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On evolving communication in multiple agent systems

Abstract -

This paper describes research on a model, where communication systems are allowed to evolve within a multiple agent system. The model is inspired the communication systems found in various groups of animals. Vocalized alarm calls were the goal of the model, however, the agents settled upon a simpler solution to the threats posed by their environment. Yet, the agents did utilize a signalling system to flock towards positive areas in the environment.

1.0 - Introduction -

Some animals have exhibited the ability to use explicit communication to their advantage. The vervet monkeys of West Africa use a set of calls to signal the three different types of threats most often encountered (Seyfarth, 1980). For instance, a bark might signify a leopard, inciting a tree climbing escape, while a single cough alerts the monkeys to eagles and the monkeys will look in the sky while they seek shelter, and a double cough could represent a snake is nearby. The actual sound to predator mapping can differ from group to group. Some ground squirrels use alarm calls as well, to warn others nearby of an immediate threat (Sherman, 1977). The size of the squirrels, combined with the varied terrain they live in, often limits their visibility. In these cases, using auditory signals to inform others of potential hazards can be a significant advantage. Also, Asian elephants use low frequency sounds to communicate over several kilometers to coordinate herd movement and find mates (Payne, 1986).

This paper presents a model inspired by these phenomena. The model creates an artificial world, where individual agents can interact with the environment and each other. Production rules with environmental cues as antecedents and agent actions as consequents, determine an agent's behavior. A genetic algorithm is used to search through the space of production rule sets. The goal is to explore the conditions, for both the environment and the individual agents, where communication would arise.

1.1 - Previous models -

Werner and Dyer (1992) presented a model where a communication system between the different sexes in their model evolved. The females in their model were unable to move, but were able to see and speak. The males in their model were able to move and hear, but were blind. The goal of the simulation was to evolve a set of signals that the females could emit, in order to lead the males to them. Their system would reward the couple that could find each other by spawning children from them. After many generations, the population of males and females had settled upon a set of genetic codes that allowed them to efficiently find each other, given their physical constraints. Their work is an impressive example of Artificial Life research, however the model makes a strong distinction between sender and receiver. How would the system change if an agent needed to act as both the sender and receiver?

Later, Werner and Dyer (1993) take on a completely different model. Trying to combine altruism and communication at a more life-like level, they created "BioLand", where the agents evolved a herding behavior. Their agents were modeled after Braitenburg's vehicles, with evolving neural networks. The model displayed some predator/prey dynamics, however, their goals of creating a communication system were not reached. This was attributed to the success of the agent's visual system. The agents were capable of visually sensing enough information for their survival and there was no need to communicate.

A communication system was evolved by MacLennan and Burghardt (1994). Their experiments involve one agent in a position where environmental cues are available. This agent is then given the opportunity to communicate with other agents and inform them of the current state of the world. The others are rewarded for performing the proper action (as defined by the programmers) in response to the actual state of the environment. Agents were evolved that were able to reliably respond to the environmental cues properly. Additionally, lifetime learning was shown to have beneficial results. In another experiment, they reduced the number of signals in the agents' vocabulary (to less than the number of responses), the agents resorted to a guessing method that had a restricted maximal fitness. Thus, the system was not able to successfully evolve a multi-symbol communication system.

2.0 - The Model -

Pulling from the strong points of the previous work, I created a new artificial world. The world is a collection of sites arranged upon a torus and the agents are able to move freely from site to site. The agents have initial health values, which are reduced each time they are activated. When the agent's health value reaches 0, it is considered dead. In addition to the agents, the world contains relatively large (with respect to the agents) areas that were either beneficial or detrimental to an agent's health. These regions would appear periodically, in random locations, and would remain for varying durations. The areas were heavily biased towards the detrimental type, creating an environment that tended to be dangerous to the agents. The world's geometry, affecting areas, and the basic agent structure are similar in spirit to the Cellular Device Machine (Sieburg and Clay, 1991).

2.1 - The Agent -

The agents are controlled by simple production system. The conditions of the production rules are combinations of possible input values logically OR'ed together. A logical NOT effecting the entire condition is optional. The agent's inputs are gathered from 6 input channels -

- 1 visual channel (directed in front of the agent, with a 40 degree field of view to either side and a limited distance). Other agents, along with positive and negative areas could be identified visually.
- 4 auditory channels (forward, left, right, behind; all again with a limited distance). This channel picks up the sounds emitted by other agents within the specified range. There are 3 different auditory signals recognized.
- 1 tactile channel - Reports what other objects are in the same site as the active agent.

