Using Parameterised Semantics for Speech-Gesture Integration

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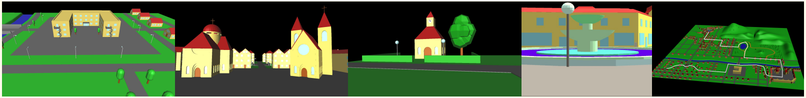
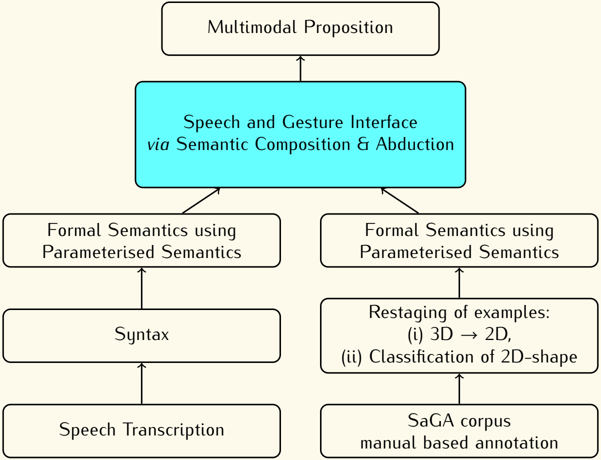


Introduction

Our talk is about the semantics and pragmatics of speech-gesture ensembles. It draws on several research lines:

- A fully annotated and rated multi-modal corpus (Bielefeld **S**peech **a**nd **G**esture **A**lignment corpus), cf. Lücking, Bergmann, Hahn, Kopp, and Rieser (2012)
- Research on gesture typology using SaGA, cf. Rieser (2010)
- Computational simulation and approximation techniques for gesture descriptions based on motion capturing, cf. Pfeiffer, Hofmann, Hahn, Rieser and Röpke (2013)
- Semantic and pragmatic theorizing using Parameterised Semantics, where the basic principle of semantic composition is conjunction (cf. Pietroski (2005)) relative to a coordination scheme (cf. Fine (2007))

Methodology



Result of the talk

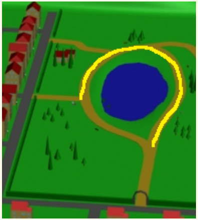
Unified semantic representation for speech-gesture ensembles

Outline of the Talk

Overview

Motivation

- Interlocutors often point at things or shape their contours.



(1) *(Du) gehst quasi drei Viertel um den Teich herum.*
"You roughly walk three quarters around the pond around."

Motivation

Crucial observations:

- The expression *drei Viertel um den Teich herum* does not specify the shape of the agent's path around the pond.
- This utterance overlaps temporally with a gesture expressing a circular trajectory.

What we want to explain:

- The gesture is interpreted as specifying the shape of the agent's path.

McNeill's Synchrony Observations

- Overlap of speech and gesture is not random (McNeill (1992)).
- Meaningful part of the gesture (stroke) is synchronized with speech regarding
  - the semantics of the speech part (i.e., presenting a related meaning)
  - phonology and pragmatics

Constraint for interfacing

The overlap is meaningful for interfacing speech and gesture meaning.

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The overlap is meaningful for interfacing speech and gesture meaning.

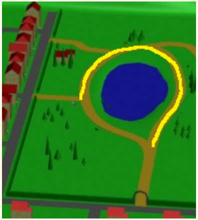
How can the interface of speech and gesture meaning be modelled?

Context of Research on Speech-Gesture Interfaces

- Finite State modelling: Johnston (1998)
- Unification-based Grammar: Johnston, Cohen, McGee, Oviatt, Pittman, and Smith (1997); Johnston and Bangalore (2000)
- LTAG: Kopp, Tepper, and Cassell (2004); Rieser (2004)
- Montague Grammar: Giorgolo (2010); Röpke, Hahn, Rieser (2013)
- HPSG: Alahverdzhieva and Lascarides (2010); Alahverdzhieva (2013); Lücking (2013)
- SDRT: Lascarides and Stone (2006, 2009a, b); Lücking, Rieser, and Staudacher (2006)
- Poesio and Traum's Dialogue Theory (PTT): Rieser and Poesio (2009); Rieser (2011)

Overview

Example



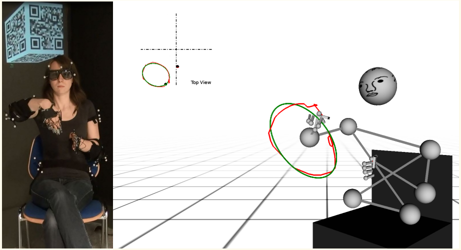
"You roughly walk three quarters around the pond around."

