Appendix I – ODD Protocol

Purpose

The purpose of this model is to understand how the dynamic interactions of dominance competitions in simple agent groups that lead to the more complex behavior of reciprocity may affect the emergence of other complex social behaviors involved in food seeking.

State Variables and Scales

The model space is divided into agents that interact with one another, and the environment which includes patches of food. Agents in the model are based on "estimators" from Hemelrijk (1996). Estimators are called such because they compete with other agents around them for dominance based on how well they estimate they will do. Thus, dominance competitions are the result of perceived dominance values. These estimators have a true dominance scores which indicate the true out come of their collective dominance interactions, given as "Dom". Estimators also have a perceived dominance score given as "D," which is the chance of that particular estimator to win in a dominance competition with a different agent, based on the estimator's memory of previous interactions with that agent. This memory comes is stored as the list "memory". The final important variable at this level is the personal space parameter "PerSpace" which indicates how close an estimator will allow other agents to come before it initiates a dominance competition. These variables and parameters define the basic interactions between estimators in the model space.

Because the model is primarily a dominance competition model, these variables constitute the framework from which we can observe the emergent of social behavior. Based on this, agents are characterized by the state variables: identity number, estimator (in the original Hemelrijk (1996) there were two breeds of agents, but one was dropped for this experiment), dominance level and perceived dominance success. Agents' size reflects their dominance level, but this is purely for visualization purposes and doesn't effect the model beyond what is already defined by the mathematics of the dominance competitions.

In the model extension that was conducted by this experiment, agents were given two additional state variable, which was their energy level, given by "energy". This defined how much energy an agent could lose in a dominance competition, and how long before an agent needed to stop competing and go look for food. With this, agents were given a metabolism rate, which was defined as the rate by which they used energy while engaging in the usual tasks of their lives. This was standardized across all agents and was generally applied to the task of moving around.

A second hierarchical level of "community" was loosely defined. This was simply the aggregate of all the agents in the model space, which usually consisted of either four or eight agents. This community was measured by the average distance between members at any given point in time. The spatial structure of the community was an emergent property of the dominance interactions of the agents (described originally by Hemelrijk (1996)).

Finally, patches were defined by a simple binary variable that indicated whether they had a food resource on their patch or not. Food resources were not eliminated upon consumption, but persisted. This developed the environment into one or several food rich areas, with barren areas inbetween.

Scheduling

Scheduling was one of the most important part of the original Hemelrijk model, and the timing regime was implemented here. The basic definition of the timing regime was a turn-based system where each agent executed its own turn before the others. This was an important time regime because it created a "line" of agents waiting to take an action, but also made it possible to define a means by which an agent could move up in line if it met some specific condition. This condition was whether or not an agent was in viewing distance of a pair of agents that were currently competing. If an agent saw other agents engaging in a dominance competition, it would move its position to the front of the line and take its turn next.

Once its turn began, an agent would first determine if its energy levels were below a global threshold defined as the starvation rate. If this was true, the agent would initiate a food seeking behavior, where it would move the the closest patch containing food and eat. This food seeking behavior continued until the agent increased its energy levels above the threshold, meaning that the estimator that was seeking food would not initiate a dominance interaction until it had eaten.

If the estimators level was not below the threshold, then the agent would follow a behavioral path wherein it would seek to be close to the main aggregate of agents, and if any other agents were within its defined personal space, it would initiate a dominance competition. When agents successfully won a dominance competition, they pursued the lose by moving one step after them. In turn, losers of dominance competitions would move away one step.

Design Concepts

Emergence: The most easily observable emergent behavior within the community of agents was the spatial configuration of the group as it came together. While group formation was ordained by a programmed behavior of searching for other agents, there was not instruction as to the structure of these groups. However, Hemelrijk found, and I was able to reproduce, a structure emerging wherein more dominant agents made up the spatial center of the group, and agents with less dominance existed on the periphery. With food requirements lending their pressures to the structure, this developed into a “king-of-the-hill” type of scenario where agents could be observed to “compete” over access to the resources in the environment. Dominant agents could be seen to take up positions at the center of food clusters, while less dominant agents existed on the periphery, having to risk being attacked in order to gain some food.

On some trials, agents could also be observed to occasionally form small splinter groups, or even completely divergent social communities. The latter was rare, and both depended on the initial starting position of the agents, the size of the model space and the location of the food clusters. If enough agents located each other away from they larger group, there was no need to seek larger group inclusion, and the splinter cell would exist on a separate food cluster. This emergent property was only observed qualitatively and was not analyzed.

Prediction: Estimators were able to predict their future success on a dominance competition based on a stored memory of their previous encounter with a particular agent. Estimators kept a list, where position of an item in the list coincided with the ID of the individual encountered, and the value of the item was the D value presented in the last dominance competition with that individual. The D value is the perceived dominance of that particular agent, so each estimator at any given time only knows how good the other estimators feel about themselves, not their true levels of dominance. This was established in Hemelrijk (1996).

Sensing: The ability to know their opponents D scores is the primary sense of the estimators as well. Based on this previous knowledge, estimators actually decide whether or not they want to engage in a dominance competition. This takes the form of an internal dominance competition, where the estimator competes against its memory of its opponent's success. If the outcome of this internal competition is negative, the estimator will simply walk away and avoid an interaction.

