

## **Project suggestions for MSc course Advanced Self-organisation of Social systems**

### **Netlogo: school size and following a gradient**

Schools have been shown to follow a gradient better than solitary individuals (Grünbaum 1998; Codling et al. 2007; Berdahl et al. 2013). In a computational model, it was shown that collective sensing of a light gradient may arise from slowing down towards darker areas and speeding up in the direction of neighbouring group members. Build a model of fish school and put it in an environment with a light gradient. Let fish increase speed at higher light levels and slow down at lower ones. Study questions such as whether accuracy in following the gradient depends on the topological neighbourhood, school size and contrast in light.

#### *References*

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Codling, E. A., Pitchford, J. W. & Simpson, S. D. 2007. Group navigation and the "many-wrongs principle" in models of animal movement. *Ecology*, 88, 1864-1870. doi: 10.1890/06-0854.1.  
Grünbaum, D. 1998. Schooling as a strategy for taxis in a noisy environment. *Evolutionary Ecology*, 12, 503-522.

### **Netlogo: Decision accuracy and spatial interaction in a moving group with 'leaders'**

If there are a few individuals in a moving group that have the same preferred direction, the whole group will tend to move in that direction (Huse et al. 2002; Couzin et al. 2005). In a recent modeling study it was found that not only the fraction of leaders, but also the movement (diffusion) in the group mattered for the accuracy of reaching the goal (Torney et al. 2013). The diffusion in the group was increased in a model on starlings by making individuals avoid only the nearest neighbor rather than all 7 nearest neighbours (Hemelrijk & Hildenbrandt 2015). Find out in the Netlogo-model how you can change the diffusion in the group. Study how it affects the accuracy of reaching the goal for different group sizes and different percentages of individuals with a goal or 'leaders'.

#### *References*

Couzin, I. D., Krause, J., Franks, N. R. & Levin, S. A. 2005. Effective leadership and decision-making in animal groups on the move. *Nature*, 433, 513-516.  
Hemelrijk, C. K. & Hildenbrandt, H. 2015. Diffusion and Topological Neighbours in Flocks of Starlings: Relating a Model to Empirical Data. *PLoS ONE*, 10, e0126913. doi: 10.1371/journal.pone.0126913.  
Huse, G., Railsback, S. & Ferno, A. 2002. Modelling changes in migration pattern in herring: collective behaviour and numerical domination. *Journal of Fish Biology*, 60, 571-582.  
Torney, C. J., Levin, S. A. & Couzin, I. D. 2013. Decision Accuracy and the Role of Spatial Interaction in Opinion Dynamics. *Journal of Statistical Physics*, 151, 203-217. doi: 10.1007/s10955-013-0700-5.

### **Netlogo: Latency, vision and school structure**

Hunter (1969) studied whether fish reacted faster and stronger to some neighbors than others, depending on the angle towards the neighbor and their distance to it. Experiments showed that

response-fish reacted earlier if it reacted stronger rather than weaker and if the stimulus-fish was to the side than ahead or behind and. Implement different tendencies to react to other fish depending on the relative location of the other fish. Study what the consequences are for schooling, for instance as regards internal structure of the school, volume, shape and their variability.

#### References

Hunter JR. Communication velocity changes in jack mackerel *Trachurus symmetricus*. *Animal Behaviour*. 1969;17:507-514.

### **Netlogo: Lateralisation of reaction by prey when escaping from predators**

The majority of prey is known to react to predators faster if they perceive the predator with their left eye, thus if the predator approaches from the left <sup>2</sup>. Lateralization of vision has been found effective, because it increases the cognitive power of individuals <sup>2</sup>. Yet individuals in a population do not have a random left or right attribution of cognitive functions. Similarity of lateralization is supposed to be useful for coordination in a group. Whereas in a game theoretic study it was shown that a skewed percentage is needed for obtaining an equilibrium of individuals preferring the left eye and those preferring the right eye <sup>3</sup>, this is not based on what happens in space and time during an attack. Study in a Netlogo model what the effect is of lateralization of reaction to a predator versus no lateralization. If time permits, study what the effect is of different percentages of prey having their escape reaction in the same hemisphere side and thus same eye as others in the group <sup>3</sup>.

