Course 5

An Evolutionist View Over Conceptualization in Language

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This course is based on a talk given in COST A31 project meeting, Budapest, May 2008

Some pictures belong to Luc Steels
Context of my talk, the subject matter

• The A-31 COST project “Stability and Adaptation of Classification Systems in a Cross-Cultural Perspective”
  – classification, hierarchies, conceptualisation …

• How concepts aroused in humans and how have they been expressed in language?
  – Why do we speak the way we do?
  – Why are there so many languages although most of us operate with the same concepts?
  – Is there a way to prove scientifically hypotheses about the evolution of languages?
The “Talking Heads” experiment

• Goal: how the language evolved?
  – In a community, over time: language emerges through self organisation
  – In individuals, meaning is build in a cumulative growth process

• The ALEAR project (2008-2010)
  – Coordinator: Luc Steels – SONY Laboratories, Paris
ALEAR – Main Objective

“Carefully controlled experiments in which autonomous humanoid robots self-organise rich conceptual frameworks and communication systems with similar features as those found in human languages.”
Synthesis of intelligence approaches

- knowledge-based or symbolic: operationalizing models from logic, generative linguistics and cognitive psychology
- machine learning: copy intelligence by learning
- behaviour-based: put the study of AI on biological grounds (see also earlier cybernetics) ➔ neural: copy the physical realization of the brain, make variations and study the effects
Approaches in studying the evolution of language

• *Whole systems approach*: physical embodiment, sensory-motor, perception, conceptualisation, language
• *Self-generated*: as opposed to designed or acquired through inductive machine learning
• *Multi-agent*: as opposed to stand-alone
• *Evolutionary*: start from scratch and see how a communication system forms and further develops
Setting

• Cognitive agents:
  – Physical aspects:
    • body
    • sensors
    • articulators
    • physical location
    • objects and agents located in the environment
  – Mental properties
    • behaviour
    • memory
    • lexicon
    • grammar
    • etc.

• The two aspects are separated: a real agent exists only when a virtual agent is loaded in a physical robot body
The robots

• Physically embodied autonomous agents
  – Motor-sensory processing
    • perception,
    • movements,
    • actions
  – Conceptual processing
    • recognise objects,
    • learn a lexicon,
    • build representations of concepts
    • towards the development of grammar
Teleporting

• Develop categories in one location and enrich his learning experience by moving to another location
• The transmission of language from one generation to the next
• Intercultural exchange and language contacts by migrating mental bodies in different parts of the world
The “guessing game”

- Two physically instantiated agents: *speaker* and *hearer*
- Why *game*?
  - Because neither agent can look into the mind of the other. They only interact through the external environment
- What triggers the game behaviour?
  - There is an innate motivation programmed: agents try to maximise their communicative success
  - This comes from the necessity to survive
Interaction games

• Rules:
  – agents can interact only conforming to stimuli coming from the external environment
  – they are bound to maximise their communicative success (programmed)

• Acquisitions
  – guessing games: develop the vocabulary and abstract concepts by saying/guessing/pointing
  – develop space and time conceptualisations: events
  – develop rudiments of syntax
The protocol of a game

- One agent (speaker) chooses an object (focus), conceptualises it and emits a string description conforming to his lexicon
- The second agent (hearer) parses that description, matches it against his own conceptualisations and returns one object he believes is the focus object
- If match, the game is successful ➔ both agents increase their confidence in the mapping conceptual space-lexicon for the words they used
- If the game fails ➔ they decrease their confidence and the hearer learns another connection between the real focus and the description string

Sussex University, NLP seminar, 17 March 2011
The Mondriaan Experiment
Perception and categorisation

• Sensory channels
  – software processes interpreting specific real world information:
    • HPOS (horizontal position)
    • VPOS (vertical position)
    • GRAY (gray level)
    • others
  – domain: 0-10 (continuous) discretised to a number of discrete values ➔ categorisation
  – categorisation could be specific to individuals
The categories trees

- Each individual can develop his own tree of categories for each sensory channel
- Example for HPOS:

```
agent A
  left
  right
```

```
agent B
  left
  right
  extreme left
  middle left
  middle right
  extreme right
```
Categorisation in individuals

This object will be interpreted as...

Important notice: the symbols **left** and **middle left** are our conventions to notate the HPOS property values – they do not belong to the acquired lexicon!
About perception again: why do we use some features and not others?

