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Emergence of Language in Multi-Agent Systems

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Motivation

- Communication and Cooperation in *Multi-Agent Systems* (MAS) play a key role in performing common tasks.
- Models and mechanisms are needed to support agents interacting in dynamic environments with no prior knowledge on others.
- Approach: a basic model to learn/acquire common language and meaning in a group of interacting agents.

Fundamentals

- Research comes from different areas, including:
  - *Cognitive Science* in which research on "origins of intelligence" has stated the "language" as evolutionary and cultural basic process to achieve adaptation (**Game of Language**).
  - *Linguistics*: Chomsky (LAD), Skinner (conditioning).

- Two main hypothesis:
  1. "Language is an adaptive and autonomous system arisen from a self-organizing process" .
  2. "Language becomes complex spontaneously".

Language Acquisition

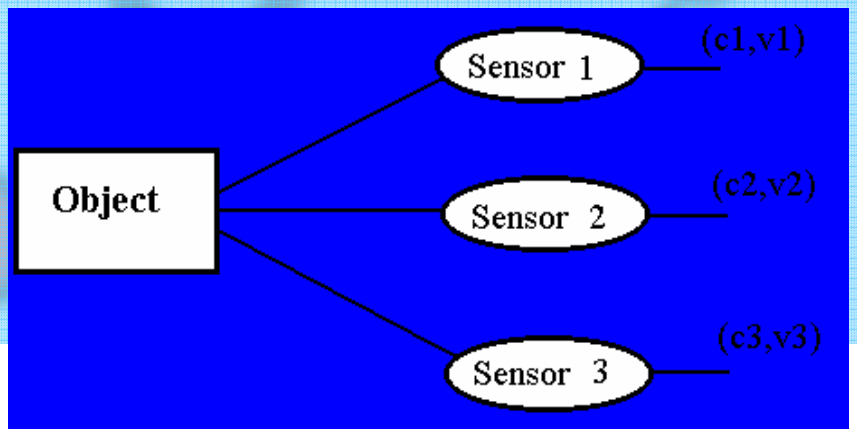
- *The Problem*: a group of agents must learn to agree common meanings for each message on a set of perceptions (signals).

- *Goal*: to provide concept-meaning associations to other agents, and to generate new concepts in the group and associate them with new meanings.

- Assumption: *an agent (**sender**) wants to transmit some meaning for some concept "w". Other agent (**receiver**) has to decode that message "w" (according to its sensorial experience).*

Game of Language

- Agents have a sensorial hierarchy which is shared by every agent, so all of them learn from the environment according to this organization (i.e. shape, color, ..).
- Each agent can be defined by categorizing the reality perceived by its sensors:



Game of Language

- Basic elements:
  - ✓ $A = \{a_1, a_2, \ldots a_m\}$: group of agents.
  - ✓ $C = \{c_1, \ldots c_n\}$: where $C_i=(f,v)$ states the feature ("f") and value ("v") for characteristic "C_i" (sensorial information).
  - ✓ L_{ai} : agent "a_i" has a lexicon with a set of words "w" and associated characteristics.
  - ✓ Some counters:
    - ✓ U(<c,w>,a): usage of association (c,w) by agent "a".
    - ✓ S(<c,w>,a): number of successes in which association (c,w) has successfully been used by agent "a"

Game of Language

- The most basic interaction activity is called a "*Conversation*".
- A ***Conversation*** involves a group of agents, concepts (i.e. words) and meanings.
- In order to establish this conversation, an agent (a *sender)* randomly chooses other agent (*receiver)*.
- The sender selects an element from the environment to be used as the *conversation's* topic.

Game of Language

- Each interaction in every conversation proceeds as follows:
  - ✓ *The sender's lexicon is not suitable: no word associated to perceived meaning, a new word is created, conversation fails and stops (S and U do not change)*
  - ✓ *The receiver's lexicon is not suitable: word sent by sender is not in lexicon (no association), word is associated to its perceived meaning, interaction stops (U is incremented).*

Game of Language

- Each interaction in every conversation proceeds as follows:
  - ✓ *The concept (word) has already a meaning for both sender and receiver:*
    - *The characteristic expected by the receiver is the same as received: both agents increment their U and S counters.*
    - *A feature associated with a receiver's word does not match the information perceived from its sensors: the receiver adds this word to its lexicon and a likely meaning provided from its sensors is linked to it, interactions stops and U is incremented.*

Game of Language

- Cooperation relies on the agents' autonomy.
- These agents are autonomous in two senses:
  - *There is no apriori language knowledge.*
  - *There is no explicit "teaching" of language by an external agent.*
- We need a cooperation protocol to establish the basic "interaction".