Example conditions are -

(see positive area)
(hear sound 1 on the left) OR (feel agent in same site)
NOT ((hear sound 1 in front) OR (hear sound 1 on right))

The values for the vision and auditory ranges were chosen as an attempt to model an agent with limited vision and decent hearing. Smaller animals, in grass and brush much taller than them, have limited visibility, but their hearing is for the most part intact. Likewise, elephants are using low frequency signals in order to communicate distances much further than they can see. The second Werner experiment suggested that the visual system was effective enough to eliminate the need to communicate and was another reason why the visual system in my model was of a limited range. In the experiments run, the ratio of the areas covered by the two senses favors audition by a factor of about 30. Future experiments will try and find relationships between this ratio and effective communication systems.

If the production rule's condition is matched by the environmental cues received by the agent, then one of 8 actions is performed -

- Start moving forward (agent will move until the stop action is performed).
- Stop moving
- Turn left 90 degrees
- Turn right 90 degrees
- Emit signal 1, 2, 3 or none.

Putting these two together, creates rules like these -

if (see negative area) then start moving.
if (hear signal 1 behind or see agent) then turn left 90 degrees.
if not(hear signal 2 left or hear signal 2 right) then stop moving.

Agents are activated each turn in an asynchronous manner. Each turn, the agent will first gather information from their local environment, creating a list of inputs to use with their production rules. The inputs are stored in a limited sized buffer, simulating a finite mental capacity and imperfect sensory system. Therefore, on any given turn, there is no guarantee that all the inputs from the environment would be available to an agent. The rule set then uses the inputs to trigger actions, with the actions taking effect immediately. Then, the agent's health value is adjusted. One health unit is subtracted for the activation, and whenever an agent is on a positive or negative area, its health is also appropriately adjusted. These environmental effects are the only reinforcement that the agent receives, in order to avoid any programmer biases. I felt that reinforcing specific actions (turning left, if a positive area is on the left) would be leading the experiment too much. Thus, the environment was the form of reinforcement. A final check is made for a health value of 0 or less. If it is zero, the age (number of activations) of the agent is recorded and the agent is removed from the world.

2.2 - The World -

The agents for an experiment were spawned from one genetic representation, creating a completely homogeneous population. Homogeneous populations were used because it was assumed that cooperation could evolve quicker if each agent "knew" the behavior of any other agent it could come in contact with. That is, with all the agents acting in an identical fashion, I assert that a communication system has fewer evolutionary obstacles to overcome. Additionally, the similar innate behaviors found in a closely related group of animals can be seen as an analogy with our homogeneous populations. Initial experiments with nonhomogeneous populations suggest that too much variety in individual behaviors substantially inhibits convergence upon a coordinated behavior. In a heterogeneous population, the individuals will react to signals in different fashions, as well as emit the same signals in different environments. Indeed, this problem still occurs within our model, though at a higher level. This will be discussed later, with the description of the genetic algorithm used.

The spawned population sizes were kept small, in a range between 15 and 30 individuals. This was done for a variety of reasons:

- The pack sizes of animals that use audible alarm calls don't tend to be that large. An ant-like society, where the number of agents involved is much larger, was not our modeling goal.
- Implementing this model in real world robots is a long term goal and in that respect, materials, space, and cost become a consideration. Using smaller population sizes in the model, should allow for a smoother transition between the simulations and real world implementations.
- The run times for the experiments have an order of n^2. The main bottleneck is the environment - calculating the environment for each object grows exponentially as the number of objects increase. Though there are some algorithms that help to dampen the effects of large population sizes,

there are still substantial differences between populations an order of magnitude apart.

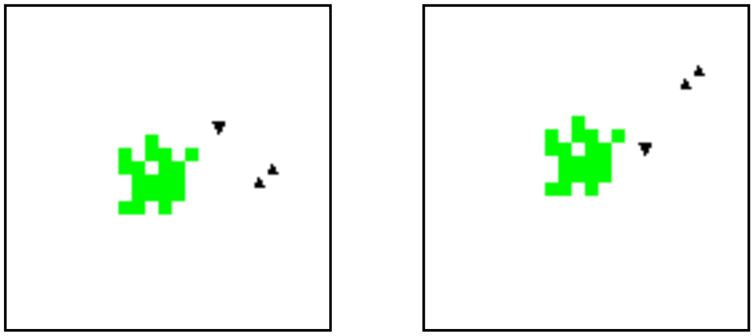
The fitness of a gene is the average lifespan of the agents spawned from it in the artificial world. Over the population of different representations for the agents, a genetic algorithm was used. When creating new agents, parents were chosen using a weighted roulette wheel paradigm. The children resulting from the mating have a random collection of rules from each parent, with an occasional random production rule added (there was no mutation performed on the individual rules themselves). The genetic algorithm was not as efficient as one might hope, as often the parents chosen were using incompatible rule-set. This is evident when one set of rules is organized to react to sound A in a specific way, while another set of rules is organized to react to sound A in a different specific way. These two sets of behaviors can be considered dialects, and the blending of the two sets of rules only yields a confused behavior. This is the same problem mentioned earlier that heterogeneous populations present, yet it's happening at the genetic level, than in the individual's lifetime. At the same time, this would be a drawback in most representations that did not provide high level, pre-defined, constructs for behavior control. I feel that the benefits of the unrestricted representation outweigh the genetic algorithm's inefficiencies.