- **Salience**: the property of one feature to distinguish the topic in the context:
  - the minimum distance between the topic’s value for that feature and all the other objects’ values for that feature
About perception again: why do we use some features and not others?

After scaling:

<table>
<thead>
<tr>
<th>obj</th>
<th>HPOS</th>
<th>VPOS</th>
<th>HEIGHT</th>
<th>WIDTH</th>
<th>GRAY</th>
<th>AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.45</td>
<td>0.30</td>
<td>0.66</td>
<td>0.45</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>0.32</td>
<td>0.40</td>
<td>0.50</td>
<td>0.90</td>
<td>0.74</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
<td>0.31</td>
<td>0.50</td>
<td>0.30</td>
<td>0.42</td>
<td>0.76</td>
</tr>
<tr>
<td>sal</td>
<td>0.05</td>
<td>0.01</td>
<td>0.10</td>
<td>0.16</td>
<td>0.45</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Lexicalisation – associating meanings to words

Game 125

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B does not know “mo”
B says: “mo?”
A points to the topic
B categorizes the topic as HPOS[right]
B stores “mo” as HPOS[right]
Lexicalisation – interpretation

Game 205

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: "mo"
B interprets "mo" as HPOS[right]
B points to the topic
A says "OK"
Lexicalisation – synonymy

Game 245

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B does not know “mo”
B says: “mo?”
A points to the topic
B categorizes the topic as HPOS[right]
B has a word for HPOS[right]: “mogash”
B stores “mo” as a synonym for “mogash”
Differences in conceptualization produce “subtle” social polysemy

Game 280

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B does not know “mo”
B says: “mo?”
A points to the topic
B categorizes the topic as HPOS[middle right]
B stores “mo” as HPOS[middle right]

• A has a two-values conceptualization of HPOS
• B has a four-values conceptualization of HPOS
Subtle social differences in meaning can give rise to generalisations

Game 302

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B knows “mo” as HPOS[middle right]
B does not recognize an object in the scene having this value
B says: “mo?”
A points to the topic
B categorizes the topic as HPOS[extreme right]
B stores “mo” as HPOS[extreme right]
Now B knows “mo” as both HPOS[middle right] and HPOS[extreme right]

By repetition he can infer a new category which subsumes both HPOS[middle right] and HPOS[extreme right], which should be HPOS[right], and this will be called “mo”
Ambiguity-1

Game 325

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B does not know “mo”
B says: “mo?”
A points to the topic
B categorizes the topic as HPOS[right] and VPOS[low] and GRAY[light]
B stores “mo” as HPOS[right] OR VPOS[low] OR GRAY[light]

However, by positive feedback the lexicon will converge towards an efficient usage
Recovering from ambiguity

It is not known a priori whether “mo” will be stabilized by B as only HPOS[right] or only VPOS[low] or the union of the two.

An example:
Game 340

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B knows “mo” as HPOS[right] OR VPOS[low] OR GRAY[light]
B recognizes an object in the scene with the value HPOS[right] and no object with the value VPOS[low] or GRAY[light]
B points to the topic
A says “OK”
B diminishes the meaning of “mo” as VPOS[low] and GRAY[light] and augments its meaning as HPOS[right]
Suppose Game 325 takes place as following, instead:

Game 325’

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B does not know “mo”
B says: “mo?”
A points to the topic
B categorizes the topic as VPOS[low]
B stores “mo” as VPOS[low]]

At this moment A and B understand different concepts by “mo”.
Ambiguity maintained

After Game 325, A knows “mo” as meaning HPOS[right] and B acquired it as VPOS[low]

Then we have this:
Game 390

A segments the scene in 2 objects
A categorizes the topic as HPOS[right]
A says: “mo”
B knows “mo” as VPOS[low]
B recognizes an object in the scene with the value VPOS[low]
B points to the topic
A says “OK”

Now and again, the two agents do not realize that they give different meanings to “mo”
What is proved?

• A lexicon in a single agent
  – new words are invented or adopted
  – scores of association between forms (words) and meanings (concepts) go up and down
  – a “virgin”, “newly born” agent will catch up with a lexicon already existent in a population

• A common lexicon that stabilizes in a group of agents
  – however, differences could still coexist
  – the lexicon is sensible to the grows or reduction of population
  – the lexicon can absorb some shocks of contacts with other groups or can be destabilized
What the plots show?

