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Evolution of autonomous hierarchy formation and maintenance

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Extended Abstract

Hierarchy among social animals is ubiquitous, and affects the social structures of gregarious species not only by interaction among species within the population, but also through other social forces such as mating, nesting location, amount and the quality of food they receive, or reproductive success. Since T. Schjelderup-Ebbe developed the structural definition of dominance and hierarchy in 1922 (see, e.g., Drews (1993)), different aspects of this social behavior have been addressed. However, exactly how hierarchies can emerge and be maintained among social species is still a conundrum. To investigate this issue, here we analyze a population of autonomous agents ("animates") through the course of evolution. The results of our experiments demonstrate the importance of memory and brain plasticity for the emergence of hierarchy and dominance behavior.

Living in groups has many advantages over living alone. Strength in numbers (Brown, 1996), division of labor (Goldsby et al., 2010),collective hunting (Alexander, 1974), protection via swarming (Olson et al., 2013) are only some of those advantages justifying the evolutionary advantage groups have over solitary living individuals. It has often been remarked that living in groups requires a higher level of organisation than the solitary mode, and provides the driving force for the evolution of more complex cognitive systems in social animals (Ashforth and Mael, 1989). In many cases, hierarchies are used to organize the group, with dominant animals leading and submissive animals falling in line (for a definition of hierarchy see (Drews, 1993)). While social insects like bees or ants solve this organization problem by literally making different organisms (such as queens) to reproduce and workers to perform the labor (Robinson et al., 2008), mammals usually establish their hierarchy using phenotypic traits like strength, aggression, or age (Alexander, 1974; Gauthreaux Jr, 1978). In addition, such hierarchies are usually robust to noise and damage. For example, in case those traits change (or animals die) the submissive animals can become dominant or else animals can reorganize the hierarchy altogether. The ability to robustly reorganize hierarchies requires animals to potentially take on every rank or role in the hierarchy. Here we evolve the capacity to form hierarchies spontaneously (and to reorganize them on the fly) in groups of animats that can communicate on multiple levels (visually, as well as via signalling) with the goal of creating robust collaborative groups.Our animats are controlled by evolvable Markov Gate networks (MGN) (Edlund et al., 2011). Each gate in an MGN is an arbitrary probabilistic (or sometimes deterministic) logic gate, whose function is determined by a set of evolvable probabilities. Here, we introduce in addition gates that can perform simple stack, threshold, counting, and temporal buffering tasks. These MGNs were embodied in a virtual robot (animat) roaming a 2d plane. Animats can turn 90 degrees left and right, move forward, wait, as well as signal a single bit. Sensors allow them to see objects in front of them, the direction it is facing, and to listen to the signals of other animats in their group. Besides these sensors, each animat can use 32 internal bits for computation. We evolve a population of 100 animats

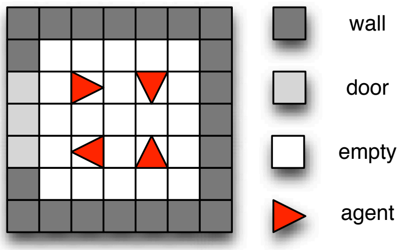

Figure 1: Layout of the test environment (arena). Red triangles: animats. Walls are in dark gray and the door in light gray. The rest of the room is empty (white).

using a classic Genetic Algorithm for 100,000 generations. Animats establish a hierarchy spontaneously by choosing an order they first leave the room. When placed in the same room in subsequent trials, they must leave it in the same exact order. However, these decisions must be made by agents with the same exact brain, that is, the different roles cannot be taken on genetically: they have to be made using information that the agents leave in the arena. The fitness of an animat's genes is determined each by placing four identical copies (clones) of the animat with random orientations in a rectangular room that is enclosed by a wall with a large door on one side of the room (see figure 1). Every time an agent leaves the room by moving through the door, it is removed from the simulation. After the agents have established the hierarchy via the first trial, they are put back randomly to the start locations with random orientations, and accumulate fitness if they leave the room in the same exact order as dictated by the hierarchy in the subsequent 19 trials. Based on the given information, we can write the fitness function as:

$$w = \frac{1}{20 \times 4} \left[\sum_{i=2}^{N} \sum_{j=1}^{4} \delta \left(v_{ij} - v_{1j} \right) \right] (1)$$

where $N \leq 20$ is the trail number, v_{ij} is the label of j^{th} robot in the i^{th} round of task, v_{1j} is the label of j^{th} agent the first time agents leave the room, and $\delta(.)$ is Dirac's delta function. Each test is repeated four times for each animat, where the brains are completely reset so that the first order of exits will be random in each test. At the end of each evolutionary experiment, we reconstruct the line of descent (LOD) (Lenski et al., 2003). To test which method of communication was used to establish the order, we re-evaluate the fitness of each agent on the LOD while impeding vision, signalling (or both) by blocking the sensors. The evolutionary experiment was repeated 100 times, and only 11 out of those 100 (from now on called *best*) evolved a population with a best fitness higher than 0.825 (arbitrary cutoff proportional to getting seven out of eight ranks right), while the average final fitness over all 100 experiments is about 0.625 (Hintze, 2014). This suggests that the task is rather hard to evolve. We find a significant loss in fitness when making