3. 0 - Results -

The system has found rule sets that could reduce the average lifespan to 45% of the expected lifespan (their rule set sought out the negative sites), as well as other sets that could extend the lifespan to over 600% of the expected lifespan. As a measuring stick, the agent that takes no actions, and stays in one spot the entire time, generates a population that lives for nearly 90% of it's expected lifespan.

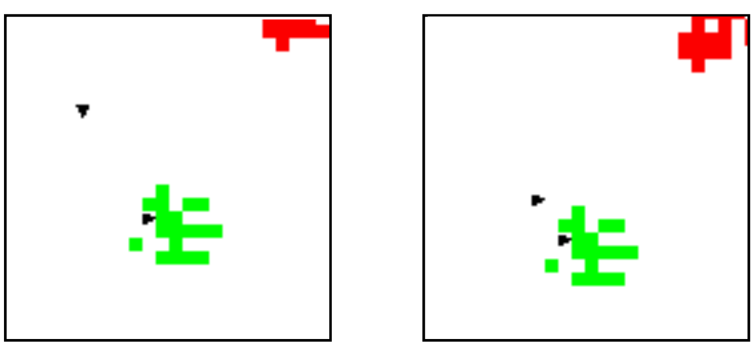
3.1 - Behaviors -

The single visual channel limited the agents quite a bit. The one visual input could lead agents in the general direction of a good spot, however, unless they were on a direct course for the patch to start with, they would not find it. The lack of a left or right visual channel kept the agents from adjusting their direction towards the beneficial locations, and often, agents would pass right by a advantageous area only one or two sites away. This is illustrated below, as 3 agents move right past a positive area (lightly shaded). One of the agents even gets as close as two sites away from the area, but it goes unnoticed.



At the same time, this limited visual ability did prove to be sufficient for avoiding the harmful areas. For this task, accuracy was not necessary, as the agents would simply turn if they could see a negative area in front of them. Indeed, a rule that turned the agent when a negative area was either visible or touching the agent was a popular rule, even though it was not perfect. The weakness of this rule comes out when the agent is near or in a dense area of negative sites - it will circle around within negative area till it dies a premature death due to the negative area's influence. Yet, the rule was effective for avoiding the majority of negative areas. Since the only dangerous areas in the environment were not mobile, the rule was very effective. In fact, the only time that agents which had this rule would ever run into a negative area, would be if one happened to be created underneath them. The agents with an avoidance type rule had average lifespans in the range of 200-300% of the expected lifespan.

Consequently, alarm calls did not evolve, the visual system provided enough defensive abilities. However, the auditory channel didn't go unused. Agents were evolved that utilized the auditory channel for flocking at a positive area. Once one agent did stumble upon a patch, it would emit a signal that attracted others. It served as an instantaneous pheromone trail, immediately effecting all those within earshot. The nearby agents then flocked towards the calling agent. Although, this behavior of calling out to others had no direct benefit to the calling agent, it did lead to longer average lifespan for all the agents, so the fitness of their shared genetic code was increased. Indeed, this altruistic behavior, combined with the ability to head towards the signal, lead to a tremendous leap in fitness, from an increase in expected lifetime of 3 fold to 6 fold. Below, the frames show one agent homing in on another that has found a positive (lightly shaded) patch.



Without any predators being attracted to the emitted sounds, one might expect communication between agents to flourish. However, since the population of agents were homogeneous, there were no “leaders”, which could direct a group of agents. As a result, the only use of communication so far has been as a homing signal for found beneficial locations (agents that could see or feel the positive area signal). Communication was kept seemingly to a minimum, for if it was used too often, meaning was lost. Indeed, agents which lacked the rule to stop emitting the signal had an average lifespan significantly less than those that did (without the stop signalling rule, agents had an average lifespan of approximately 160%). Imagine a group of people constantly shouting “Over here” from all around you - it is hard to gain any information from that situation.

