Embodied Semantics

Towards a cognitive grounding of formal semantics

Tillmann Pross

Institute for Computational Linguistics/Institute of Philosophy, University of Stuttgart

TUM,17.04.2009

Outline

A starting point

- Acceptance of robotic assistance crucially depends on the possibility of natural interaction between man and machine.
- 'Natural':
  - Multimodal, Realtime, Goal-directed,. . .
  - In general: Aspects of spatiotemporal embodiedness of both cognitive *and* bodily abilities.

$\Rightarrow$ Grounding of higher mental functions connects Computational Linguistics (CL) and Robotics.

State of the art, roughly

CL and Robotics figuratively approach each other:

- CL: Top-Down to the model theory of formal NL-semantics (e.g. CandC Tools: CCG+DRT).
- Robotics: Bottom-Up to behaviour-based pragmatics (e.g. BDI-based planning).

State of the art, figuratively

Computational Linguistics (Dis-embodied)
$\Downarrow$
What exactly is the point of contact between CL and Robotics?
$\Uparrow$
Robotics (Embodied)

Objective: Connect CL and Robotics

- $\rightarrow$ Extend the sensomotoric capabilities of a robot with the ability to construct, maintain and manipulate complex symbolic representations and corresponding models
- $\leftarrow$ Ground complex symbolic representations and corresponding models in the sensomotoric embodiedness of a robot
- $\Rightarrow$ How to achieve this?

Events

- The proper processing of events constitutes the core mechanism of natural human-machine interaction
- E.g., events carry the pragmatic force of speech acts by means of their semantic structure
- A proper account to events must consider both semantics and pragmatics of events

$\Rightarrow$ Does the traditional approach to events in CL fulfill these requirements?

Events

- Davidson [1967]: Introduce a new ontological class of entities besides individuals: events.
- E.g. 'x build a house':
  $\exists e.\exists x.\exists y.agent(x) \wedge house(y) \wedge build(e, x, y)$

Vendler Classes

- Vendler [1957]: different verbs can have very different ’temporal profiles’ in that they are used to describe very different *event complexes*:
- E.g. ’build a house’ refers to a process of construction that brings about a house
- E.g. ’reach the top’ refers to a punctual event

Event Nucleus

- Moens and Steedman [1988] capture Vendler's observation by the introduction of a subatomic structure of events:
- Event Nucleus:= preparatory state, culmination, consequent state
- E.g. 'build a house':= process of construction, topping-out ceremony, existence of the house

Simple-minded DRT

In Discourse Representation Theory (Kamp et al. [2007])

x, y, e
$e : build(x, y)$
$house(y)$

Meaning Postulate 1:

x, y, e $e : build(x, y)$ $house(y)$	$\Rightarrow$	s^{res} $e : build(x, y)$ $e)(s^{res}$ $s^{res} : house(y)$

Meaning Postulate 2:

x, y, e $e : build(x, y)$ $house(y)$	$\Rightarrow$	s^{prep} $e : build(x, y)$ $s^{prep} \subseteq e$ $s^{prep} : \neg house(y)$

Model theory: Evaluation of DRS event conditions

Given a set of events and states EV structured by $<$, a universe of individuals U and an interpretation function I,

- $g \vDash_M e : R(x_1, \ldots, x_n)$ iff $\langle g(e), g(x_1), \ldots, g(x_n) \rangle \in I(R)$

where g is an assignment that maps e onto an element of EV and $x_1, \ldots, x_n$ onto elements of U.

For 'x build a house': Events described by occurrences of 'build a house' are events that stand in some 'build'-relation to the one who is doing the building (or the ones who are doing the building) and the thing that is built.

Some consequent Problems

- This semantics does not *identify* (Searle [1969]) the building of a house as an action but as a relation $\Rightarrow$ No pragmatic dimension of meaning.
- Where do U, I, EV, g come from? $\Rightarrow$ Requires cognitive grounding, vs. the purely structural nature of Tarski-Models
- How can a robot draw any information from such a semantics about an appropriate understanding of what it means to build a house?

$\Rightarrow$ 'Blind alley' with respect to the desiderata of natural human-robot interaction.

Improve on the model theory

Computational Linguistics

$\Downarrow$

Grounded Model Theory

$\Uparrow$

Robotics

$\Rightarrow$ Provide the robot with mechanisms to construct and maintain U, I, EV, g

How do humans do that?

Given a perception of unsegmented temporal variation:

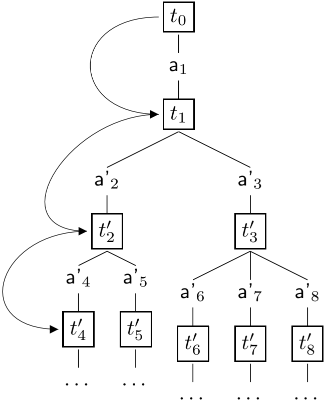
- Psychology: Humans structure a perceived temporal variation along the lines of plan-goal relationships and causal structures Zacks et al. [2001], Zacks and Swallow [2007]
- Philosophy: Causal, behavioural and intentional explanation of temporal variation. (E.g.Dretske [1988], Dennett [1989], Hartmann and Janich [1991])
- E.g. 'x is building a house': ascription of an underlying intention to x to predict x's behaviour.