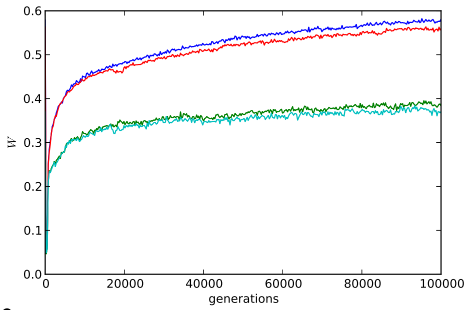

Figure 2: Average fitness (W) on the line of decent over 100.000 generations for all 100 replicates in blue. Fitness for the same bots when they were invisible to each other in green, when they were unable to use their communication channel in red, and when both senses were impaired in light blue.

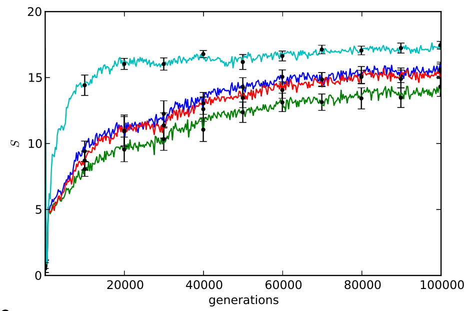

Figure 3: Average success to get individual ranks correct (S) on the line of decent for those eleven *best* bots. Success that the rank is correct for the first bot in blue, for the second bot in green, for the third bot in red, and for the last bot leaving the room in light blue. In black the standard error.

bots invisible to each other (see figure:2 green), and almost no additional loss in fitness when we block the communication channel (see figure:2 red), indicating that the communication channel is of no important in organizing the hierarchy, and vision alone suffices. It has been argued that the formation of hierarchies requires organisms to evolve submission first (Alexander (1974)). While in our experiment it is not obvious if bots leaving the room early are dominant over those that leave the room later or the other way around, we find that bots evolve to wait first. When testing the 11 *best* bots, we find a much better success rate for the last bot leaving the room early on in evolution (see figure:3), than on all other ranks. Only later in evolution the other ranks catch up. We showed that one can evolve virtual clonal bots to form a hierarchy and maintain it over an extensive period. Instead of having distinct properties, these bots were identical and needed to establish an internal representation of a rank through memory and communication. Even though this is a very simplistic environment, we think that this is an important stepping stone towards autonomous self organisation in virtual bots with implications to embedded systems. In the future we plan on studying the robustness of these systems, and how different reward or selection schemes (individual vs. group level selection) effect the formation of hierarchies.

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References

Alexander, R. D. (1974). The evolution of social behavior. *Annual review of ecology and systematics*, pages 325–383.

Ashforth, B. E. and Mael, F. (1989). Social identity theory and the organization. *Academy of management review*, 14(1):20–39.

Brown, C. R. (1996). *Coloniality in the cliff swallow: the effect of group size on social behavior*. University of Chicago Press.

Drews, C. (1993). The concept and definition of dominance in animal behaviour. *Behaviour*, 125(3/4):pp. 283–313.

Edlund, J. A., Chaumont, N., Hintze, A., Koch, C., Tononi, G., and Adami, C. (2011). Integrated information increases with fitness in the evolution of animats. *PLoS computational biology*, 7(10):e1002236.

Gauthreaux Jr, S. A. (1978). The ecological significance of behavioral dominance. In *Social Behavior*, pages 17–54. Springer.

Goldsby, H. J., Knoester, D. B., and Ofria, C. (2010). Evolution of division of labor in genetically homogenous groups. In *Proceedings of the 12th annual conference on Genetic and evolutionary computation*, pages 135–142. ACM.

Hintze, A. (2014). evolved brain replicate id 19 all gates. `http://dx.doi.org/10.6084/m9.figshare.987155`.

Lenski, R. E., Ofria, C., Pennock, R. T., and Adami, C. (2003). The evolutionary origin of complex features. *Nature*, 423(6936):139–144.

Olson, R. S., Hintze, A., Dyer, F. C., Knoester, D. B., and Adami, C. (2013). Predator confusion is sufficient to evolve swarming behaviour. *Journal of The Royal Society Interface*, 10(85):20130305.

Robinson, G. E., Fernald, R. D., and Clayton, D. F. (2008). Genes and social behavior. *science*, 322(5903):896–900.