Again, the sensory structure limited the abilities of the agents. Without the 2 rules to turn left and right according to the locations of the sounds, the agents could not reliably find the calling agent. With only one of the rules, the agents were severely handicapped. Without the 2nd rule to steer themselves back in the proper direction, the agent would turn itself once, then move away from the positive area. I will be exploring the effects of changing the structure of the actions (for instance, the actions might be orient towards and orient away from, instead of turn left and turn right).

When the positive and negative areas were close to each other, the most fit agents did not settle on a behavior. They were continuously trying to move away from the negative areas, while either being drawn to the positive area or trying to draw others to the positive area. More aggressive threats that are mobile might force the agents to commit to escaping.

4.0 - Concluding remarks -

The agents evolved behavior sets that allowed them to increase their average lifespan to over 6 times their life expectancy. These agents found a way to increase their foraging efficiency by utilizing an auditory channel to supplement their poor visual system. However, the goal of alarm calls were not reached. Additionally, these preliminary experiments point out the differences between avoidance and detection tasks. While the visual system is much more limited in range than the auditory system, it is sufficient for the avoidance task. Yet its limitations are severe enough to restrict aiding the detection task, as close positive areas are often ignored without communication. The omnidirectional characteristic of the auditory senses provides enough precision to assist (when combined with the proper turning rules) the detection task.

A reason for this seems to be that the threats posed by the environment were not aggressive enough. The effects of more able predators on the behavior of the agents is our next study. By co-evolving a separate population of predators, an arms race might lead to the development of alarm calls - where avoiding threats much earlier is beneficial to an individual. An internal state register for the agents and its effects on the behavior of the individual and group, will also be studied.

Although many systems have shown group behavior such as flocking and herding without communication (Kube and Zhang, 1993, Mataric 1993, Reynolds 1987, Werner 1993; to name just a few), biological systems do use communication to their advantage. I feel that the study of omnidirectional communication merits more attention, as it allows agents to extend their representation of the world, without explicit programming or design. It is similar in some aspects to pheromone based communication, as the environment is affected and the signal is available for any agent to utilize. However, the immediate effect (both the onset and termination) of auditory signals might be more suitable for some tasks. Also, implementations of pheromone systems in robotics would be simulated or virtual representations, while a communication system as described here, could be directly implemented via infrared signals.

Finally, the simulator used is available on the World Wide Web as a Java applet - http://www.cs.indiana.edu/hyplan/cbaray/cse

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References -

Braitenburg, Valentino. (1984) *Vehicles.* Cambridge, MA : MIT Press

Goldberg, D. E. (1989) *Genetic Algorithms in Search, Optimization, and Machine Learning,* Reading, MA : Addison-Wesley

Kube, R.C. And Zhang, H (1993) Collective Robotic Intelligence.*From animals to animats 2*, eds. Meyer, Roitblat, and Wilson. Cambridge, MA : MIT Press

MacLennan, B. J. and Burghardt, G. M. (1994) Synthetic ethology and the evolution of cooperative communication. *Adaptive Behavior*, Vol 2 (2), 161-188

Mataric, M. J. (1993) Designing emergent behaviors : from local interactions to collective intelligence. *From animals to animats 2*, eds. Meyer, Roitblat, and Wilson. Cambridge, MA : MIT Press

Payne, K. B., Langbauer, W.R., and Thomas, E.M. (1986) Infrasonic calls of the Asian elephant. *Behavioral Ecology and Sociobiology,* Vol 18, 297-301

Reynolds, C. W. (1987) Flocks, herds, and schools : a distributed behavioral model.

Computer Graphics, Vol 21 (4), 25-34

Seyfarth, R. M., and Cheyney, D. L. (1980) Monkey response to three different alarm calls: Evidence of predator classification and semantic communication. *Science,* Vol 210, 801-803

Sherman, P. W. (1977) Nepotism and the evolution of alarm calls. *Science,* Vol 197:1246-1253

Sieburg, H. B. And Clay, O.K. (1991) The CDM Development System for Modeling Biology on the Computerr. *Complex Systems,* Vol 5

Werner, G. M. and Dyer, M. G. (1992) Evolution of communication in artificial organisms. *Artificial Life II* , eds. Langton, Tayler, Farmer and Rasmussen. Reading, MA : Addison Wesley

Werner, G. M. and Dyer, M. G. (1993) Evolution of herding behavior in artificial animals. *From animals to animats 2*, eds. Meyer, Roitblat, and Wilson. Cambridge, MA : MIT Press