#### References

Rogers LJ. (2012) The two hemispheres of the avian brain: Their differing roles in perceptual processing and the expression of behavior. *Journal of Ornithology* 153: S61-S74.

Ghirlanda S, Vallortigara G. (2004) The evolution of brain lateralization: A game-theoretical analysis of population structure. *Proc R Soc B-Biol Sci* 271: 853-857.

### **Netlogo: How the predator manages to catch moving prey. Study navigation strategies ('guidance rules') of the predator**

When a predator hunts a school of fish or a flock of birds, there are several guidance strategies to consider. The most obvious strategy would be to move towards the current position of the prey. However, at the time of arrival, the prey would have moved towards a new position. An alternative strategy would be to move towards a position at which the predator expects to intercept the prey. This can be achieved by applying 'proportional navigation', a strategy in which the predator adjusts the rotation of velocity vector proportionally to the rotation rate of line of sight of its prey. This strategy is frequently used in homing missiles and is optimal when the prey moves in a straight line. But is it also optimal when the prey tries to escape? In this project, two or more strategies should be implemented in an existing Netlogo model. The model will be run for different navigation strategies and predation success will be compared.

#### References

Olberg, R., Worthington, A. & Venator, K. 2000 Prey pursuit and interception in dragonflies. *Journal of Comparative Physiology A-Sensory Neural and Behavioral Physiology*. **186**, 155-162.

### **Netlogo: Predation on Fish schools, several predators**

When predators hunt fish schools they are attack sometimes on their own and sometimes in groups with other predators together (Major 1978; Parrish 1993; Lett et al. 2014). Study whether cooperation among predators increases their catching success by comparing the predation success for a single and several predators on the same prey schools. Find out under what behavioral rules and parameters groups of predators do better than single ones.

*References*

- Lett C, Semeria M, Thiebault A, Tremblay Y (2014) Effects of successive predator attacks on prey aggregations. *Theoretical Ecology*:1-14
- Major, P. 1978 Predator-prey interactions in two schooling fishes, *Caranx ignobilis* and *Stolephorus purpureus*. *Animal Behaviour* 26, 760-777.
- Parrish, J. K. 1993 Comparison of the hunting behavior of 4 piscine predators attacking schooling prey. *Ethology* 95, 233-246.

**Netlogo: Predation on fish schools; prey escape strategies**

Prey may escape a predator using different kinds of strategies, which may involve different kinds of fleeing behavior (Hilton et al. 1999; Domenici et al. 2011) and this may depend on the size of the group they travel in. Try out several escape strategies for several group sizes to understand what helps them best to escape the predator.

*References*

- Hilton, G. M., Cresswell, W. & Ruxton, G. D. 1999 Intraflock variation in the speed of escape flight response on attack by an avian predator. *Behavioral Ecology* 10, 391- 395.
- Domenici, P., Blagburn, J. M. & Bacon, J. P. 2011. Animal escapology I: theoretical issues and emerging trends in escape trajectories. *The Journal of experimental biology*, 214, 2463-2473. doi: 10.1242/jeb.029652.

**Netlogo: Predation on bird flocks; the effect of individual escape maneuvers on collective escape**

Prey use different kinds of strategies for escaping a predator (Hilton et al. 1999; Domenici et al. 2011). The majority of computational models of collective escape assume that individuals react in the same way to the specific environmental cues; for instance, moving away from the predator based on the distance to it (Inada & Kawachi 2002). In reality, individuals may react differently to the same external stimuli. In small groups, individual variation in whether and how to escape the predator, in combination with rules to coordinate with group members, affects what patterns of collective escape emerge. For instance, the change of heading of a single flock member in response to the predator may be enough to cause a collective turn.