⇒ Conservative transfer of these insights to a DRT-like setup.

Grounding

- Sensomotoric grounding: Output of a perpetual flow of snapshots from the object recognition.
- Behavioural grounding: Output from a BDI-based multi-agent planner.
- Combined grounding results in a branching time model, where the past and present is anchored by sensomotoric grounding and the future is anchored in behavioural grounding.

Grounded branching-time Models



Dynamic online models

- Combined grounding can be formalized with a modal Kripke semantics/CTL.
- But: the model must incorporate a notion of dynamics resulting from the permanent temporal move of the present and consequent revisions of the future (vs. the timelessness and offline construction of Tarski-Models).

⇒ Dynamic 'online' model of an agent x at time t: M(x)(t)

- How must the semantic representations of events look like to match such dynamic models?

⇒ Dovetail semantic representations and model structures.

Event anchoring

- Semantic specification of the event $\Rightarrow$ Event anchoring (Extend [Asher, 1986, Kamp, 1990] to temporal anchors).
  - Involved agents
  - The explanation type that identifies/constructs the event
  - Causes/Goals/Intented states of affairs
  - Tense
- Pragmatic specification of the event $\Rightarrow$ Course of action corresponding to the event
  - Causal Chains, Plans, Intentions, other action-related information
  - Specifies a partial structure of the model (!)

Dummy example for event anchoring

E.g. 'x is building a house':

SEM

$$\begin{array}{|l|}\hline x, e, n \\ \langle e, x\text{INT} \begin{array}{|l|}\hline y \\ house(y) \\ \langle y, ?\rangle \\ \hline\end{array} \rangle \\ build(e) \\ n \subseteq e \\ \hline\end{array}$$

PRG t_0 — get-materials — t_1 — lay-bricks — t_2 — make-roof — t_3

Embodied semantics of events

Embodied event semantics comprises both the semantic and pragmatic dimension of events by means of anchoring.

- Semantic: truth-conditional structure embedding (word-to-world fit).
- Pragmatic: model manipulations via the adoption of new goals, beliefs or the execution of actions (world-to-word fit) specified by the semantic structure of the representation.

$\Rightarrow$ Reciprocal influence of semantics and pragmatics.

$\Rightarrow$ Computation of event meaning via incremental anchor resolution.

$\Rightarrow$ Leads to a notion of dynamic realtime interpretation

The connection between CL and Robotics

Computational Linguistics

$\Downarrow$

Truth-Conditional Semantics

$\Downarrow$

Grounded Model Theory

$\Uparrow$

Plan-based pragmatics

$\Uparrow$

Robotics

$\Rightarrow$ Grounding of higher mental functions connects Computational Linguistics (CL) and Robotics.

Thank you for your attention.

- Discussion
- Questions

References I

N. Asher. Belief in discourse representations theory. *Journal of Philosophical Logic*, 15:127 – 189, 1986.

D. Davidson. The logical form of action sentences. In N. Rescher, editor, *The Logic and Decision of Action*, pages 81 – 95. The University of Pittsburgh Press, Pittsburgh, 1967.

D. Dennett. *The intentional stance*. MIT Press, Cambridge, 1989.

F. Dretske. *Explaining Behavior. Reasons in a World of Causes.* MIT Press, Cambridge, 1988.

D. Hartmann and P. Janich. *Methodischer Kulturalismus.* Suhrkamp, Frankfurt a. M., 1991.

References II

H. Kamp. Prolegomena to a structural account of belief and other attitudes. In J. Anderson, C. Owens, editor, *Propositional Attitudes. The Role of Content in Logic, Language and Mind.*, volume 20, pages 27 – 90. CSLI Lecture Notes, Stanford, 1990.

H. Kamp, J. van Genabith, and U. Reyle. Discourse Representation Theory. In D. Gabbay and F. Guenthner, editors, *Handbook of Philosophical Logic*, Dordrecht, 2007. Kluwer.

M. Moens and M. Steedman. Temporal ontology and temporal reference. *Computational Linguistics*, 14:15–28, 1988.

J. R. Searle. *Speech Acts: An Essay in the Philosophy of Language*. Cambridge University Press, Cambridge, 1969.

Z. Vendler. Verbs and times. *The Philosophical Review*, 66(2):143 – 160, April 1957.

References III

J. M. Zacks and K. M. Swallow. Event segmentation. *Current Directions in Psychological Science*, 16(2):80–84, 2007.

J. M. Zacks, B. Tversky, and G. Iyer. Perceiving, remembering and communicating structure in events. *Journal of Experimental Psychology: General*, 130:29 – 58, 2001.