Cognitive semantics and cognitive theories of representation:
Session 8: Meaning and grammar

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Príprava štúdia matematiky a informatiky na FMFI UK v anglickom jazyku
ITMS: 26140230008
Main approaches to grammar

- **Nativists** – Universal grammar (Chomsky), LAD module (Fodor)
- **Empiricists** – Usage-based theories (Tomasello)
  - Construction grammar – cognitive linguists (Lakoff, Fillmore, Kay, Langacker – those west coast guys 😊)
  - Statistical approaches (Elman, Bates, Karmiloff-Smith, Bates, Plunkett,...)
How can we use language to talk about our experience?
How is language processing “implemented” in brain?

Neural Theory of Language – NTL group @ Berkeley
What does language do?

A sentence can evoke an imagined **scene** and resulting **inferences**:

“Harry walked to the cafe.”
- Goal of action = at cafe
- Source = away from cafe
- cafe = point-like location

“Harry walked into the cafe.”
- Goal of action = inside cafe
- Source = outside cafe
- cafe = containing location

(This and the next 8 slides thanks to Nancy Chang and NTL group @ Berkeley)
A construction is a form-meaning pair whose properties may not be strictly predictable from other constructions.

(Construction Grammar, Goldberg 1995)
The meaning pole may evoke schemas (e.g., image schemas) with a local alias. The meaning pole may include constraints on the schemas (e.g., identification constraints →).
TO vs. INTO:
INTO adds a Container schema and appropriate bindings.

The INTO construction

construction INTO

form

self_f.phon ← /Int^hu^w/

meaning

evokes

Trajector-Landmark as tl
Source-Path-Goal as spg

Container as cont

constraints:

tl.trajector ↔ spg.trajector

tl.landmark ↔ cont

cont.interior ↔ spg.goal
cont.exterior ↔ spg.source
The **CAUSED-MOTION** construction

<table>
<thead>
<tr>
<th>construction</th>
<th>CAUSED-MOTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>subcase of</td>
<td>Pred-Expr</td>
</tr>
<tr>
<td>constructional constituents</td>
<td></td>
</tr>
<tr>
<td>agent</td>
<td>Entity</td>
</tr>
<tr>
<td>action</td>
<td>Action</td>
</tr>
<tr>
<td>patient</td>
<td>Entity</td>
</tr>
<tr>
<td>path</td>
<td>SPG</td>
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<tr>
<td>form</td>
<td></td>
</tr>
<tr>
<td>agent&lt;sub&gt;f&lt;/sub&gt;</td>
<td>before action&lt;sub&gt;f&lt;/sub&gt;</td>
</tr>
<tr>
<td>action&lt;sub&gt;f&lt;/sub&gt;</td>
<td>before patient&lt;sub&gt;f&lt;/sub&gt;</td>
</tr>
<tr>
<td>action&lt;sub&gt;f&lt;/sub&gt;</td>
<td>before path&lt;sub&gt;f&lt;/sub&gt;</td>
</tr>
<tr>
<td>meaning</td>
<td></td>
</tr>
<tr>
<td>evokes</td>
<td>Caused-Motion as cm</td>
</tr>
<tr>
<td>self&lt;sub&gt;m&lt;/sub&gt;</td>
<td>scene ↔ cm</td>
</tr>
<tr>
<td>cm.agent</td>
<td>↔ agent&lt;sub&gt;m&lt;/sub&gt;</td>
</tr>
<tr>
<td>cm.action</td>
<td>↔ action&lt;sub&gt;m&lt;/sub&gt;</td>
</tr>
<tr>
<td>cm.patient</td>
<td>↔ patient&lt;sub&gt;m&lt;/sub&gt;</td>
</tr>
<tr>
<td>cm.path</td>
<td>↔ path&lt;sub&gt;m&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
Simulation-based language understanding

“Harry walked into the cafe.”  Utterance

General Knowledge

Belief State

Simulation

Analysis Process

Constructions

Semantic Specification

```
construction WALKED
    form
    self, phon ← [wakt]
    meaning : Walk-Action
    constraints
    self_m, time before Context.speech-time
    self_m, aspect ← encapsulated
```
Language Understanding Process

**FORM**
- Phonological schemas
- Utterance

**MEANING**
- Conceptual schemas
- Communicative context

**Analysis**
- Semantic Specification

**Simulation**
- Inferences
Constructional analysis

**Active-Ditransitive**

- **/meΧi蠡/** → **M A R Y**
- **/tɔst/** → **T O S S E D**
- **/mi蠡/** → **M E**
- **/θ/** → **A-CN-EXPR**
- **/dɾİŋk/** → **D R I N K**

**Predication**

- **Referent**
  - resolved-referent: **Mary**
  - accessibility: inactive
- **Predication**
  - schema: **Toss**
  - toser: tossed
  - event-structure: encapsulated setting, time: past
- **Referent**
  - resolved-referent: **speaker**
  - accessibility: active

**Transfer**

- scene: **Transfer**
  - agent: **Mary**
  - theme: **toss**
  - recipient: **tossed**
  - means: **encapsulated**

**Referent**

- accessibility: unidentifiable number: singular
- category: **Drink**
A different – bottom-up approach...

