A MULTI-AGENT SIMULATION OF THE EVOLUTION OF LANGUAGE

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ABSTRACT
This paper discusses the evolution of language as an emerging phenomenon with both genetic and social components that are shaped under evolutionary pressure. Communication between relatives is seen as an act of kinship-driven altruism and the chances of survival of such behaviour discussed from a Neo-Darwinist point of view. The paper provides motivation for the use of multi-agent systems in the simulation of the evolution of language and describes one setup taking into account the above-mentioned issues.

1 INTRODUCTION
In recent years, there has been much research carried out in attempting to model the evolution of language through computer simulation. Within this field, there are two somewhat disjoint problems being tackled. One set of researchers are investigating communication systems that are stored and passed between entities genetically [2, 10], while others are approaching the problem of learned communication systems [4, 7, 8]. A few are attempting to study the interaction between the two [1].

Our research is based within the domain of simulating learned communication systems and focusses on why any creature should develop or choose to use such a system to speak. More specifically, we present a framework in which the urge to use language is seen as an inherited feature selected by evolution, while language itself is a social phenomenon that is passed on through interaction rather than genetically inherited. Clearly an entity that is able to use such a communication system to understand the meanings of others' speech is at an advantage, as it can gain information through the work of other entities rather than its own toil. However, it is less apparent why a creature should choose to speak, when this will clearly give other creatures an advantage which this one has had to work hard to gain.

2 ALTRUISM AND NEO-DARWINISM
In Darwinian terms, by helping other creatures with no obvious benefit to itself, the creature has acted altruistically decreasing its own fitness relative to that of others, and therefore we would expect such behaviour to be selected against by nature. However, the existence of human language clearly shows that in at least one case natural selection has acted opposite to this expectation. Researchers studying learned languages have not studied this question, but several researchers [6, 11] have looked at similar problems in the domain of innate communication systems and we look to this work for possible approaches. They have found that, in their most abstract models, communication does indeed seem to be selected against if an agent can choose not to speak without penalty. However, there are possible modifications to these systems that seem to encourage communication to occur. A spatial distribution is one such modification that can be applied, with agents interacting more with those spatially adjacent to them. This promotes reciprocal altruism, in which both entities benefit by cooperating rather than competing.

Another possible explanation is to look at the issue of altruism from a Neo-Darwinian perspective. Hamilton [3] shows us that if we view the basic element of evolution not as the individual, but as the gene, we find that natural selection may actually favour selfless acts in the form of kinship-driven altruism. This form of altruism involves helping relatives proportionally to their degree of kinship to the altruistic entity. For instance, should such an entity die saving the lives of three of its children, there will probably be more copies of its genes remaining alive than if the creature had preserved its own life. Through this mechanism, a hypothetical gene promoting altruism would be able to spread itself. We propose to investigate whether either this form of altruism or reciprocal altruism can be used to explain the existence of learned language.
3 EVOLUTION OF LANGUAGE IN MULTI-AGENT SYSTEMS

We have chosen to simulate the evolution of language within a multi-agent system (MAS) setting. This allows us to simulate with ease many of the potentially relevant phenomena, such as the density and spatial distribution of agents (language speakers) and resources, along with the degree of agents’ mobility. The MAS framework also permits to study the behaviour and social (both verbal and non-verbal) acts of each and every individual, if necessary.

Simulations of the evolution of language using the multi-agent paradigm can be also of interest to the designer of any general-purpose agent-based applications. In a dynamic environment that is expected to change considerably during an agent's lifetime, the faculty of learning could be essential to its success. Machine learning techniques could be used for this purpose [5]. Learning biases that specify the range of possible hypotheses are indispensable in machine learning, and their choice is crucial to the success of any of its algorithms. The learning bias is by its nature the invariable part of a learning algorithm. In an evolutionary MAS setting, sexual reproduction and mutation can be used to explore a range of possible learning biases, from which natural selection would choose the best.