In this project, you study a different mechanisms underlying the birds' reaction to the predator which increases individual variation in the way that prey escapes an attack. Each individual chooses between either performing a maneuver to escape the predator, or a maneuver for coordinating with its neighbors and potentially follow the escape motion of others. By varying the degree of coordination among individuals or the probability of individuals to perform escape maneuver, you will examine how parameters affect what collective events emerge (e.g. a split or a collective turn) and you will try to develop new explanations for the collective escape patterns we observe in nature.

*References*

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- Domenici, P., Blagburn, J. M. & Bacon, J. P. 2011. Animal escapology I: theoretical issues and emerging trends in escape trajectories. *The Journal of experimental biology*, 214, 2463-2473. doi: 10.1242/jeb.029652.
- Inada, Y. and Kawachi, K. 2002. Order and Flexibility in the Motion of Fish Schools. *Journal of Theoretical Biology* 214, 371-387.

## Netlogo: The effects of social relationships on flocking

The majority of models of collective motion of animals assumes that individuals are identical [Hildenbrandt *et al.* 2011]. In flocks of birds, coordination among individuals is thought to be achieved by local interactions between each individual and its 6-7 closest neighbors independent of the identity of neighbors [Ballerini *et al.* 2008]. However, in jackdaws, the relative position of birds during flocking is influenced by their social relationships; individuals fly closer to their mating partner. In line with this, the number of topological neighbors of the individuals flying with their mating partner is half of that of those that are non-paired and the coordination with their mating partner is higher than that of an unpaired individual with its closest neighbor [Ling *et al.* 2019].

Try to implement social relationships in a model of flocking by adding interactions that are biased to specific individuals in the group. Use this model to study, for different flock sizes, the effect of these local interactions on characteristics of the flock, for instance, its shape, its polarization and nearest neighbor distribution.

### References

M. Ballerini, N. Cabibbo, R. Candelier, A. Cavagna, E. Cisbani, I. Giardina, A. Orlandi, G. Parisi, A. Procaccini, M. Viale, and V. Zdravkovic, "Empirical investigation of starling flocks: a benchmark study in collective animal behaviour," *Animal Behaviour*, vol. 76, no. 1, pp. 201-215, 2008.

C. K. Hemelrijk and H. Hildenbrandt, "Some causes of the variable shape of flocks of birds", *PloS one*, vol. 6, no. 8, 2011.

Ling H, McIvor G.E., van der Vaart K., Vaughan R.T., Thornton A., Ouellette N.T. "Local interactions and their group-level consequences in flocking jackdaws", *Proc. R. Soc. B*, vol. 286, 2019

## Netlogo: Modelling flocks of different bird species

Research on collective behavior in birds has focused on very large flocks of European starlings [Ballerini *et al.* 2008, Hildenbrandt *et al.* 2010]. Computational models have identified factors affecting the shape of these flocks [Hemelrijk & Hildenbrandt 2011] and their internal structure [Hemelrijk & Hildenbrandt 2012], as well as patterns of collective escape, such as agitation waves [Hemelrijk *et al.* 2015]. Less attention has been given to other species of birds. Flocks of other species are often smaller in size and differ in shape and internal structure from those of starlings. For instance, in flocks of gulls, variation in distance to the nearest neighbor is greater and degree of alignment among individuals is lower than in flocks of starlings.

Here you will create models of collective motion of several caricatures of 'species'. For this, you adjust the main interaction rules (attraction, avoidance, alignment) by changing the behavior they are based on (e.g. attraction to others by speed or by turning) and their relative effect (e.g. make alignment twice as strong as attraction). You conceptualize your representation of different species-caricatures by observing movies of their flocks under natural conditions. You find what combinations of rules lead to each species-caricature in terms of characteristics of the flock, for instance shape, polarization and nearest neighbor distribution.

