Algorithmic Dependent-Type Theory of Situated Information

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56th Linguistics Colloquium
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A New Approach to Situated Informations in Human Language

- Barwise [1] is the most influential, early work on Situation Theory and Situation Semantics with applications to computational semantics in grammar, e.g., HPSG
- Loukanova [3, 4] (2014–2019) initiated new prospects of Situation Theory based on
  - a new theory of the math notion of algorithm introduced by Moschovakis [5] (2006)
- Here, I shall present some of the new development of a type-theory of information
  - possibilities for integration of situated propositions with quantitative information, e.g., from
    - statistical approaches to data of human language
    - Machine Learning of human language

Primitive (basic) types of L_{gp}^{st}: a set of type constants

$$\mathsf{BTypes} = \{\, \mathrm{IND}, \mathrm{REL}, \mathrm{FUN}, \mathrm{ARGR}, \mathrm{LOC}, \mathrm{POL}, \mathrm{EVAL}, \mathrm{PAR}, \mathrm{INFON}, \mathrm{SIT}, \mathrm{PROP}, \mathrm{SET}, \mathrm{TYPE}, \models \,\} \tag{1}$$

- IND: for primitive and complex individuals
- REL: for primitive and complex relations
- FUN: for functions, primitive and complex
- ARGR: for primitive and complex argument roles
- LOC: for space-time locations
- POL: for numerical polarities, e.g., between 0 and 1 (these are for degree of having a property or being in a relation, not for truth values, even when limited to 0 and 1)
- EVAL: for extra value for numerical assessments of verification
- PAR: for primitive and complex parameters
- INFON: for basic or complex information units
- SIT: for situations
- PROP: for basic or complex propositions
- TYPE: for basic and complex types
- $\models$ is a designated type

- $\models$ is a special type called "supports" ("holds"), e.g., used in the type of propositions that a situation s and an infon σ are of the type "supports", i.e., "s supports σ":

$$(s \models \sigma) \qquad \text{(a proposition)}$$
$$s \models \sigma \qquad \text{(a verified proposition)}$$

- A class of primitive and complex types
  - Complex types are constructed at stages, e.g., as needed (not necessarily all of them)

Vocabulary and Syntax of L^{st}_{gp}

For all $\tau \in$ Types:

- Typed constants

$$K_\tau = \{ \mathsf{c}^\tau_0, \mathsf{c}^\tau_1, \ldots, \mathsf{c}^\tau_{k_\tau}, \ldots \} \tag{3}$$

- Typed pure and recursion (memory) variables
  - pure variables (for λ-abstractions)

$$\mathsf{PureV}_\tau = \mathsf{PV}_\tau = \{ \mathsf{v}^\tau_0, \mathsf{v}^\tau_1, \ldots \}$$

  - recursion variables (for memory "slots")

$$\mathsf{RecV}_\tau = \mathsf{RV}_\tau = \{ \mathsf{p}^\tau_0, \mathsf{p}^\tau_1, \ldots \}$$

- Notations for typed constants, variables, and terms

$$A : \tau \iff A^\tau \in \mathsf{Terms} \iff A \in \mathsf{Terms}_\tau \tag{4}$$

- Complex terms of situated information are defined by structural induction — mutual recursion

$$ArgR(\text{read-to}) = \{\text{reader}^{T_{a_1}},\ \text{readed}^{T_o},\ \text{listener}^{T_{a_1}}\} \tag{5a}$$

$$T_{a_1} := \{\lambda(x)\big[\big(s_1 \models\ \ll human, \tag{6a}$$

$$\text{arg}^{\text{IND}} \mapsto x^{\text{IND}}, \tag{6b}$$

$$loc^{\text{LOC}} \mapsto l_d,\ pol^{\text{POL}} \mapsto 1 \gg, \tag{6c}$$

$$eval^{\text{EVAL}} \mapsto 40\%\big) \tag{6d}$$

$$\vee\ \big(s_1 \models\ \ll device, \tag{6e}$$

$$\text{arg}^{\text{IND}} \mapsto x^{\text{IND}}, \tag{6f}$$

$$loc^{\text{LOC}} \mapsto l_o,\ pol^{\text{POL}} \mapsto 1 \gg, \tag{6g}$$

$$eval^{\text{EVAL}} \mapsto 60\%\big)\big]\} \tag{6h}$$

$$T_o := \{\lambda(x)\big(s_o \models\ \ll written, \tag{7a}$$

$$\text{arg}^{\text{IND}} \mapsto x^{\text{IND}}, \tag{7b}$$

$$loc^{\text{LOC}} \mapsto l_o,\ pol^{\text{POL}} \mapsto 1 \gg, \tag{7c}$$

$$eval^{\text{EVAL}} \mapsto 70\%\big)\} \tag{7d}$$

Example (infons: specific or parametric)

- c_a reads c_b to c_c at the space-time location l

$$\begin{aligned} \ll \text{read-to},\ & \text{reader}^{T_{a_1}} \mapsto c_a, \\ & \text{readed}^{T_o} \mapsto c_b, \\ & \text{listener}^{T_{a_1}} \mapsto c_c, \\ & loc^{\mathrm{LOC}} \mapsto l; \\ & pol^{\mathrm{POL}} \mapsto 0.60 \gg \end{aligned} \tag{8}$$

- The proposition (9a)–(9f) states that the infons hold in the situation s, jointly, by at least 70%