Gesture Semantics Based on Manual Annotations

$$\begin{bmatrix} \text{Path\_of\_Wrist} & \text{ARC<ARC<ARC<ARC} \\ \text{Representation\_Technique} & \text{Drawing} \end{bmatrix}$$

$$\begin{aligned} \exists x_1 y_1 y_2 y_3 y_4 (\quad & \mathsf{trajectory}(x_1) \wedge \\ & \mathsf{seg}(y_1, x_1) \wedge \mathsf{seg}(y_2, x_1) \wedge \mathsf{seg}(y_3, x_1) \wedge \mathsf{seg}(y_4, x_1) \wedge \\ & \mathsf{bent}(y_1) \wedge \mathsf{bent}(y_2) \wedge \mathsf{bent}(y_3) \wedge \mathsf{bent}(y_4) \wedge \\ & y_1 < y_2 < y_3 < y_4) \end{aligned}$$

Gesture Semantics Based on Motion Capturing



circular.traj$(x) =_{\text{DEF}}$

$\exists yz($ trajectory$_2(x) \wedge$

projection$(y, x) \wedge$

approximates$(y, z) \wedge$

circle$(z))$

$\exists x$(circular.traj(x))

Overview

Parameterised Semantics – An Example

- Lexical items:

$$\frac{\textit{praised}}{\mathsf{praised}'(x,y)};\ \frac{\textit{Bill}}{x = \mathsf{bill}'};\ \frac{\textit{Sam}}{x = \mathsf{sam}'}$$

Parameterised Semantics – An Example

- Lexical items:

$$\frac{\textit{praised}}{\text{praised}'(x, y)};\ \frac{\textit{Bill}}{x = \text{bill'}};\ \frac{\textit{Sam}}{x = \text{sam'}}$$

- Combining verb and direct object:

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$$x \quad = \text{bill'}$$

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- Combining subject and verb phrase:

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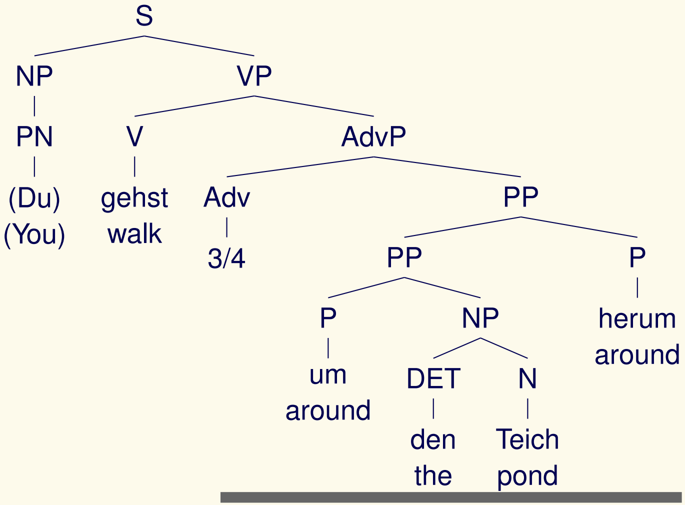
Principles of Parameterised Semantics

- **Semantic composition** amounts to:
  - **Conjunction** (cf. Pietroski (2005)) relative to
  - a **coordination scheme** indicating which variables get identified (cf. Fine (2007)) and
  - a **renaming** of free variables to avoid accidental identification.
- Coordination schemes are determined by:
  - Morphology and/or syntax (cf. Kracht's (2013) Referent Systems), or by
  - Pragmatic inferences (e.g., abduction).
- Parameters: the free variables in the semantic representations on which the value of the semantic representations depends.

