THE USE OF AGENT-BASED MODELS IN COGNITIVE LINGUISTICS: AN APPROACH TO CHOMSKY'S LINGUISTICS THROUGH THE CLARION MODEL

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Abstract

In this paper we propose the use of Agent-Based Models (ABM) (Gilbert 2008) to study the development of historical natural languages starting from a universal grammar according to Chomsky's "Theory of the principles and parameters" (Chomsky 1995) .

The CLARION architecture, designed by Ron Sun (Sun 2002) integrates implicit and explicit knowledge, cognitive and meta-cognitive levels, with the motivational aspect, i.e. accepting the cardinal principles of the embodied mind (Clark 1997) and recognizing the basic role of direct men- environment interaction in cognitive mechanisms. Ron Sun develops these points in a theory of mind and in a thorough discussion of learning problems.

The goal of an artificial neural network (ANN), based on a CLARION architecture, is to verify theoretical assumptions through simulation, bringing together the dichotomy between implicit (subsymbolic) and explicit (symbolic) knowledge through a learning mechanism realized by the extraction of explicit rules by subsymbolic knowledge, based on interaction with the world. In the real world, cognitive operations are mostly performed unconsciously. Moreover, learning is carried out through attempts, in dynamic circumstances. The methodology allows to observe the development of cognitive structures of individual agents through ABM and contribute to studying the emergence of unplanned and unexpected routines or mechanisms. The use of neural models as learning tools implies that the simulations are realistic, considering the relationship between intentional behaviour, learning, desires, individual structures and social structures. The simulation, thus, enables a study the mind from an evolutionary perspective (that of satisfying a particular need in a physical and sociocultural world), understanding how individual structures and social institutions and environment could change each other.

Through ANN-based models one can build realistic 'intelligent agents', i.e. with a 'mind', minimizing the programming of rules of behaviour and letting the interaction with the environment produce efficient behaviour.

Key words: ABMS, Agent Based Model System, CLARION, implicit (subsymbolic) and explicit (symbolic) knowledge, embodied cognition, language and grammar.

1. Introduction

Following Heidegger (2013), *being-in-the-world* is an essential condition of the human cognition: this means to recognize the basic role of the direct, immediate, non-deliberative humans-environment interaction. It does not require the mediation of any form of representation, but consists in a functional-associative process, in which the knowledge of an object is strongly related to the instrumental value of it, in relation with the subject. Furthermore, a central idea is that also the explicit knowledge is strongly influenced by this aspect.

In this paper, we focus on the study of the development of historical natural languages starting from a universal grammar according to the Chomsky 's "Theory of the principles and parameters" (Chomsky 1995). To do this, we needed to identify a model suited to perform a cognitive simulation of all mechanisms.

But, how could we simulate and comprehend a disordered and non-intuitive system like the humans-environment learning paradigm?

«One promising approach involves what has become known as an *autonomous-agent theory*. An autonomous agent is a creature capable of survival, action, and motion in real time in a complex and somewhat realistic environment» (Clark 1997, 6).

Studying the process in their relationship with the world becomes essential, as well as the attention we must assign to the interdependency between learning and acting.

A useful tool «is the use of *simulated evolution* as a means of generating control systems for (real or simulated) robots. Simulated evolution (like neural network learning) promises to help reproduce the role of our rationalistic prejudices and predispositions in the search for efficient solution» (Clark 1997, 87).

The central element is the evolutionary character of the model. The immediateness of the cognitive processes characterizes human action also in structured social contexts: «The idea, in short, is that advanced cognition depends crucially on our abilities to *dissipate* reasoning: to diffuse achieved knowledge and practical wisdom through complex social structures, and to reduce the loads of individual brains by locating those brains in complex webs of linguistic, social, political, and institutional constraints [...]. Human brains, if this is anywhere near the mark, are not so different from the fragmented, special purpose, action-oriented organs of other animals and autonomous robots» (Clark 1997, 180).

