J\}) \wedge Smile(e_2) \wedge Subj(e_2, \{B\}))$

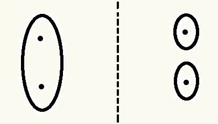
- Assumption: all events are conducted by a **group** of entities
- The subject position is occupied by a set, e.g., $\{J, B\}$, $\{J\}$
- Type transforming: “e” to “$e \rightarrow t$”

Naive Conclusion

- An intuitional representation (1st version):
  $\exists e_1 \exists e_2 ... \exists e_n.(Simle(e_1) \wedge Subj(e_1, G_1) \wedge Smile(e_2) \wedge Subj(e_2, G_2) \wedge ... \wedge Simle(e_n) \wedge Subj(e_n, G_n))$
- A more general representation (2nd version):
  $Condition\_On\_Subject \rightarrow \exists e.(Smile(e) \wedge Subj(e, G))$
- Problem: to specify and restrict the **condition** for subject

A More General Representation

- Observation
  1. Two elements in the set:



  2. Three elements in the set:

- Conclusion: different **combinations** of elements in the whole set result in different structures of events

A More General Representation

- Observation
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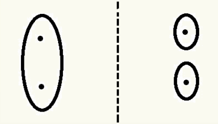
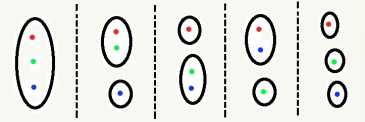


  2. Three elements in the set:



- Conclusion: different **combinations** of elements in the whole set result in different structures of events

A More General Representation Continued

Definition ("and" Function - F_{and}/Partition Function)

Let F_{and} be a partition function, which takes any set with finite number of elements (e.g., $A = \{a_1, a_2, ..., a_k\}$) as input, and returns a set of sets (e.g., $G^2_{and} = \{G_1, G_2, ..., G_n\}$) such that:

1. For any G_x, G_y (x, y from 1 to n), if $a_i \in G_x$ and $a_j \in G_y$ (i, j from 1 to k), then $a_i \neq a_j$
2. For all a_i (i from 1 to k), $a_i \in G_x$ (x from 1 to n)

- A modified general representation (3rd version):

$$\forall G.(G \in G^2_{and} \rightarrow \exists e.(Smile(e) \wedge Subj(e, G)))$$

Event in Coordination - “or”

(8) a. *John or Bill smiles.* $\Longrightarrow$
$\exists e_1.(Smile(e_1) \wedge Subj(e_1, \{J\})) \vee \exists e_1.(Smile(e_2) \wedge Subj(e_2, \{B\}))$

b. *John or Bill or Mike or ... smiles.* $\Longrightarrow$
$\exists e_1.(Smile(e_1) \wedge Subj(e_1, \{J\})) \vee \exists e_2.(Smile(e_2) \wedge Subj(e_2, \{B\})) \vee ... \vee \exists e_n.(Smile(e_n) \wedge Subj(e_n, \{N\}))$

- We assume **every element** in the set conjoined by “or” will result in an independent event
- The representation of the sentence is the disjunction of all events

Intuitional Clues

(9) a. *Every child smiles.* $\Longrightarrow$
$\exists e.(Smile(e) \wedge Subj(e, \{C_1 \& C_2 \& ... \& C_n\}))$ or
$\exists e_1 \exists e_2 ... \exists e_3.(Smile(e_1) \wedge Subj(e_1, \{C_1\}) \wedge Smile(e_2) \wedge Subj(e_2, \{C_2\}) \wedge ...Smile(e_n) \wedge Subj(e_n, \{C_n\}))$ or
......

b. *A child smiles.* $\Longrightarrow$
$\exists e.(Smile(e) \wedge Subj(e, \{C_1/C_2/.../C_n\}))$

Comparison between:

- Universal quantifier "*every*" and coordination "*and*"
- Existential quantifier "*a*" and coordination "*or*"

Event in Universal Quantifier

- Events are still conducted by a **group** of entities
- Unlike coordination "*and*", different groups could contain overlapping elements

Example (*everyone smiles*)

1. 2 elements - A and B
   - $Smile(A)$, $Smile(B)$
   - $Smile(A\&B)$, $Smile(A)$
2. 3 elements - A, B and C
   - $Smile(A)$, $Smile(B)$, $Smile(C)$
   - $Smile(A\&B)$, $Smile(B\&C)$, $Smile(C)$
   - *$Smile(A)$, $Smile(A\&B)$
   - ......