Agents also sense their energy levels and use these to determine whether they can afford to be in a dominance interaction or whether they avoid interactions and search for food.

Interaction: Agents interact with other agents entirely through dominance competitions. However, in this model the dominance competition does not only ascertain the rank of the individual, it is also the primary mover of energy resources within the community of agents. When an agent wins a dominance interaction, its dominance level increases, proportional to the difference between its previous rank and the rank of its opponent. Thus beating an agent higher on the hierarchical scale then yourself will get you more dominance than beating one lower. The same procedure works in reverse for losers. Additionally, winning and losing confer resource gains and losses respectively. When an agent wins it effectively takes some of the losers energy and adds it to its own energy reserves. This was based on the idea that a real world dominance competition might involve the taking of food, or some other energy cost to the loser.

Observation: For this particular analysis, data is best collected at each individual time step so that the evolution of the hierarchical levels, distances between agents and changes in energy levels can be observed as a function of the time spent within the community for each individual agent. It is for this reason that a dynamical analysis is recommended. However, this researcher currently lacks the tools necessary to conduct the rigorous mathematical analysis required by dynamics so the average distance between agents was recorded. However model plots show the trends and changes over time qualitatively.

Initialization

The Hemelrijk's original model used a model space of 200 x 200 patches. However, in replication, it was found that the patterns that were supposed to be emerging were more difficult to observe when the space between agents was so great. Mainly, agents were having a difficult time locating one another since the population levels were fairly low (4 or 8). For this reason, the model space was reduced to 100 x 100 patches for this paper, a change which is supported by Hemelrijk in a later version of the model.

Location of patches with food in the environment are generated semi-randomly. This initial sprouting location is random, but once a sprouting location is determined, all patches within a certain radius have a random probability of also sprouting food. Thus the food clusters are small circular areas of patches, many of which will contain food. Agent starting position is also random upon initialization. Agents begin with a medium Dom value (5) and no preconceived notions of their success (D values are initialized at 0). The memory list is initialized as an empty list whose length is equal to the number of agents defined by the population parameter. Agents are initialized with three different viewing specifications, a near view distance set to 8 units, a maximum view distance set to 50, and a viewing angle set to 120º. Finally, energy levels are initialized to their maximum (in this case 5).

Input

The energy levels gained and lost throughout interactions are defined based on a random chance distribution. Dominance levels presented and gained or lost are dependent on previous experience with the opponent and the opponents dominance rank.

Submodels

Dominance Perception (D): Dominance perception is the primary determiner of agent behavior. It is the confidence an agent has in its ability to win, based on its own true dominance values and its perception of the other agents it has previously encountered. This is the value used for the estimations of dominance competition success. D is calculated by...

$$D_{self} = \frac{Dom_{self}}{Dom_{self} + Dom_{r,\,opponent}} \quad (1)$$

where Dom_{self} is the true dominant score of the calling agent and $Dom_{r,opponent}$ is the remembered dominance score of the current opponent as pulled from the agent's memory. The estimation procedure is given by...

$$win_{?,estimate} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} D_{self} > Random(0,1) \quad (2)$$

Similarly, actual competitions are evaluated by the same equations, but the D values are present in place of true dominance values. Thus, dominance is product of perceived success as well as rank.

$$win_{?,actual} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \frac{D_{self}}{D_{self} + D_{a,opponent}} > Random(0,1) \quad (3)$$

where $win_{?,actual}$ is the binary outcome of the competition and $D_{p,opponent}$ is the D score presented by the opponent. Opponent D scores are calculated exactly the same as equation 1, but with the opponent occupying the role of "self". Following a competition, the dominance scores are updated based on the relative rank of the opponents and the outcome for each. The calculations are again based on each agents perceptions of the others scores. Therefore,

$$Dom_{i,i} = Dom_{i,i} + \left(win_i - \frac{Dom_{i,i}}{Dom_{i,i} + Dom_{i,j}} \right) * stpdom \quad (4)$$

$$Dom_{i,j} = Dom_{i,j} - \left(win_i - \frac{Dom_{i,i}}{Dom_{i,i} + Dom_{i,j}} \right) * stpdom$$

where the subtext i,i refers to agent i's perception of agent i, and i,j refers to agent i's perception of agent j. The same is done for j but with j's and i's switched in the equation. Stpdom here is a scaling factor initialized at 0.5.

Food Seeking: Food seeking behavior was given by a series of logical boolean statements that checked whether or not an agent's energy was below the given starvation threshold. This threshold was given as a percent of the agent's total possible energy. The average energy of each agent for each run was calculated by

$$E_{average} = \frac{E_{average,t-1} * (t-1) + E_{current}}{t} \quad (5)$$

Where $E_{average,t-1}$ is the previous average calculated by this equation, $E_{current}$ is the current level of energy and t is the time step. This allowed for the average energy level of an agent across the whole run of the model to be recorded and evaluated as a predictor of behavior.

Distance: Based on the previous Hemelrijk model, distance between agents was a good factor to observe as an indicator the group structure and the parameters that affected it. The average total distance between agents for a single run was calculated in a similar manner to equation 5.

$$D_{average} = \frac{D_{average,t-1} * (t-1) + D_{Mean\,Current}}{t} \quad (6)$$

where $D_{average,t-1}$ is the average distance between agents on calculated on the last time step, and $D_{mean\ Current}$ is the current mean distance between agents.