### References

M. Ballerini, N. Cabibbo, R. Candelier, A. Cavagna, E. Cisbani, I. Giardina, A. Orlandi, G. Parisi, A. Procaccini, M. Viale, and V. Zdravkovic, "Empirical investigation of starling flocks: a benchmark study in collective animal behaviour," *Animal Behaviour*, vol. 76, no. 1, pp. 201-215, 2008.

H. Hildenbrandt, C. Carere, and C. K. Hemelrijk, "Self-organized aerial displays of thousands of starlings: A model", *Behavioral Ecology*, vol. 21, no. 6, pp. 1349-1359, 2010.

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C. K. Hemelrijk and H. Hildenbrandt, "Schools of fish and flocks of birds: their shape and internal structure by self-organization", *Interface focus*, vol.2, pp. 726-737, 2012.

C. K. Hemelrijk, L. van Zuidam, and H. Hildenbrandt, "What underlies waves of agitation in starling flocks", *Behavioral ecology and sociobiology*, vol. 69, no. 5, pp. 755-764, 2015.

### **DomWorld: Differences between the sexes in stability of absolute and relative rank positions**

In chimpanzees, the sexes have recently been shown to differ in the dynamics of their dominance ranks. Whereas ranks among males change regularly over time, among females ranks seem almost static (Foerster et al., 2016). Dynamics of ranks of chimpanzees are suggested to be due to external factors, such as invasion of immigrants, emigration of individuals and death. In the present project you investigate whether dynamics may also be due to interactions among group members and inherent differences between the sexes, such as a stronger tendency to aggregate among males than among females as suggested for chimpanzees. The aim of this project is thus to investigate what conditions influence the differences in hierarchical stability between the sexes. Conditions may involve for instance, degree of cohesion among same-sex group members, initial dominance of both sexes, dominance style, group cohesion, group size *etcetera*. NOTE: In this project no changes are made to the model, rather you alter parameters and perform data analysis on the output, using *r* or *python*.

#### *References*

Foerster, S., Franz, M., Murray, C. M., Gilby, I. C., Feldblum, J. T., Walker, K. K., et al. (2016). Chimpanzee females queue but males compete for social status. *Scientific Reports*, 6, 35404.

### **DomWorld: Network motifs and dominance hierarchies**

The network motifs of dominance hierarchies were compared over a range of species, primates, ungulates, elephants, carnivores, birds, social insects and fish (Shizuka & McDonald 2015; Shizuka & McDonald 2012). They were studied in terms of the patterns at the level of the triads. Transitive triads and patterns of double dominance and transitivity were found more than expected compared to random networks (expected is 75%) (Fig 2). They did not depend on group size or taxon, but the frequency of double dominants increased, and frequency of pass along also, when the network was denser (there was a lower percentage of dyads without interactions). Further if the top-ranking individuals interacted more, there were more double dominants and fewer pass-along triads. It is argued that these are effects of self-organisation therefore it is of interest whether you can find similar patterns in the dominance interactions in DomWorld with self-reinforcing outcomes (Hemelrijk 1999). The aim is that you investigate these triadic patterns for different group sizes and density of networks and degree with which alpha males interacted with others (compare despotic society). Explain what parameters you

chose in DomWorld and why. NOTE: In this project no changes are made to the model, rather you alter parameters and perform data analysis on the output, using r or python.

### References

Hemelrijk, C. K. 1999. An individual-oriented model on the emergence of despotic and egalitarian societies. *Proceedings of the Royal Society London B: Biological Sciences.*, 266, 361-369.

Shizuka, D. & McDonald, D. B. 2012. A social network perspective on measurements of dominance hierarchies. *Animal Behaviour*, 83, 925-934. doi: 10.1016/j.anbehav.2012.01.011.