Event in Universal Quantifier Continued

- A general representation:
  $Condition\_On\_Subject \rightarrow \exists e.(Smile(e) \wedge Subj(e, G))$

Definition (Universal Function - F_{uni})

Let F_{uni} be function, which takes any set with finite number of elements (e.g., $A = \{a_1, a_2, ..., a_k\}$) as input, and returns a set of sets (e.g., $G^2_{uni} = \{G_1, G_2, ..., G_n\}$) such that:

1. For all a_i (i from 1 to k), $a_i \in G_x$ (x from 1 to n)

- A modified general representation:

$$\forall G.(G \in G^2_{uni} \rightarrow \exists e.(Smile(e) \wedge Subj(e, G)))$$

Event in Existential Quantifier

- The subject group only contains **one** element
- Every element is possible to be applied

Example (*a man smiles*)

1. 2 elements - A and B
   - *Smile*(*A*)
   - *Smile*(*B*)
   - *Smile*(*A*), *Smile*(*B*)
   - **Smile*(*A*&*B*)
2. 3 elements - A, B and C
   - *Smile*(*A*), *Smile*(*B*), *Smile*(*C*)
   - **Smile*(*A*&*B*), *Smile*(*B*&*C*), *Smile*(*C*&*A*)
   - ......

Event in Existential Quantifier Continued

- A general representation:
  $Condition\_On\_Subject \wedge \exists e.(Smile(e) \wedge Subj(e, G))$

Definition (Existential Function - F_{ex})

Let F_{ex} be function, which takes any set with finite number of elements (e.g., $A = \{a_1, a_2, ..., a_k\}$) as input, and returns a set of sets (e.g., $G_{ex}^2 = \{G_1, G_2, ..., G_n\}$) such that:

1. There exists a_i (i from 1 to k), $a_i \in G_x$ (x from 1 to n)
2. If $a_i \in G_x$, for any other a_j, if $a_j \in G_x$ then $a_i = a_j$

- A modified general representation:

$$\exists G.(G \in G_{ex}^2 \wedge \exists e.(Smile(e) \wedge Subj(e, G)))$$

Scope Ambiguity

(10) *Every man loves a woman.* $\Longrightarrow$

a. $\forall x.(Man(x) \rightarrow \exists y.(Woman(y) \wedge Love(x, y)))$

b. $\exists y.(Woman(y) \wedge \forall x.(Man(x) \rightarrow Love(x, y)))$

c. $\forall x.(x \in G^2_{uni} \rightarrow \exists y.(y \in G^2_{ex}) \wedge \exists e.(Love(e) \wedge Subj(e, x) \wedge Obj(e, y)))$

d. $\exists y.(y \in G^2_{ex} \wedge \forall x.(x \in G^2_{uni}) \rightarrow \exists e.(Love(e) \wedge Subj(e, x) \wedge Obj(e, y)))$

Relations Among Representations

$$b \subset a,\ d \subset c$$
$$a \approx c,\ b \approx d$$

Comparison with Traditional MG

- In traditional MG, quantifiers are represented semantically as:
  - $[\![every]\!] = \lambda P \lambda Q \forall x.(P(x) \rightarrow Q(x))$
  - $[\![a]\!] = \lambda P \lambda Q \exists x.(P(x) \wedge Q(x))$
- With a similar structure, we proposed:
  - $[\![every]\!] = \lambda P \forall G.(G \in G^2_{uni} \rightarrow P(G))$
  - $[\![a]\!] = \lambda P \exists G.(G \in G^2_{ex} \wedge P(G))$
- No essential difference, however:
  - We focus on group of entities, not single entities
  - We distinguish events by different combination of subjects and objects (e.g., "*every man loves a woman*", but different man might have different ways to love a woman.)