• Ontology size as compared to communication success
  • Communication success dips each time the ontology is enlarged with new concepts, since new words have to be invented to deal with them.
  • However, the agents clearly manage to become again successful in guessing.
What the plots show?

• Increasing the population size
  • The agents create a word without knowing that one word already exist somewhere in the population (as it takes time to propagate) ➔ the risk of synonymy increases.
  • However, a steady progress towards an effective communication system is noticed.
What the plots show?

- What happens when two populations interact?
  - There is an initial destabilisation period when the coherence is low as the ambiguity increases.
  - However, the new community catches up and a new common lexicon emerges, abundant in synonyms.
How to prove the origins of language?

• In a simplified form: language = lexicon + grammar
  
  – The lexicon gives names for concepts and objects: the guessing games
  – The grammar expresses relations between concepts and objects: how to put it in terms of interactions between agents?
Guessing games implicit assumptions

• Experiments are made in a controlled setting that simplifies many aspects:
  – The world is simplified to the content of the table (scene)
  – The agents have the attention focused towards the scene
  – Their “aim” is to identify objects (they are motivated)
  – The agents dispose of a set of channels which are sufficient to put in evidence identifying properties of the objects populating the scene
  – The maximum vocabulary sufficient to cover the concepts, as values produced by channels, is strictly limited
  – The words used by the agents apply to property values and not to objects

• This setting is assumed (given, programmed)
Establishing settings for exercising the birth of a grammar

- **Setting 1:**
  - The world: the content of the table (scene)
  - Attention: focused towards the scene
  - Motivation: identifying objects
  - Channels: identify properties of objects (enriched)
  - Maximum vocabulary: strictly limited
  - The agents already share a background vocabulary for naming properties of objects (as in phase 1), not directly objects
  - Only one property is not enough for disambiguation ➔ necessity to use combinations of words to express conjunctions
  - Implicit supposition: combinations express conjunction and not disjunction
Putting words together

New channels:

COLOR: black, red, blue
SHAPE: circle, triangle

Important: the above symbols are our conventions to notate the mentioned property values – they do not belong to the acquired lexicon!
Putting words together

Game 1014

A segments the scene in 4 objects
A categorizes the topic as \{VPOS[low], SHAPE[circle], COLOR[red]\}
A has the lexicon:
   “bagadiru” for VPOS[low]
   “gugeawa” for SHAPE[circle]
   “camende” COLOR[red]
A correctly identifies on the decision tree that VPOS[low] AND SHAPE[circle] are sufficient to identify the topic
A says: “bagadiru gugeawa”
B has the lexicon:
   “bagadiru” for VPOS[low]
   “camende” for COLOR[red]
B says: “gugeawa?”
A points to the topic
B categorizes the topic as \{VPOS[low], SHAPE[circle], COLOR[red]\}
B correctly discovers on the decision tree that either SHAPE[circle] or COLOR[red], in combination with VPOS[low] are sufficient to identify the topic
B stores “gugeawa” as both SHAPE[circle], and COLOR[red], with a confidence = 0.5
Conclusions of a set of experiments of this kind

• Will not give rise to a grammar of expressing conjunctions: the implicit assumption was that putting words together restricts the selection (in conformity with most modern languages)

• The order of words is not important

red circular or circular red
One step further in building a grammar

• Setting 2:
  – The world: the content of the table (scene)
  – Attention: focused towards the scene
  – Motivation for: identifying spatial relations among objects
  – Channels: identify properties of objects BUT ALSO spatial relations among objects
  – Maximum vocabulary: strictly limited
  – The agents have as background a common vocabulary for naming properties of objects (as in phase 1), not directly objects
  – Implicit supposition: in a linear expression Obj₁ R Obj₂, the focus is Obj₁
New channels expressing spatial relations

- HREL: left-of, right-of
- VREL: above, below

\[
\begin{align*}
\text{obj}_1 & \text{ left-of } \text{obj}_2 (0.9) \\
\text{obj}_1 & \text{ left-of } \text{obj}_3 (0.4) \\
\text{obj}_1 & \text{ left-of } \text{obj}_4 (0.6) \\
\text{obj}_3 & \text{ left-of } \text{obj}_2 (0.1) \\
\text{obj}_3 & \text{ left-of } \text{obj}_4 (0.9) \\
& \ldots
\end{align*}
\]
But grammar is all about form

“HREL[right-of(obj₂)]” expresses the concept “whatever is to the right of obj₂”

One way to say that in this relation is obj₁:

“obj₁ lexical-item-for(right-of) obj₂”

But, the agent knows a term for “right”: “mo”

Then, he might combine this term with a new word expressing the concept of “relation”, for instance “ga”: “mo-ga”
Expressing relations between objects

Initial lexicon:

“mo” = HPOS[right]
“bagadiru” = VPOS[low]
“gugeawa” = SHAPE[circle]
“zamira” = SHAPE[triangle]
“camende” = COLOR[red]
“gamaru” = COLOR[gray]

Derived expressions:

“zamira mo-ga gugeawa”
Expressing relations between objects

Initial lexicon:
- “mo” = HPOS[right]
- “bagadiru” = VPOS[low]
- “gugeawa” = SHAPE[circle]
- “zamira” = SHAPE[triangle]
- “camende” = COLOR[red]
- “gamaru” = COLOR[gray]

Derived expressions:
- “camende gugeawa mo-ga bagadiru gamaru gugeawa”
**Guessing relations**

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**Game 2020**

A segments the scene in 5 objects

A categorizes the topic as \{VPOS[low], HPOS[right], SHAPE[circle], COLOR[red], HREL[right-of(SHAPE[circle])], HREL[right-of(COLOR[gray])], …\}

Both A and B have the lexicon:

- “mo” = HPOS[right]
- “bagadiru” = VPOS[low]
- “gugeawa” = SHAPE[circle]
- “zamira” = SHAPE[triangle]
- “camende” = COLOR[red]
- “gamaru” = COLOR[gray]

A correctly identifies on the decision tree that HREL[right-of(obj_1)] is sufficient to identify the topic

A identifies obj_3 as \{SHAPE[circle], VPOS[low], COLOR[red]\}

A says: “camende gugeawa mo-ga bagadiru gamaru gugeawa”

B says: “mo-ga?”

A points to the topic

B identifies “camende gugeawa” as either obj_2 or obj_3

but, based on A’s pointing, eliminates obj_2

B identifies “bagadiru gamaru gugeawa” as obj_1

B stores “mo-ga” as HREL[right-of()]
How to diminish the amount of initial assumptions?

• Remember our Setting 2:
  – ...
  – Implicit supposition: in a linear expression $Obj_1 \mathbin{R} Obj_2$, the focus is $Obj_1$

• This is a direct and artificial immixture in the very heart of the birth process of the language!

• Solution: parameterize all grammatical features of the language and let them evolve naturally
• Word order and prepositions
  John gave Mary a book in the library

• Affixes
  Das Mädchen gibt den schweren Koffer
  The Girl gives the heavy suitcase
  ihres Bruders den Freunden
  (of) her brother (to) the friend

• Inflection
  Brutus Marcellus librum dedit
  Brutus gave a book to Marcellus [Source: palmer, p. 8]

• Particles
  Tanaka-san wa Tokyo de o-to-san ni atta
  Tanaka TOPIC Tokyo (in) father (loc) meet
  Tanaka met his father in Tokyo

from Luc Steels
Examples of semantic roles:

Agent: the instigator of the event

Counter-agent: the force or resistance against which the action is carried out

Object: the entity that moves or changes or whose position or existence is in consideration

Result: the entity that comes into existence as a result of the action

Instrument: the stimulus or immediate physical cause of the event

Source: the place from which something moves

Goal: the place to which something moves

Experiencer: the entity which receives or accepts or experiences or undergoes the effect of an action

Source: Fillmore
Fluid Construction Grammar

- Structures to represent the information needed in language processing about a specific sentence (feature structures)
- Structures to represent the lexical and grammatical constructions (rules)
- Operations of Unify and Merge
- Structures specifying how new rules are built (templates)

a chemical metaphor from Luc Steels
Sensori-motor  Conceptual  Grammatical  Form
Constructions

- Semantic and syntactic categories do not operate in isolation
- They are part of frames (schemas, patterns)
- Constructions are mappings from semantic to syntactic schema
- Constructions can also add additional meaning to meaning of the parts and add additional form

Fillmore, Kay, Michaelis, Croft, Goldberg, ...

from Luc Steels
Conclusion

• The language is considered from an evolutionistic point of view
• Lexicon formation: proved experimentally
• Grammar and dialogue: was in the study in ALEAR
  – Perhaps Fluid Construction Grammar
    • integrates syntax and semantics (Fillmore’s roles)
    • unification and merge mechanisms
Thank you...

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