Two approaches

Language and sensorimotor (SM) processing are **modules**

Language and SM processing share mechanisms

Semantic representations **abstract away** from details of SM processing

Semantic representations **retain** details of SM processing
Embodied view on language

• Language comprehension
  – Numerous empirical evidence (review in e.g. Barsalou, 2008, Glenberg & Kaschak, 2003).

• Individual words access SM representations
  – Pulvermüller et al. (1999) ERP study: concrete nouns activate visual cortices; action verbs activate motor/premotor cortices
  – Pulvermüller et al. (2005): TMS over hand and leg areas differentially affects processing of hand and leg verbs
  – Pulvermüller et al. (2005b) MEG study: leg and mouth verbs activate corresponding areas of motor cortex
How about grammar?

• What is the relation between **SM mechanisms** for *combining* object and action representations into events and **language syntax**?
How about grammar?

• What is the relation between SM mechanisms for combining object and action representations into events and language syntax?
• (Knott, 2012)
Central hypothesis

• The syntactic structure of a sentence describing a concrete event in the world provides a direct encoding of the cognitive processes via which this event is experienced and stored in memory.
Methodology

• Choose a concrete episode: MAN GRABBED CUP
• Study in detail what happens when such an episode is experienced (as doer, or observer)
• Study the syntactic structure of a sentence describing the episode
• Look for correspondences
Talk roadmap

• *MAN GRABS CUP*: SM account
• “John grabs a cup.”: Syntactic analysis
• Reinterpretation of the syntax in SM terms
• Computational model of sentence generation
Talk roadmap

- **MAN GRABS CUP**: SM account
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SM account of episodes

- Our big claim: experiencing an episode involves a canonically structured sequence of sensorimotor (SM) operations.
- **Perceiving** an episode involves a canonical SM sequence.
- **Executing** an episode involves a canonical sequence.
- Episodes are stored in working memory (WM) as prepared SM sequences.
- **Reporting** an episode in language involves rehearsing a prepared SM sequence.
Step 1: attention to the agent

The observer who experiences an episode could be watching it, or doing it.
The **agent** of the episode is experienced very differently in these two cases. But in each case, the agent is represented early.

- If the observer is doing the action, he generates a representation of ‘himself’ at the point when he decides to act (see e.g. Haggard, 2008).
- If the observer is watching the action, he typically attends to the agent first, because animate objects are salient (Pratt et al., 2010).
Step 2: attention to the target/patient

Before the observer can activate a representation of an action, he must attend to the target object.

• If the observer is the agent, he must fixate the target before he can activate a detailed motor programme. (Johansson et al., 2001)

• If the observer is watching an external agent, he attends to the target well before the observed agent’s hand reaches it. (Flanagan and Johansson, 2003; Webb et al., 2010)
Steps 1 and 2 for action perception

• (Webb, Knott and MacAskill, ‘Eye movements during transitive action observation have sequential structure’, Acta Psychologica 2010)
Step 3: action monitoring

After the observer attends to the target, alternative action representations compete in premotor cortex, and one is selected. At this point, the character of SM processing changes from discrete to continuous.

- **Action execution:** the selected action representation becomes part of a circuit implementing a dynamical system, which moves the agent’s hand onto the cup. (Cisek and Kalaska, 2010)

- **Action observation:** the selected action representation is used to model the perceived pattern of movement (Oztop and Arbib, 2002; Oztop et al., 2005)
We argue that both agent and target are reattended to when a reach-to-grasp action is experienced.

• During action monitoring, the agent is reattended to as a dynamic entity. (Damasio, 1999)
• At the end of the action, the target is reattended to as a motor state. (Goodwin and Wheat, 2004)

These actions of reattention are crucial for the development of cross-modal object representations.
Canonical SM sequence

Sequence for observing or doing an action

• 1 attention to agent
• 2 attention to patient
• 3 agent reattended
• 4 patient reattended
Deictic routines (Ballard et al. 1997)

- The building block of SM processing is a **deictic operation**: an attentional or motor operation that takes place in an **initial context**, and generates a **new context**, along with a **reafferent sensory signal**.
- SM processes are naturally organised into **sequences** of deictic operations, called **deictic routines**.