Making Things Compositional

- Since we already have the general semantic representations, the next step is to obtain them **compositionally**
- Possible proposition:

Example (Semantic Representations)

$[\![stab]\!] = \lambda ose.(stab(e) \wedge Subj(e,s) \wedge Obj(e,o))$
$[\![with\_a\_knife]\!] = \lambda Pe.(P(e) \wedge with\_a\_knife(e))$
$[\![EOE]\!] = \lambda P \exists e.P(e)$

- Infinite number of adverbial modifier could be added
- Thematic roles for verbs need to be predefined
- The "*EOE*" operator is used to terminate an event

Making Things Compositional Continued

General Representations

$$Conditions \rightarrow \exists e.(Predicate(e) \wedge Subject(e, G)......) \text{ or}$$
$$Conditions \wedge \exists e.(Predicate(e) \wedge Subject(e, G)......)$$

- Event variable "*e*" is always located deepest
- However, if processing subject or object first, other quantifiers would fall inside the scope of "*e*", such as in:

$$[\![stab]\!] = \lambda ose.(stab(e) \wedge Subj(e, s) \wedge Obj(e, o))$$

Making Things Compositional Continued

- Proposal: The $\lambda\mu$-Calculus
- Steps of semantic processing:
  1. Assign subject/object (also other thematic roles, if there are) as μ-terms, the representations for verbs keep unchanged
  2. Form the semantic representation with the μ-term frozen
  3. Apply the representation to "*EOE*" operator
  4. Retrieve the μ-terms in different orders to obtain the final representation

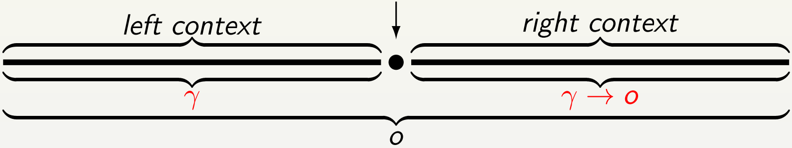
Bring Dynamics to MG

Basic Types

Based on Church's simple type theory, Montague Semantics provides two basic atomic types:

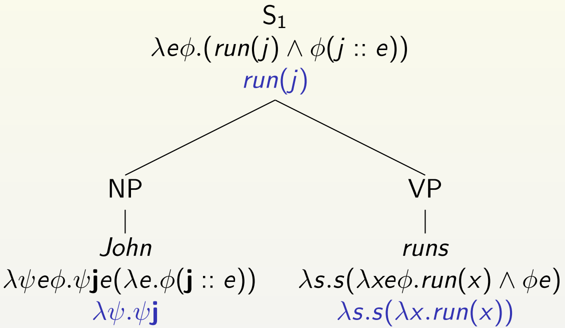
- ι (also known as e), the type of individuals (entities)
- o (also known as t), the type of propositions (truth values)

Besides, another atomic type is introduced: γ, which stands for the type of the left context

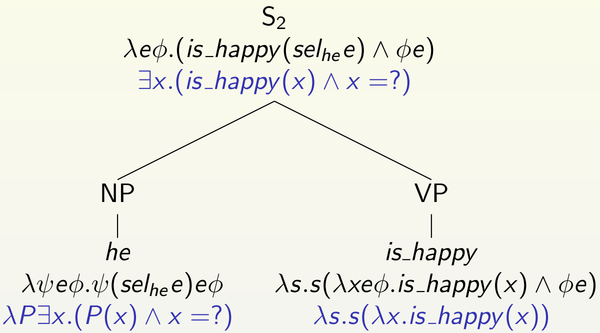


Discourse Example

(11) *John smiles. He is happy.*



Discourse Example Continued



Discourse Example Continued

S

$$\lambda e\phi.(run(j) \wedge is\_happy(sel_{he}(j :: e)) \wedge \phi(j :: e))$$

Composition

$$[\![S_1.S_2]\!] = \lambda e\phi.[\![S_1]\!]e(\lambda e'.[\![S_2]\!]e'\phi)$$

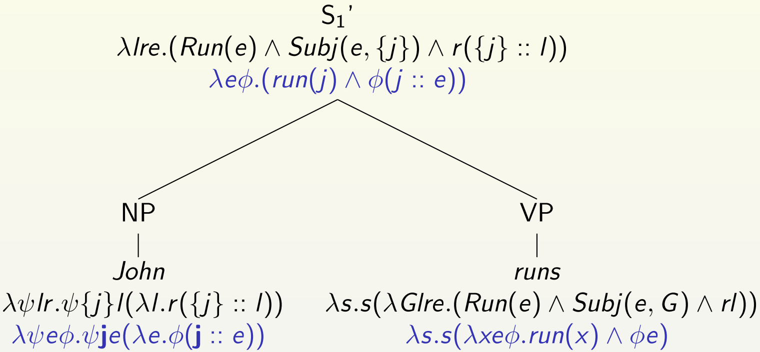
S_1: $\lambda e\phi.(run(j) \wedge \phi(j :: e))$