Evolution in the MAS can follow the Darwinian principle that individual experience cannot change one's genes. One would expect from Darwinian evolution to advance in small steps, and select only very general concepts, as they would have to remain relevant to most of the population for many generations. One could also implement Lamarckian evolution, that is, use a MAS in which the parents’ individual experience can be reflected in the learning bias inherited by their offspring. Lamarckian evolution is faster, but brings the risks of inheriting too specific concepts based on the parents’ personal experience, which have no analogue in the life of the offspring.

There is yet another way of evolving a learning bias that is open to populations of agents able to communicate. Language uses concepts that are specific enough to be useful in the description of a variety of aspects of the agent’s environment (including other agents), yet general enough to correspond to shared experience. In this way, the concepts of a language serve as a bias used to describe the world that is inherited through social interaction rather than genes. However, to preserve the additional advantage that the use of language brings about in the case of a changing environment, the MAS designer should allow the language to evolve.

Here the accent will be on exploration of new environments and how language can develop to aid the survival of a population of genetically related agents.

4 OUR APPROACH

The main characteristics of our approach are as follows:

- use a MAS to simulate the evolution of language;
- assume that altruistic behaviour between relatives (i.e., kinship-driven altruism) exists in the population, e.g., has been promoted by natural selection as demonstrated in our previous work [9];
- allow the agents to choose between an altruistic act of sharing the physical resource (food, water, etc.) and sharing information about the location of that resource.

Information about resource location is shared in the form of paths, consisting of sequences of landmarks that are to be seen along the way to the target destination. Landmarks are identified by the names that the speaker uses to identify them. The names are non-descriptive, i.e., they are not derived from the landmark properties. Initially, these names are arbitrarily chosen by the agents. Since the names used by the speaker and the receiver may be different or the latter may not have seen the landmark in question at all, linguistic games similar to the ones described by Luc Steels [8] are used to evolve a common lexicon of landmark names. Whether a path is discovered by exploration or described by another agent, it is stored internally in the form of set of rules of the form:

\[ \text{TargetResource} \to \text{Pos}(X), L_1, L_2, \ldots, L_n \]

where \( L_i \) are landmark names, and \( \text{Pos}(X) \) is the current position of the listener defined by the snapshot of its surroundings, stored as a two-dimensional matrix of the visible landmarks; the vision range is limited and no particular orientation of the agent is assumed. Rules of the above form can be interpreted either as:

- procedural rules guiding the agent from location \( X \) to resource of the given type or, alternatively, as
- grammar rules of a regular language.

It should be noted that the description of path chosen is a relatively impoverished one. So, for instance, no absolute or relative co-ordinates of landmarks are used, neither is the direction to follow or distance between consecutive landmarks described. The assumption made is that each landmark would be visible from the previous (or random exploration would be needed to find it). One would intuitively expect to find a relationship between the range of sight that the agents possess and the frequency of landmarks in the environment, on one hand, and the usefulness of the above type of description, on the other. For instance, the nearest resource should be out of sight if communication is to be useful, and one landmark should not be too far from another. If, in a given environment, these descriptions prove useful, i.e., storing and exchanging them promotes the
survival of the agents involved, one would expect to observe the following two phenomena (or, better, two sides of the same phenomenon):

- agents possess sets of rules describing paths, which ultimately lead to a useful resource;
- this set of rules can be seen as a proto-language, the grammatical structure of which copies the structure of the landscape.

On observing the internal language (set of rules) of each agent, one could measure the similarity between the languages used by each pair of agents and (hierarchically) cluster all agents accordingly. If agents are split into a set of mutually exclusive clusters, all agents within the same cluster can be seen as speakers of the same, shared, language. In this case, language is seen as a social artefact that only exists in the community of its speakers. Alternatively, the sum of all rules used by the agents can be clustered by using as a measure of similarity of a pair of rules the number of agents sharing both rules. Again, any partitioning of the resulting hierarchy of rules would correspond to a set of languages, where each language is defined by the set of its rules.

5 CONCLUSION

In conclusion, it should be mentioned that the above approach can be modified to promote information exchange as a mutually beneficial act, and so replace the currently used mechanism based on kinship-driven altruism. This would make the knowledge of the degree of kinship between two agents unnecessary. One possible mechanism implementing the above change would be the one where information about the location of different types of resource is exchanged. This act would be mutually beneficial when either agent would need both resources in order to survive.

References