<table>
<thead>
<tr>
<th>Initial context</th>
<th>Deictic operation</th>
<th>Reafferent signal</th>
<th>New context</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>$O_1$</td>
<td>$S_1$</td>
<td>$C_2$</td>
</tr>
<tr>
<td>$C_2$</td>
<td>$O_2$</td>
<td>$S_2$</td>
<td>$C_3$</td>
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Deictic routine for cup-grabbing action

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<td>Attend_agent</td>
<td>Agent</td>
<td>C₂</td>
</tr>
<tr>
<td>C₂</td>
<td>Attend_target</td>
<td>Cup</td>
<td>C₃</td>
</tr>
<tr>
<td>C₃</td>
<td>Activate “grasp”</td>
<td>Agent</td>
<td>C₄</td>
</tr>
<tr>
<td>C₄</td>
<td></td>
<td>Cup</td>
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Deictic routines in working memory

• Hypothesis: **deictic routines (episodes) are stored in memory as plans and can be replayed/simulated upon retrieval.**
  – In accord with simulationist theories of meaning (Barsalou, 1999, 2008; Feldman & Narayanan, 2004; Gallese & Lakoff, 2005).
  – Evidence for planned attentional and motor sequences in dlPFC of macaques (Baron & Joseph, 1989; Averbeck et al., 2002).
  – Episodic buffer (Baddeley, 2000).
  – Suggested role in hippocampal learning (Abraham et al, 2002).
  – Computational model (Takac & Knott, 2015).
## Deictic routine for cup-grabbing action

<table>
<thead>
<tr>
<th>Stored SM plan</th>
<th>Transient signals</th>
<th>Initial ctx</th>
<th>Replayed operation</th>
<th>Reactivated stimulus</th>
<th>New ctx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attend_Man/Attend_Cup/Grasp</td>
<td>C₁</td>
<td>Attend_Man</td>
<td>Man</td>
<td></td>
<td>C₂</td>
</tr>
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<td>C₂</td>
<td>Attend_Cup</td>
<td>Cup</td>
<td></td>
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<td></td>
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Conjecture for language: In order to express an episode verbally, a speaker needs to internally replay the stored episode representation in working memory.
Talk roadmap

• *MAN GRABS CUP*: SM account
• “John grabs a cup.”: Syntactic analysis
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“John grabs a cup.”

Syntactic analysis

• As a syntactic framework, we chose Minimalism (Chomsky, 1995).

• In Minimalism, a sentence has two levels of syntactic structure:
  – **Phonetic Form (PF)**, which is language-specific,
  – **Logical Form (LF)**, which is language-independent and interfaces with meaning.
Logical form

• LF has a tree structure. Its basic building block is called **X-bar schema**.

• Each word in a sentence contributes an XP structure.  
  – The **head** of the structure (X) is the word itself.  
  – The structure also has slots for a **specifier** and a **complement**.  
  – These slots can (recursively) be occupied by other XPs.
Logical form

• LF structures are for the most part right-branching chains of X-bar schemas.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

VP is headed by a verb, and introduces two noun phrases (DPs):
“John grabs a cup.”

Syntactic analysis (Knott, 2014)

Now there are various movement operations, where material moves from one LF position to another.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

One type of movement is **DP movement**.
“John grabs a cup.”

Syntactic analysis (Knott, 2014)

The subject DP raises to the Spec of AgrSP to get Case (assigned by AgrS)
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The subject DP raises to the Spec of AgrSP to get Case (assigned by AgrS)
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The object DP raises to the Spec of AgrOP] to get Case (assigned by AgrO)
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The object DP raises to the Spec of AgrOP] to get Case (assigned by AgrO)
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The object DP raises to the Spec of AgrOP] to get Case (assigned by AgrO)
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The other type of movement is head movement.
“John grabs a cup.”

Syntactic analysis (Knott, 2014)

The verb has morphology agreeing with subject and/or object.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

It raises to the heads of AgrSP and AgrOP to ‘check’ this morphology.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

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Movement involves *copying*, so each moved element ends up represented in multiple positions.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

The task of an infant language learner is to work out where each element is pronounced at PF.
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

English PF looks like this:
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

French/Italian PF looks like this:
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

Māori PF looks like this:
“John grabs a cup.”
Syntactic analysis (Knott, 2014)

Japanese PF looks like this:
Talk roadmap

- **MAN GRABS CUP**: SM account
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SM interpretation of the X-bar schema

My sensorimotor interpretation of LF is stated as an interpretation of the X-bar schema.
SM interpretation of the X-bar schema

My sensorimotor interpretation of LF is stated as an interpretation of the X-bar schema.

- Each XP describes a single sensorimotor operation.

```
XP
   spec  X'
   X     comp
```
My sensorimotor interpretation of LF is stated as an interpretation of the X-bar schema.