There are situations in which the environment is structured so that an individual does not need great elaboration processes to achieve an objective. The objective of a simulation is comprehending and analysing the totality of the humans-environment relationships and Clark (1997) recognizes these possibilities.

The starting point of our work is the acknowledgement that cognitive science call for a methodological approach allowing a cross-discipline study of the mind based on an evolutionary perspective. As already mentioned, in this paper we propose the use of Agent-Based Models (ABM) [Gilbert 2008] to study the development of historical natural languages using the CLARION architecture, designed by Ron Sun (Sun 2002). The simulation allows to study the mind from an evolutionary perspective (satisfying a particular need in a physical and sociocultural world), understanding how individual structures and social institutions and environment could change each other.

Section two is devoted to Ron Sun's mind theory and to the description of his CLARION model (Sun, 2002), while section three describes the designed simulation. In section four we will discuss the results and in last chapter five we will draw our conclusions and suggest possible future developments.

2. Ron Sun's mind theory and the CLARION model

Ron Sun (2002) developed these points in a mind theory and, in particular, in a thorough discussion of the learning problem. Both these aspects are then realized in a cognitive modular architecture, namely CLARION (Connectionist Learning with Adaptive Rule Induction ON-line), that integrates implicit and explicit knowledge, cognitive and meta-cognitive level and together with the motivational aspects, whose objective consists in verifying the theoretical assumption through a simulation. The fundament of this mind theory is the dichotomy between implicit (sub-symbolic) and explicit (symbolic) knowledge and the learning mechanism that is the construction of explicit rules of the sub-symbolic knowledge. The latter is founded on the interaction with the world: it is a fundamental implicit process, direct and not mediated by representations. In daily activities, under the time pressure, most of the cognitive operations realised, are performed without any reflection. Furthermore, learning happens by attempts, in circumstances in which the scenario is not stationary, stable and not for the individual who acts and learns. These adaptability and dynamism are reproducible only by neural networks or simulations environments. In Sun's model this implicit process is based on the reinforcement learning and on the Q-learning algorithm. These methods simulates humans' learning that is graduated and action-oriented (Sun 2002, 25). The following phase of the bottom-up learning corresponds to the algorithm for the extraction of rules called Rule-Extraction- Revision (RER) (Sun, 2002). This algorithm allows to extract from neural networks the essential elements to construct a rule formed in an explicit manner, that is in the "if-then" form.

Our purpose is based on the use of the CLARION cognitive architecture (Sun 2002) and the agent-based model, to enable individuals to learn a language from a universal grammar, drawing on Chomsky's "principles and parameters theory" (Chomsky 1995) and then to act and interact within an environment.

The methodology allows us to observe the development of cognitive structures of individual agents through ABM and contribute to studying the emergence of unplanned and unexpected routines or mechanisms. The use of neural models as learning tools implies that the simulations are realistic, considering the relationship between intentional behavior, learning, desires, individual structures and social structures.

The sub-symbolic knowledge is suited to grasp the peculiarity of the men-environment and men-men interaction. The extraction method consisting in selecting information from the implicit knowledge allows to formulate the concepts themselves in an explicit form. The fundament of the symbols must be sought in the sub-symbolic knowledge and particularly in the interaction among agents and between agents and environment.

In this context, the neural models can significantly contribute to set the significance of representations and the concept of intentionality.

3. Tools and Methodology

The adopted methodology is interesting for the effects we can observe in the development of the cognitive structures of single agents in information technology simulation realized through ABM (Agent Based Models) we will describe in the following. In fact, this kind of simulations allow to study the emergence of non-programmed and unexpected routines or mechanisms. The use of neural networks as learning instruments make realistic the simulations, thanks to complex architecture not limiting to act in a "reactive" way to the stimuli from the environment.

The realized model is composed of a cognitive architecture that allows learning and of a platform where it is possible to develop the agents simulation.

The cognitive architecture is CLARION, chosen for its modularity and for the capability to integrate implicit and explicit knowledge, cognitive and meta-cognitive levels, combining all these element with the motivational aspect.