S_2: $\lambda e\phi.(is\_happy(sel_{he}e) \wedge \phi e)$

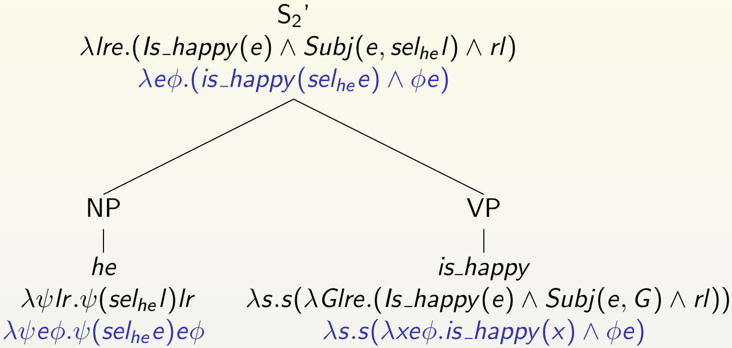
Points to Notice

- Type for "::" is $\iota \rightarrow \gamma \rightarrow \gamma$
- Type for "sel_{he}" is $\gamma \rightarrow \iota$
- The sense of "dynamic" is realized through the **list structure**, which can update the variables for future processing

Discourse Example with Event



Discourse Example with Event Continued



Discourse Example with Event Continued

- To avoid misunderstanding, we assume the following new set denotations:
  - Left context "*l*", of type γ
  - Right context "*r*", of type $\gamma \rightarrow t$
  - Event "*e*", of type v
- The current sentence S_1' and S_2' are of type:

$$\gamma \rightarrow (\gamma \rightarrow t) \rightarrow v \rightarrow t$$

- We propose an "$EOE_{dynamic}$" operator to specify the existence of events:

$$\lambda Plr \exists e.(Plre)$$

- After applying S_1' and S_2' to "*EOE*" operator, they are of type:

$$\gamma \rightarrow (\gamma \rightarrow t) \rightarrow t$$

Discourse Example with Event Continued

- S
  $\lambda lr \exists e_1 e_2.(Run(e_1) \wedge Subj(e_1, \{j\}) \wedge Is\_happy(e_2) \wedge Subj(e_2, sel_{he}(\{j\} :: l)) \wedge r(\{j\} :: l))$
  $\lambda e\phi.(run(j) \wedge is\_happy(sel_{he}(j :: e)) \wedge \phi(j :: e))$
  - Composition
    $[\![S_1.S_2]\!] = \lambda e\phi.[\![S_1]\!]e(\lambda e'.[\![S_2]\!]e'\phi)$
    - S_1
      $\lambda lr \exists e.(Run(e) \wedge Subj(e, \{j\}) \wedge r(\{j\} :: l))$
      $\lambda e\phi.(run(j) \wedge \phi(j :: e))$
    - S_2
      $\lambda lr \exists e.(Is\_happy(e) \wedge Subj(e, sel_{he} l) \wedge rl)$
      $\lambda e\phi.(is\_happy(sel_{he} e) \wedge \phi e)$

Summary

- Motivations and evidences for the existence of explicit event argument in semantic analysis
- Not only for adverbial modifiers, event structure can also be applied for coordination, quantification and dynamic semantics
  - A general structure is proposed:
    $$Conditions \rightarrow \exists e.(Predicate(e) \wedge Subject(e, G)......)$$
    $$Conditions \wedge \exists e.(Predicate(e) \wedge Subject(e, G)......)$$
  - Conditions could be specified by a set of functions "F_{and}", "F_{uni}", "F_{ex}" and etc.
- An intermediate level between semantics and pragmatics

Future Work

- Other coordination situations (e.g., coordination over predicate, modifiers) need deeper investigation
- The details for those condition functions needs to be further determined, so that they could be implemented with pure λ-calculus
- More complicated cases (involving both subject groups and object groups, subject quantifiers and object quantifiers) need to be considered
- More choices for event in dynamic semantics (e.g., sentence composition, the "$EOE_{dynamic}$" function) could be compared
- More complicated accessibility problem in dynamic semantics should be studied
- The rhetorical relation (λ-DRT) should be attempted to add in the dynamic event structure
- ......

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