Protocol

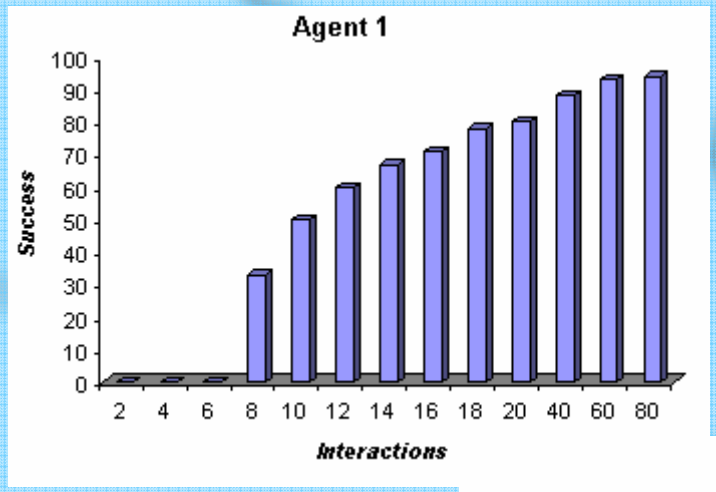
- Agents have only a basic set of skills needed to carry out the interaction.
- The "Learning" strategy is based on reinforcement provided by other agents.
- Counters (U and S) are used as a success metrics.
- There are four basic steps:
  1. *To make contact.*
  2. *To identify a topic.*
  3. *To sent/receive concepts (i.e. words).*
  4. *To send a feedback signal.*

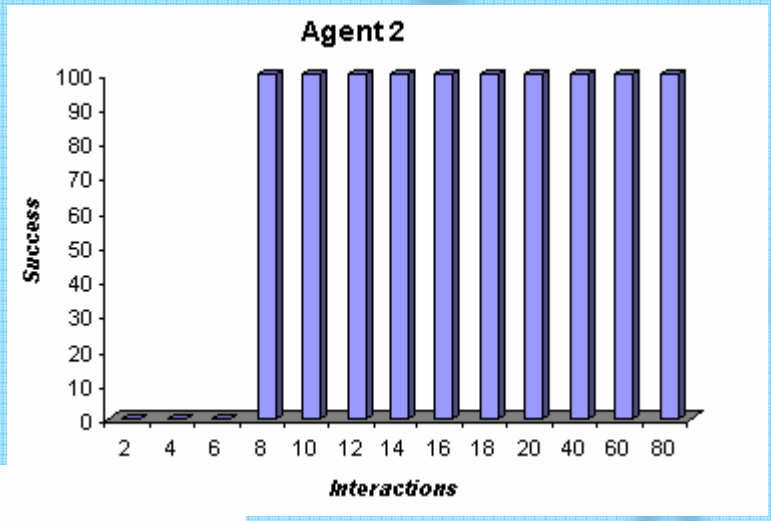
Experiments

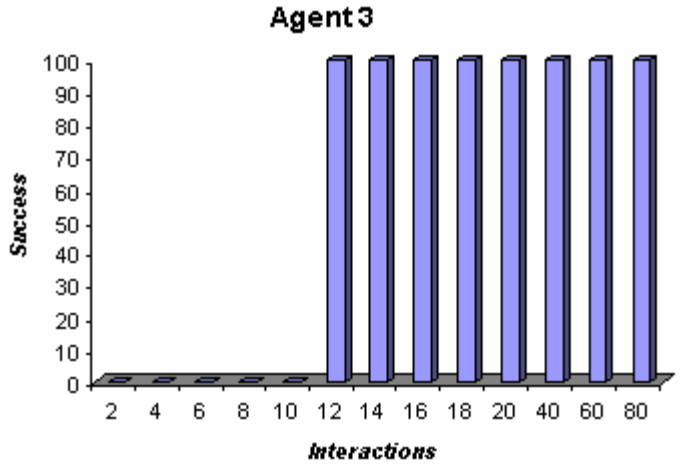
- Some experiments were performed with a variable number of agents and characteristics.
- Aim: assess learning and cooperation capabilities to acquire and agree word-meaning associations.
- Two scenarios for evaluation:
  1. The topic is the same for all the agents.
  2. A conversation has no constraints, anyone can become the sender, receiver, or topic.