Overview

Speech Syntax



Speech Semantics

$$\frac{\textit{um}}{\begin{array}{l}\text{mover}(e) = x \wedge \\ \text{trajectory}(x, e) = t \wedge \\ \text{around}(t, r, d)\end{array}} \bullet_{\{\langle r,p \rangle\}} \frac{\textit{den Teich}}{p = \iota x.\text{pond}(x)} = \frac{\textit{um den Teich}}{\begin{array}{l}\text{mover}(e0) = x0 \wedge \\ \text{trajectory}(x0, e0) = t0 \wedge \\ \text{around}(t0, r0, d0) \wedge \\ p1 = \iota x.\text{pond}(x) \wedge \\ r0 = p1\end{array}}$$

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Speech Semantics

$$\frac{\textit{drei Viertel}}{d = 0.75} \bullet_{\{\langle d, d \rangle\}} \frac{\textit{um} \ \ldots \ \textit{herum}}{\begin{array}{l}\text{mover}(e) = x \wedge \\ \text{trajectory}(x, e) = t \wedge \\ \text{around}(t, r, d) \wedge \\ r = \imath x.\text{pond}(x) \wedge \\ d \geq 0.5\end{array}} = \frac{\textit{drei Viertel} \ \ldots \ \textit{herum}}{\begin{array}{l}d0 = 0.75 \wedge \\ \text{mover}(e1) = x1 \wedge \\ \text{trajectory}(x1, e1) = t1 \wedge \\ \text{around}(t1, r1, d1) \wedge \\ r1 = \imath x.\text{pond}(x) \wedge \\ d1 \geq 0.5 \wedge \\ d0 = d1\end{array}}$$

Overview

Interface

The speech-gesture interface is constructed in two steps:

1. Infer (by abduction) an explanation for why gesture G is synchronized with utterance U (written as $G \sim U$).
2. Assuming this explanation, perform parameterised semantic composition of gesture and speech denotations.

Interface – Explaining $G \sim U$

- To explain why G is synchronized with U we assume the following gesture interpretation rule (cf. Constraint for interfacing):

  R: If a semantic parameter x of gesture G approximates a semantic parameter y of utterance U, then $G \sim U$.

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- Abduction:

	First premise:	$G \sim U$
	Second premise:	If ϕ then $G \sim U$
	$\therefore$	ϕ

Interface – Enriching Parameterised Composition by Abduction

Pragmatic enrichment of parameterised semantic composition of gesture and speech denotation:

$$\frac{G}{\textsf{circular.traj}(g)} \bullet_C \frac{\textit{drei} \;\ldots\; \textit{herum}}{\begin{array}{l}\textsf{mover}(e) = x \wedge \\ \textsf{traj}(x, e) = t \wedge \\ \textsf{around}(t, r, d) \wedge \\ r = \imath x.\textsf{pond}(x) \wedge \\ d = 0.75\end{array}}$$

Interface – Enriching Parameterised Composition by Abduction

One possible instantiation of the rule, given our example:

First premise:	$G \sim U$
Second premise:	g of G approximates t of $U \rightarrow G \sim U$
$\therefore$	g of G approximates t of U

$$\frac{G}{\mathsf{circular.traj}(g)} \bullet_C \frac{\textit{drei} \ \ldots \ \textit{herum}}{\begin{array}{l}\mathsf{mover}(e) = x \wedge \\ \mathsf{traj}(x, e) = t \wedge \\ \mathsf{around}(t, r, d) \wedge \\ r = \imath x.\mathsf{pond}(x) \wedge \\ d = 0.75\end{array}}$$

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$$\frac{G}{\mathsf{circular.traj}(g) \wedge \mathsf{approx}(g,t)} \bullet_{\{\langle t,t\rangle\}} \frac{\textit{drei} \ \ldots \ \textit{herum}}{\mathsf{mover}(e) = x \wedge \mathsf{traj}(x,e) = t \wedge \mathsf{around}(t,r,d) \wedge r = \iota x.\mathsf{pond}(x) \wedge d = 0.75}$$

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Conclusions

- Formal semantics of gestures is based on rigorous empirical investigation.
- Parameterised semantic composition amounts to conjunction relative to a coordination scheme (which specifies which free variables are to be identified).
- The coordination schemes for composing the denotations of natural language expressions are (partly) determined by morphology and syntax.
- Parameterised semantic composition captures also the interfacing of speech and gesture denotations.
- In this case the variables to be identified are determined by abduction.
- Parameterised Semantics provides a unified semantic representation of speech-gesture ensembles.

Acknowledgements

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We also want to thank our colleagues Thies Pfeiffer and Florian Hofmann.

Thank you for your attention!