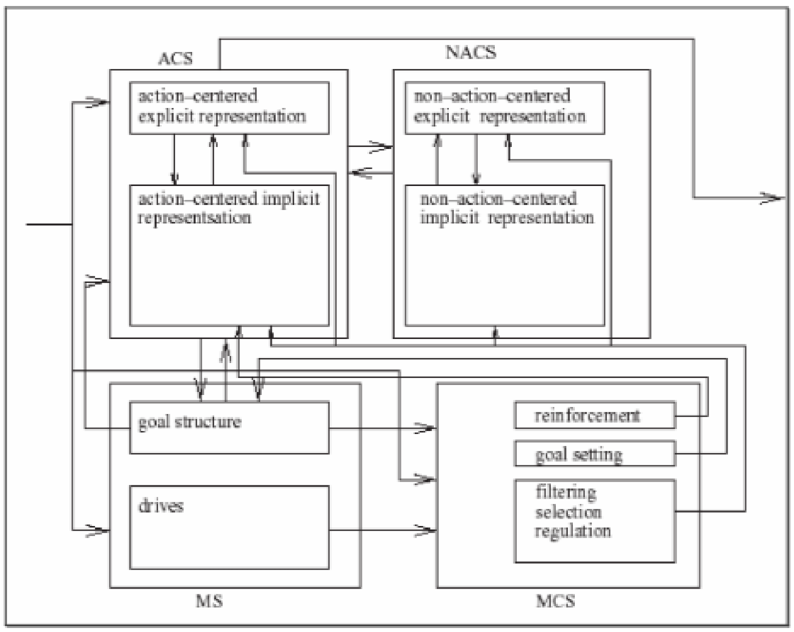

Figure 1: CLARION (The Connectionist Learning with Adaptive Rule Induction ON-line)

We wish to highlight that the three innovative aspects of this architecture are:

I. The interaction between cognition-motivation and environment: the motivations of the agent correspond to social needs, the trigger of every action and cognition.

II. The ability of the agent to learn autonomously, regardless of the cultural context provided a priori. The learning and the formation of implicit knowledge is based on a trial-and-error criterion. The abstract and explicit knowledge can be extracted from the implied knowledge. It is gradually acquired through a "bottom-up" process.

III. The constant interaction of multiple subsystems.

Neural networks are the first step of the hierarchy of knowledge: through parameter estimation it is possible to build a function that can associate *(*such as*, map)* different values, through a reward-punishment process, in a continuous interaction with the outside world. The algorithms used are the *reinforcement learning* and *Q-learning:* the advantage of these processes is that no preset external value is required in order to estimate the values of the network variables. Once the network is trained, it is possible to derive rules and concepts to create explicit knowledge.

The simulation with ABMs is defined within a delimited environmental system, populated by actors who perceive a certain state of the system, interact with each other, and express a certain preference structure which might change in the very course of the simulation.

To design the simulation, we chose the NetLogo (https://ccl.northwestern.edu/netlogo/) platform because this software is suitable for complex systems evolving over time. More specifically, the purpose of this simulation is to explore how and to what extent the properties of language users, learning, environment, structure of the social network, may influence the spread of a language.

In this model, two linguistic variants are at work within the social network: one variant is generated by grammar 0 and the other is generated by grammar 1. Speakers interact, at each time cycle, according to the network links. At each iteration, every speakers pass on a sentence expressed in Grammar 0 or Grammar 1 to neighbors in the network. Then individuals listen to their neighbors and change their grammars according to what they have heard.