Shizuka, D. & McDonald, D. B. 2015. The network motif architecture of dominance hierarchies. *Journal of the Royal Society Interface*, 12, 20150080. doi: 10.1098/rsif.2015.0080.

## Netlogo: DomWorld - variation in female dominance over males in lemur species

Female dominance over males is rare in most species of primates but widespread in the lemurs of Madagascar. This has been previously linked to scarcity of food and increased competition by females for food to meet their energetic demands during reproduction (Wright 1999). However, what has not been studied is how the variation of female dominance over males emerges; egalitarian species of lemur have weaker female dominance over males than despotic species (e.g. table 1). Previously, an agent-based model, DomWorld, has shown that in despotic species of macaques, female dominance increases with the proportion of males in the group and differences between egalitarian and despotic species emerge because of a difference in intensity of aggression (Hemelrijk 1999, Hemelrijk *et al.* 2008). Because lemurs have equal adult sex ratios, they lack sexual dimorphism and do not differ in intensity of aggression across species (Kappeler & Fichtel 2015), these factors are not responsible for the differences in social systems and degree of female dominance over males. Instead, species of lemur differ in the proportion of fights that are undecided (fights without a clear winner) (Kappeler 1995) and in the distribution of their preferred food (Table 1). In this project you will code in a Netlogo version of DomWorld and create rules for 1) how fights may remain undecided (and therefore dominance scores are not updated) and 2) agents to interact with food resources based on distribution of food in empirical data. You will look whether and how social systems emerge. You classify different social systems in terms of degree of female dominance, proportion of undecided fights, and steepness of dominance hierarchy and study how this social system depends on different spatial distributions of food resources.

Table 1. Description of three species of lemur with varying social style and degree of female dominance over males.

	<i>Eulemur rufifrons</i>	<i>Propithecus verreauxi</i>	<i>Lemur catta</i>
Female dominance (Female dominance index)	Co-dominance of sexes (0.5)	Moderate female dominance (0.75)	Strong female dominance (0.9)
Social system	Egalitarian	Moderately despotic	Despotic
Distribution of preferred foods	Evenly distributed	Moderately patchy	Patchy
Proportion of undecided fights	High (40-60%)	Moderate (20%)	Low (2-5%)

### References

- Wright, P. C. Lemur traits and Madagascar ecology: coping with an island environment. *Am. J. Phys. Anthropol. Suppl* 29, 31–72 (1999).
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- Hemelrijk, C. K., Wantia, J. & Isler, K. Female dominance over males in primates: Self-organisation and sexual dimorphism. *PLoS One* 3, (2008).
- Kappeler, P. M. & Fichtel, C. Eco-evo-devo of the lemur syndrome: did adaptive behavioral plasticity get canalized in a large primate radiation? *Front. Zool.* 12, S15 (2015).
- Kappeler, P. M. Reconciliation and post-conflict behaviour in ringtailed lemurs, Lemur catta and redfronted lemurs, *Eulemur fulvus rufus*. *Anim. Behav.* 45, 901–915 (1993).

## **Reproductive competition and distribution of food in species of lemur.**

According to the cost-asymmetry hypothesis (Dunham, 2008) in monomorphic species, the sex that values the resource over which individuals compete most should be dominant. In lemurs, we think the most valued resource is food because of the extreme scarcity in Madagascar. Females have higher energetic demands than males during reproduction, thus they should value food more than males do and put more effort into winning contests over food. This is represented in the model LemurWorld as effort in relation to hunger (hungrier individuals have a higher probability to win than less hungry individuals). Another resource that individuals are likely to compete over is mates. Here, we expect males to compete more and thus during this period, males may become dominant over females. It may also happen in some species and not others, depending on the relative dominance of females compared to males. For instance, in species where males and females share dominance (co-dominance of the sexes), males may be more likely to become dominant during the mating season than when species have strong female dominance over males. In lemurs, females enter into oestrus asynchronously. Each female is reproductively active for about 1-2 days each and the mating season lasts around 2 weeks per year. In this project you will implement reproductive season for lemurs. Females enter into oestrus asynchronously and will be attractive to males during this time. You should implement a rule for how males and females behave during mating season. Males may have to compete with other males to 'mate' with a female. Questions to investigate are how does the dominance hierarchy/degree of female dominance over males change during the mating season compared to the rest of the year? You may also want to investigate reproductive skew of males and females and what factors influence this.