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Referent systems – An Example

$$\langle \texttt{Cicero}, \boxed{\langle x : \triangle\ \bigcirc : nom \rangle}, \begin{array}{|l|}\hline x \\ \hline \texttt{Cicero}(x) \\ \hline \end{array} \rangle \bullet$$

$$\langle \texttt{videt}, \begin{array}{|l|}\hline \langle x : \nabla \obar : nom \rangle \\ \langle y : \nabla \obar : acc \rangle \\ \hline \end{array}, \begin{array}{|l|}\hline \\ \hline \texttt{videt}(x, y) \\ \hline \end{array} \rangle =$$

$$\langle \texttt{Cicero videt}, \begin{array}{|l|}\hline \langle x^2 : -\bigcirc : nom \rangle \\ \langle y^2 : \nabla \obar : acc \rangle \\ \hline \end{array}, \begin{array}{|l|}\hline x^2 \\ \hline \texttt{Cicero}(x^2) \\ \texttt{videt}(x^2, y^2) \\ \hline \end{array} \rangle$$

Referent systems – An Example (continued)

$$\langle \texttt{Marcum}, \boxed{\langle x : \triangle \bigcirc : acc \rangle}, \begin{array}{|l|} \hline x \\ \hline \texttt{Marcum}(x) \\ \hline \end{array} \rangle \bullet$$

$$\langle \texttt{Cicero videt}, \begin{array}{|l|} \hline \langle x^2 : -\bigcirc : nom \rangle \\ \langle y^2 : \nabla \obar : acc \rangle \\ \hline \end{array}, \begin{array}{|l|} \hline y^2 \\ \hline \texttt{Cicero}(x^2) \\ \texttt{videt}(x^2, y^2) \\ \hline \end{array} \rangle =$$

$$\langle \texttt{Marcum Cicero videt}, \begin{array}{|l|} \hline \langle x^{22} : -\bigcirc : nom \rangle \\ \langle y^{22} : -\bigcirc : acc \rangle \\ \hline \end{array}, \begin{array}{|l|} \hline x^{22}, y^{22} \\ \hline \texttt{Cicero}(x^{22}) \\ \texttt{Marcum}(y^{22}) \\ \texttt{videt}(x^{22}, y^{22}) \\ \hline \end{array} \rangle$$

Deduction and Abduction

- Deduction:

$$\begin{array}{ll} & \alpha \rightarrow \beta \\ & \alpha \\ \hline \therefore & \beta \end{array}$$

- Abduction:

$$\begin{array}{ll} & \alpha \rightarrow \beta \\ & \beta \\ \hline \therefore & \alpha \end{array}$$

Principles of Parameterised Semantics

- Given two formulas α and β, let $FV(\alpha)$ be the set of free variables of α, and $FV(\beta)$ be the set of free variables of β. Then a coordination scheme for α and β is a subset $C \subseteq FV(\alpha) \times FV(\beta)$.
- Parameterised semantic composition amounts to conjunction relative to a coordination scheme C and renaming of free variables:

$$\alpha \bullet_C \beta := \mathbf{r_0}(\alpha) \wedge \mathbf{r_1}(\beta) \wedge \bigwedge \{\mathbf{r_0}(x) = \mathbf{r_1}(y) : \langle x, y \rangle \in C\}$$

$\mathbf{r_0}(\alpha)$ renames the free variables in α by adding a 0.

$\mathbf{r_1}(\beta)$ renames the free variables in β by adding a 1.

Parameters and conjunctive semantics

- Pietroski's (2005, p. 28) hypothesis: "when expressions are concatenated, they are interpreted as (conjoinable) monadic predicates; and the resulting phrase is interpreted as a predicate satisfied by whatever satisfies both constituents"
- Kracht's (2013) distinction between referents and parameters: referents are identified by matching morphosyntactic information, parameters are identified differently

(2) Im Jahr 1963 wurde der damalige US-Präsident ermordet.
In year 1963 was the then US-president assassinated.

Gesture interpretation rule

- Let $\alpha := \bigwedge_{i=1}^{m} \alpha_i$ and $\beta := \bigwedge_{j=1}^{n} \beta_i$ be the semantic representations of gesture G and utterance U, respectively. Then:

(3) $\quad x \in FV(\alpha) \wedge y \in FV(\beta) \wedge \alpha_i = \mathsf{approx}(x, z) \wedge \langle z, y \rangle \in C \rightarrow G \sim U$