The model is organized into three distinct but interacting elements:

– the environment;
– speakers acting within this environment;
– the social network

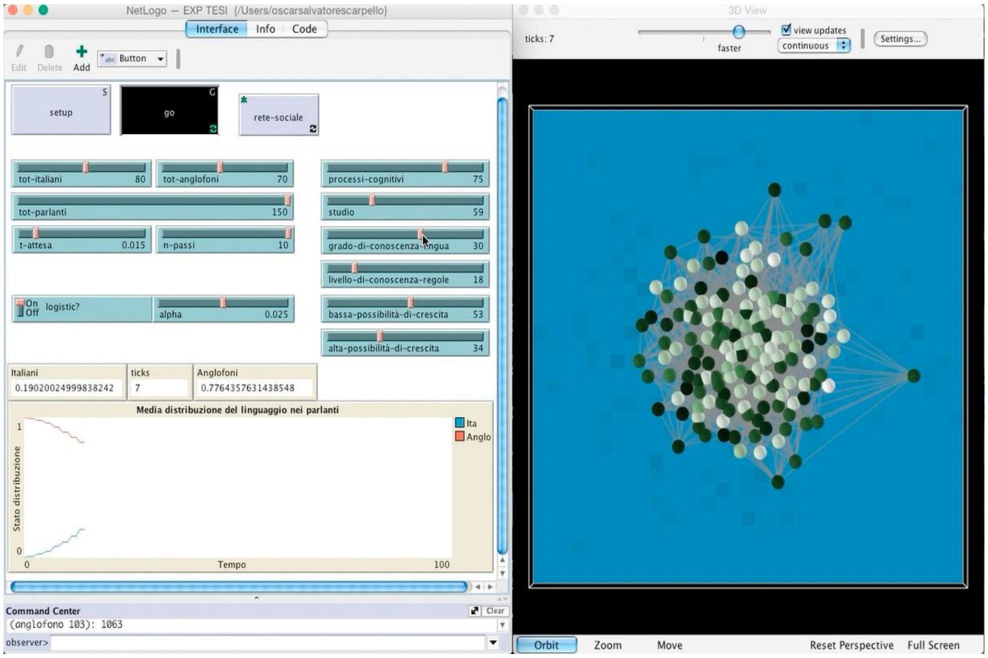

Figure 2: the simulation developed in NetLogo

The structure given to *the environment* has been characterized by defining variables and procedures that provide a dynamic foundation for agents that act within it, interacting with each other and with the created environment.

The speakers interact with two different grammars that are learned using the CLARION cognitive architecture. In this model, each grammar is associated with a weight, which determines for every speaker, the probability to access that grammar. The speakers still produce statements in compliance with the grammar of access, but individuals now have a probability to produce sentences with or without the original parameters. This allows us, according to what Troutman, Goldrick, and Clark stated in their study (2008), to detect *intraspeaker* variations when changing the language.

Learning determines the interaction modality with the environment and, consequently, the degree of language proficiency that the speakers will acquire during the simulation. The degree of competence achieved allows to activate the algorithms and communication procedures in order to create the link between the individual speakers environment and the procedures for dissemination in the social network.

English speakers and Italian speakers interact with each other according to the network links. Every iteration make all *agents* speak, and listen at the same time, thus passing an statement to their neighbors and consequently modifying their grammars according to what they receive as input from other speakers. All speakers, after each iteration, update their grammar immediately after listening. This implies a choice for one of the two polarizing grammars on the basis on its weight. If the selected grammar is able to analyze the expression correctly, the grammar is rewarded by increasing its weight. Otherwise, the grammar is penalized by decreasing its weight.

In addition, the speakers have a *bias* in favour of the English grammar that was introduced by Troutman, Clark and Goldrick (2008). Their results show that a bias is a crucial component in the variation pattern of the language.

Finally, the implementation of the social network characterizes the interaction between speakers making communication possible and influencing with its form and structure, evolving in time, the time and modes of communication. Starting from this assumption, the implemented network was reconsidered as a structure with a mesh topology, where each node is directly connected to the other nodes by random bonds, using for each connection a dedicated branch.

More specifically, the model starts from the creation of links between nodes (speakers) over time, trying to realize a fully meshed topology within a limited group of speakers who represent a kind of "eco-village" following the *"Rule of 150"*. The number of Dunbar (or rule 150) states that the size of a social network capable of supporting stable relationships is limited to about 150 members (Hill Dunbar 2002).

