Evolving Conceptual Spaces for Symbol Grounding in Language Games

Suelen M. de Paula and Ricardo R. Gudwin

DCA-FEEC-UNICAMP

{suelen,gudwin}@dca.fee.unicamp.br
A standard approach in the simulation of language evolution is the use of Language Games to model communicative interactions.

- The agent uses the results from its perceptual layer to conceptualize world objects:
  - Categorization

A traditional approach to do categorization (classic AI) is to use symbolic logic as a background:

- Knowledge is represented by means of symbols;
- Inference rules are used to generate new symbols;
- Usually, knowledge comes from an expert.
Introduction

- **Problem:** it is not possible to say that systems understand the meaning of symbols they manipulate.
  - These symbols are amodal and arbitrary (BARSALOU, 1999);
  - Their internal structures bear no correspondence with the perceptual states that produced them;
  - This leads us to the Symbol Grounding Problem (HARNAD, 1990).
- The use of only amodal symbols imposes strong limitations for researching the emergence of language in intelligent agents.
Perceptual Symbol System Theory

- Barsalou (1999)
  - Perceptual Symbols;
- Two processes are required for the development of a Perceptual Symbol:
  - The storage of multi-modal states (arriving by perception, action and introspection) in long-term memory to create simulators;
  - The partial re-enactment of these states to create a mental simulation.
- The perceptual symbols are not amodal, because they are represented by the perceptual states producing them.

- To define the meaning of linguistic symbols by means of concepts.
- Collection of quality dimensions divided into domains, e.g., the Fruits Space:

```
<table>
<thead>
<tr>
<th>Color Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>hue</td>
</tr>
<tr>
<td>saturation</td>
</tr>
<tr>
<td>brightness</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>Quality Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>nutritional value</td>
</tr>
<tr>
<td>sweet</td>
</tr>
<tr>
<td>sour</td>
</tr>
</tbody>
</table>
```

```
A property is a convex region in some domain.
```
When properties are defined as convex regions in a domain, prototype effects are expected.

- A prototype is the most representative member of a category (ROSCH, 1975; ROSCH, 1978)
  - To find the region comprising the category it represents.

Derived concepts from prototypes in a conceptual space, formed by a single domain, using a Voronoi tessellation.
Our Proposal

- To develop a categorization process, where the decomposition of reality in meaningful experiences is co-evolved with the lexicon formation:
  - Barsalou's notion of mental simulation;
  - Gärdenfors' notion of conceptual spaces;
    - Prototypes will segment the conceptual space in semantic regions which comprises concepts.

- A cognitive architecture can be developed, where mental concepts and lexicon are able to co-evolve during a language game.
We used the Cognitive Systems Toolkit (CST), to design the proposed framework.
Proposed Mental Simulation Framework
How to create prototypes?

- **Criteria**
  - Prototypes have to be created during the agent’s interactions, without prior training.

- We chose an artificial neural network named Evolving Self-Organizing Map (ESOM) (DENG and KASABOV, 2000).
  - Based on Self-Organizing Map (SOM);
  - Self-adaptive and incremental structure.
  - Unsupervised and online learning.
ESOM - Evolving Self-Organizing Map

- ESOM network starts without any node and during learning iterations, it self-updates to categorize the input data;
  - The $\varepsilon$ parameter controls the growing rate of the network.
    - If a distance between input data and the nearest node is greater than $\varepsilon$, a new node is created. Otherwise, no node is created.
  - Each node is connected to its two closest neighbors.
  - The strength of connections is determined by $\gamma$ parameter.
    - Every N steps, the connection between the two most distant nodes is pruned.
ESOM network categorizes the perceived objects:
- Its nodes play the role of prototypes:
  - They will find semantic regions partitioning the conceptual space, during the language game.
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))

Manager

Agents
Objects

Context

Speaker

Listener

Conceptual Space
Lexical Dictionary

Category Name

Our Language Game (naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))

**Manager**

**Agents**

**Object**

**Context**

**Speaker**

**Listener**

**Conceptual Space**

**Lexical Dictionary**

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
</tr>
</thead>
</table>

Our Language Game (naming Game, as proposed by Steels (2012))
Our Language Game
(naming Game, as proposed by Steels (2012))

Our Language Game is a naming game, as proposed by Steels (2012).
Our Language Game
(naming Game, as proposed by Steels (2012))
A population of 50 agents;

A world with 8 types of abstract objects, described by a set of modal features:

- Composed of 2 quality dimensions in the same domain, with random values in the interval [0;30];
- 300 points were sampled following a normal distribution (μ = 0, σ = 2).
Experimental Protocol

- We ran a total of 100 experiments, each of them with 500 games per agent.
- The experiment measured the alignment success population, given by:
  - The communicative success: the listener’s ability to correctly identify the name uttered by the speaker, pointing to the correct referent;
Results

- We use 3 different strategies to reinforce and punish the words that compete to name a concept
  - In both strategies, the agents reached communicative success.
Results

Modal representations of objects. Each cluster characterizes a different category, identified by ESOM.

Voronoi tessellation generated from the ESOM nodes at the end of the naming game. Each color represents a category object and the large black dots the prototypes.
Evolution of segmentation

Conceptual Space

4th iteration

5th iteration

7th iteration

8th iteration

9th iteration

13th iteration

14th iteration

15th iteration

16th iteration
Conclusion

- Mental simulation framework
  - Based on conceptual spaces
- Communicative success under three different conditions
  - Agents can exchange the meaning of linguistic symbols during a naming game, without relying on external representational structures
  - The meaning of names is defined in real-time, while the agents learn to identify the objects in the world
  - ESOM nodes implement prototypes, decomposing the conceptual spaces into a number of semantics regions (concepts).

- Future work
  - Conceptual Space theory in more challenging tasks, as in the field of grammatical language.
Thank you!

Suelen M. de Paula and Ricardo R. Gudwin
DCA-FEEC-UNICAMP
suelen@dca.fee.unicamp.br
gudwin@dca.fee.unicamp.br

CST: http://cst.fee.unicamp.br
References