Experiments and Results

- Scenario A: 3 agents, topic is on agent 3, random word "be" with meaning (1,1).

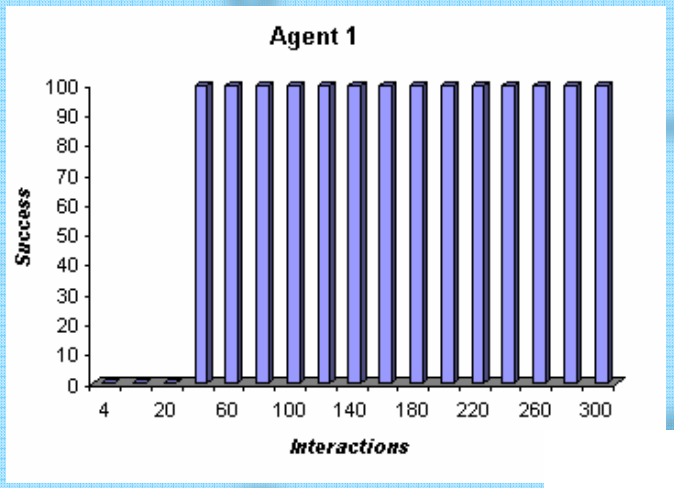


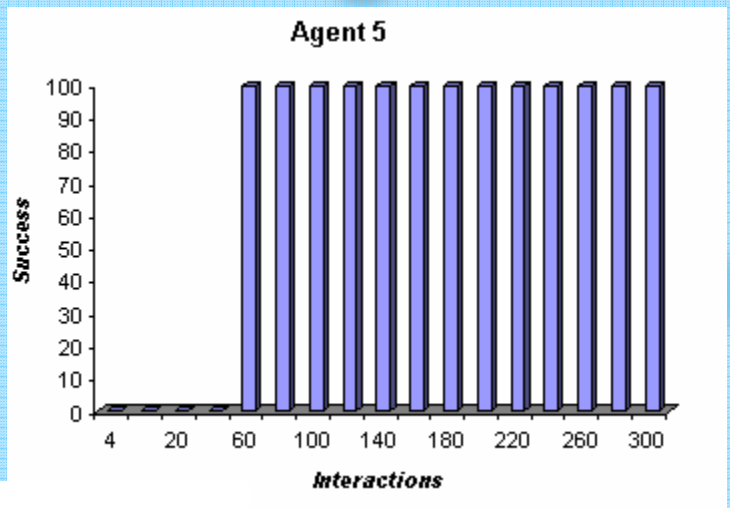


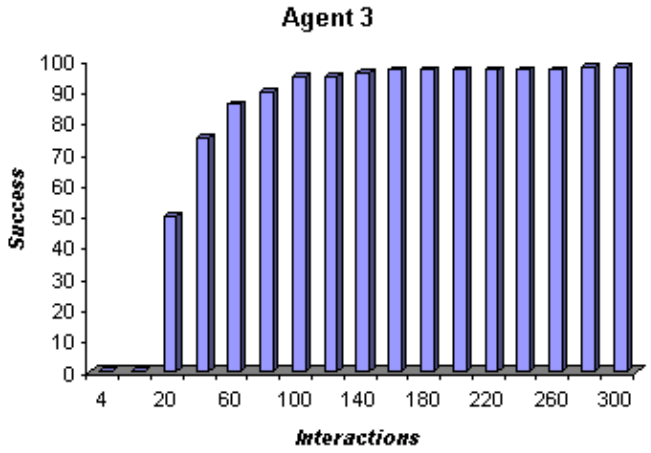


Experiments and Results

- Scenario B: 5 agents, word is “cu” with meaning (1,3):







Experiments and Results

- Random lexicon for some selected agent:

Word	Charac.	Value	Success	Usage	Overall Success (%)
do	3	11	18	19	95
de	1	5	23	25	92
ga	3	2	33	37	89
ha	1	4	1	3	33
he	1	2	4	6	67
hi	2	8	9	14	64
ja	1	3	1	3	33
ka	1	4	4	4	100
ji	2	9	4	4	100
ki	1	4	3	3	100
fa	3	12	2	2	100

Synonyms !!

Conclusions

- Approach shows good results for modeling a language acquisition process in a society of agents.
- Some relationships: lexicon's characteristics vs agent's features, number of agents vs number of interactions (or time elapsed until some agreement is achieved).
- Some applications: robotic group tasks, modeling human language acquisition (cognitive science), internet, databases, etc.