- Each XP describes a single sensorimotor operation.
SM interpretation of the X-bar schema

According to this definition, a right-branching structure of XPs describes a sequence of SM operations.
SM interpretation of the X-bar schema

According to this definition, a right-branching structure of XPs describes a *sequence* of SM operations.
Deictic routine for cup-grabbing action

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<td>$C_4$</td>
</tr>
<tr>
<td>$C_4$</td>
<td></td>
<td>$Cup$</td>
<td></td>
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</table>
SM interpretation of the LF for “John grabs a cup.” (Knott, 2014)

The three XPs in the LF structure map onto the three stages of the SM sequence.
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So: what's the SM characterisation of movement?
SM interpretation of the LF for “John grabs a cup.” (Knott, 2014)

DP raising reflects operations of *re-attention to agent and patient.*
SM interpretation of the LF for “John grabs a cup.” (Knott, 2014)

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SM interpretation of the LF for “John grabs a cup.” (Knott, 2014)

DP raising reflects operations of re-attention to agent and patient.
Recall:

- Verb morphology denotes actions of attention to the agent or patient: it ‘belongs’ at AgrS or AgrO.
- The verb stem denotes a motor action: it ‘belongs’ at V.

So how come the verb morphology can be attached to the verb?

Attentional/motor actions seem able to appear out of sequence.
SM interpretation of V-AgrO-AgrS movement

Proposal:
- SM operations (attentional and motor) feature in LF as *prepared operations*, rather than transient signals.

```
+------------------+
| XP               |
+------------------+
|                  |
| reafferent signal|
| [Spec,XP]        |
|                  |
| X                 |
| prepared sm operation (sustained) | X |
|                  |
|                  |
|                  |
|                  |
|                  |
+------------------+
| YP               |
+------------------+
| next context     |
```

- Note: each prepared operation is active at each stage of the replayed sequence.
SM interpretation of V-AgrO-AgrS movement (Knott, 2009)

Transient (executed) SM operations
SM interpretation of V-AgrO-AgrS movement (Knott, 2009)

Sustained (planned) SM operations
Deictic routine for cup-grabbing action

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<td>$C_3$</td>
</tr>
<tr>
<td></td>
<td>$C_4$</td>
</tr>
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</table>
Consequences - summary

• Generative grammar can be reinterpreted as a processing model.
• Linguistic universals may be the consequence of universal constraints in SM processing.
• Methodological consequence: linguistics and neuroscience can inform each other
Talk roadmap

- *MAN GRABS CUP*: SM account
- “John grabs a cup.”: Syntactic analysis
- Reinterpretation of the syntax in SM terms
- Computational model of sentence generation
Computational model

- How a child learns to map the universal LF onto a PF of the language it is exposed to?
- What is the process of generating LF/PF from meaning?
Computational model – overview

• Collection of interconnected artificial neural networks (ANNs).
• ANNs learn from examples, so are good for modelling language acquisition from exposure.
• Model is trained on [meaning + utterance] pairs.
  • Meaning is replayed as a SM sequence in the layer representing episode rehearsal system (WM).
  • A training sentence is stored in a phonological input buffer.
• The system learns to synchronize SM sequences with training sentences and to generate (morphologically, syntactically, semantically) correct sentences in the exposure language.
Computational model

Computational model

Computational model

Computational model

Computational model

Computational model

Exposure languages

• Model tested on transitive sentences in artificial languages (SVO, SOV, VSO, VOS, OVS, OSV) with English vocabulary of nouns, pronouns, and verbs, subj-verb agreement, irregular plurals, and idioms like “Winnie the Pooh” or “kiss NP good bye”.
Results

• lexicon

• morphology
Results – Inhibition patterns
Results

- Inhibition patterns for the 6 word orders

<table>
<thead>
<tr>
<th>Word-order</th>
<th>C1a (AG)</th>
<th>C1b (ACT)</th>
<th>C2a (PAT)</th>
<th>C2b (ACT)</th>
<th>C3a (AG)</th>
<th>C3b (ACT)</th>
<th>C4a (PAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVO</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SOV</td>
<td>↓</td>
<td>—</td>
<td>↓</td>
<td>↓</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>VSO</td>
<td>—</td>
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<td>VOS</td>
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Results

- idioms

- generalisation ability
Results

• Able to acquire
  – lexicon
  – morphology
  – abstract syntax (word order for each of the 6 types)
  – surface syntax (idioms).

• Able to generalize to new episodes/sentences

• Mimics child developmental trajectory (from single words, through 2-word stage, and item-based constructions (Tomasello, 2003) to full syntax.
Extensions

• Causative and intransitive sentences
• Real languages
  – English – richer morphology (regular/irregular plurals and past tense)
  – Slovak – more flexible word order, subj pro-drop, clitic pronouns, rich morphology (cases, gender agreement)
  – Maori – VSO with rich tense/aspect markers, idioms, three numbers (+dual)
• Results similar to the original experiment (EN 99.5/99.1% on train/test sets, SK 99.0/98.1%).