4. Results and discussion

In the simulation, at the initial moment of interaction of a group, the speakers of two different languages, implement accommodation strategies to communicate. Later, the increase of linguistic competence obtained by speakers during the cycles of the simulation time, transforms the process of diffusion into an individual exchange interaction. The users of a language choose one of neighbours they are randomly linked to, by adopting the grammar of the other, simply by proximity. The individual exchange between speakers is intuitively the moment where individual elements of a group, having acquired a good linguistic competence individually interact with the others in order to create personal relationships with other individuals.

Increasing the language competence, the simulation ends with a third phase where speakers do not start from opposite positions, since they have mediated the differences and have developed skills since the beginning of the simulation, and may aim at a common result.

The following picture shows the average distribution of the languages among speakers. Italian speakers are represented by the blue line, while Anglophone agents are in the red one; the ordinate shows the distribution while the abscisses the time in the simulation.

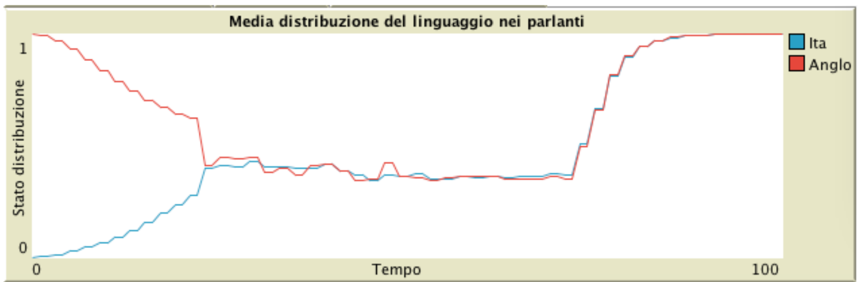

Figure 3: average distribution of the languages in speakers

As a result, it is possible to notice the development of the use of one grammar instead of another to communicate among all members of the group, without being anchored to a basic form of communication given by the mediation of two different grammars.

It has also been noted that the value of the bias in favour of grammar 1 has a very strong weight, and this is essential to enrich the social network with a motivation element by the subjects.

Moreover, it is possible to find the percentage of the initial distribution of grammars to establish the minimum number of Italians that is required in order to invalidate the *bias* of prejudice in favor of the spread of English grammar.

5. Conclusion

The first conclusion considering the results of the simulations and the cases examined, concerns the actual occurrence of an adjustment by the speakers and a development in the use of a grammar instead of another to communicate between all members of the group.

The interaction with the environment and the interaction within the social network permit the achievement of a high level of language competence. When this level is acquired, the speakers reach constantly the threshold value of one of the two grammars examined.

It has also been noted that the value of the bias in favour of the English grammar is a very strong weight, and this is essential to enrich the social network with a motivational framework of speakers. The preference of a grammar enhances the language competence.

Finally, it has been observed that some initial distributions into groups of speakers can invalidate the prejudice in favor of the use of a language because of their number. This might mean that an environment that is strongly characterized by the presence of a language (e.g., Italian grammar) leads the speakers not to communicate with the other (English grammar), even if the individual and the aggregate preference would say the opposite.

The action of an agent within a simulation is the result of complex dynamics among factors such as action, thought and external structures. In short, the agent simulates cognitive processes.

Only within an evolutionary perspective the world becomes a space of computational resources that are complementary to human cognitive processes. Therefore the mind has created much of its representations that are local and action-oriented. Under this new light, defining knowledge as "distributed" acquires even greater meaning.

In fact, cognitive architectures that are based on networks, are inspired by the brain structure and it is claimed they provide excellent tools for the study of the mind and its functioning. Their development has played a very important role in the philosophical debate, in particular, within the domain of cognitive sciences and the philosophy of mind.

A serious mistake, however, would be to take radical positions disregarding representational and computational methods. The problem is still open, but the concept of action-oriented representation is crucial in order to grasp one of the many aspects of the brain-world relationship. This new interpretation gives prominence to the simulation, and in particular to simulation through agents, fostering new methodological perspectives for the cognitive sciences.

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