Example (A proposition that the situation s supports several infons)

$$(\mathsf{s} \models \tag{9a}$$

$$[\ll \mathsf{read\text{-}to}, \mathsf{reader} \mapsto \mathsf{x}, \mathsf{readed} \mapsto \mathsf{y}, \mathsf{listener} \mapsto \mathsf{z}, loc \mapsto \mathsf{l}; 1 \gg, \tag{9b}$$

$$\ll \mathsf{book}, \mathsf{arg} \mapsto \mathsf{y}, loc \mapsto \mathsf{l}_1; 1 \gg, \tag{9c}$$

$$\ll \mathsf{listen}, \mathsf{arg} \mapsto \mathsf{z}, loc \mapsto \mathsf{l}_2; 0.80 \gg, \tag{9d}$$

$$\mathsf{l} \subseteq \mathsf{l}_1,\ \mathsf{l}_2 \subseteq_t \mathsf{l}], \tag{9e}$$

$$eval \mapsto 70\%) \tag{9f}$$

Example (recursion variables: for denoting semantic parameters)

- q is a recursion (memory) variable
  restricted to be of the type C, by the proposition $(q : C)$
  q is restricted to be of the type of being read by c_a to

$$\{q\} \text{ such that } \{\, (q : C) \,\} \tag{10a}$$
$$\text{where} \quad \{\, C := \lambda(y)\big(s \models \ll \text{read-to}, \tag{10b}$$
$$\text{reader}^{T_{a_1}} \mapsto c_a, \tag{10c}$$
$$\text{readed}^{T_o} \mapsto y, \tag{10d}$$
$$\text{listener}^{T_{a_1}} \mapsto z, \tag{10e}$$
$$loc^{\text{LOC}} \mapsto l; \tag{10f}$$
$$pol^{\text{POL}} \mapsto 0.45 \gg, \tag{10g}$$
$$eval^{\text{EVAL}} \mapsto 60\%\big) \,\} \tag{10h}$$

Ongoing and Future Work

- Theoretical Development of Formal Situation Theory
- Choice and development of approach for the quantitive assessments and integration with situated information:
  Deep Machine Learning
- Reasoning based on semantic representations of formal and human languages
- Syntax-semantics interface in computational grammar of human language

- With gratitudes to the team of 56th LINGUISTICS COLLOQUIUM
- Special thanks to Coordinator Reinhard Rapp

THANK YOU!

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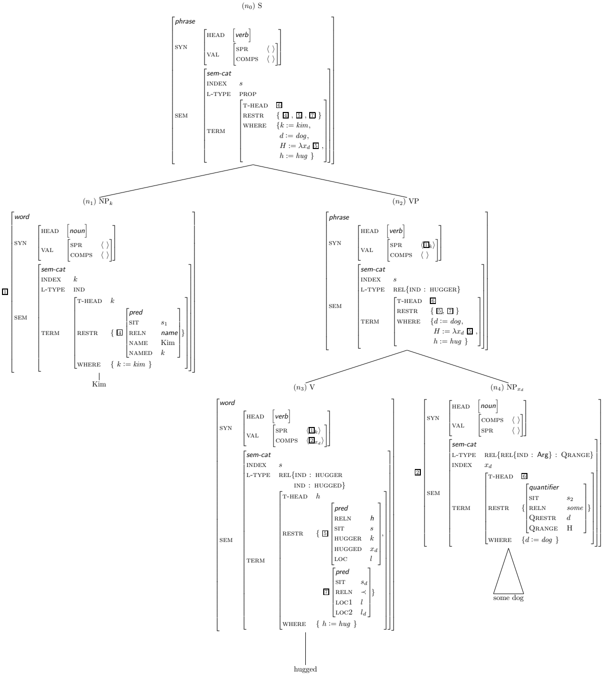
(n0) S
phrase
SYN HEAD verb
VAL SPR ⟨ ⟩ COMPS ⟨ ⟩
SEM sem-cat
INDEX s
L-TYPE PROP
TERM T-HEAD 6
RESTR { 4 , 5 , 7 }
WHERE {k := kim, d := dog, H := λx_d 5 , h := hug }
(n1) NP_k
word
SYN HEAD noun
VAL SPR ⟨ ⟩ COMPS ⟨ ⟩
1
SEM sem-cat
INDEX k
L-TYPE IND
TERM T-HEAD k
RESTR { 4 pred SIT s1 RELN name NAME Kim NAMED k }
WHERE { k := kim }
Kim
(n2) VP
phrase
SYN HEAD verb
VAL SPR ⟨1k⟩ COMPS ⟨ ⟩
SEM sem-cat
INDEX s
L-TYPE REL{IND : HUGGER}
TERM T-HEAD 6
RESTR { 5, 7 }
WHERE {d := dog, H := λx_d 5 , h := hug }
(n3) V
word
SYN HEAD verb
VAL SPR ⟨1k⟩ COMPS ⟨2x_d⟩
SEM sem-cat
INDEX s
L-TYPE REL{IND : HUGGER IND : HUGGED}
TERM T-HEAD h
RESTR { 5 pred RELN h SIT s HUGGER k HUGGED x_d LOC l ,
7 pred SIT s_d RELN ≺ LOC1 l LOC2 l_d }
WHERE { h := hug }
hugged
(n4) NP_x_d
2
SYN HEAD noun
VAL COMPS ⟨ ⟩ SPR ⟨ ⟩
SEM sem-cat
L-TYPE REL{REL{IND : Arg} : QRANGE}
INDEX x_d
TERM T-HEAD 6
RESTR { quantifier SIT s2 RELN some QRESTR d QRANGE H }
WHERE {d := dog }
some dog