### *References*

- Dunham, A. E. (2008) 'Battle of the sexes: cost asymmetry explains female dominance in lemurs', *Animal Behaviour*, 76(4), pp. 1435–1439. doi: 10.1016/j.anbehav.2008.06.018.
- Kappeler, P. M. and Port, M. (2008) 'Mutual tolerance or reproductive competition? Patterns of reproductive skew among male redfronted lemurs (*Eulemur fulvus rufus*)', *Behav Ecol Sociobiol*, 62, pp. 1477–1488.

## **Measurements of female dominance in DomWorld**

Although the degree of dominance of females over males is rarely quantified in the literature, it has been done using different methods. In this project you investigate whether different ways of measuring female dominance over males lead to different results. You do this in a computational model, DomWorld. The advantage of using a model to do this, is that agents in this model have a 'true' (internal) dominance value which reflect its tendency to win fights. Look in the literature to find several ways of measuring female dominance (and also think of some of your own!) and compare how accurately these measurements describe the degree of female dominance over males in comparison to the internal dominance of the individuals in the model.

### *References*

- Hemelrijk, C. K., Wantia, J. and Isler, K. (2008) 'Female Dominance over Males in Primates: Self-

Organisation and Sexual Dimorphism', *PLoS ONE*. Edited by S. F. Brosnan, 3(7), p. e2678. doi: 10.1371/journal.pone.0002678.

### **Eviction from the group by targeted aggression**

In species of lemur, some females are the receivers of repeated targeting aggression that causes them to be evicted from the group (Vick and Pereira, 1989). This is thought to be a consequence of increased reproductive competition among females and the likelihood of evictions increases with increasing group size (Kappeler and Fichtel, 2012). Why some females are targeted and evicted from the group is unclear, although it may be a side-effect of increased competition for food or mates. A larger group size or skewed sex ratio may increase the degree of competition individuals experience over food and mates and thus induce repeated aggression towards a female, causing her to be evicted from the group. In this project, you introduce a rule for reproduction. Females enter into oestrus (when they become attractive to males) asynchronously for 1-2 days per year. The whole period lasts roughly 2-3 weeks per year. You will also implement a rule for evictions and when and why these might occur. Study the effect of sex ratio and group size on the frequency of female evictions to pinpoint the possible causal factors for this unusual occurrence. You may also study how reproductive success differs with and without evictions at certain group sizes, and if on average fitness increases for the group if some females are evicted.

#### *References*

- Kappeler, P. M. and Fichtel, C. (2012) 'Female reproductive competition in *Eulemur rufifrons*: Eviction and reproductive restraint in a plurally breeding Malagasy primate', *Molecular Ecology*, 21(3), pp. 685–698. doi: 10.1111/j.1365-294X.2011.05255.x.
- Vick, L. G. and Pereira, M. E. (1989) 'Episodic targeting aggression and the histories of Lemur social groups', *Behavioral Ecology and Sociobiology*, 25(1), pp. 3–12. doi: 10.1007/BF00299705.

### **Netlogo: Thermoregulation in Honeybees - additional fitness constraints**

Honey bees regulate swarm temperature to minimize energy consumption and to avoid hypothermia. Fitness of swarming decreases when the environmental temperature increases above 18 degrees. At such high temperatures smaller swarms do better. In real honey bees, there are more aspects to take into account than currently implemented in the model. For instance, the bees need to defend themselves against intruders, which they do better when their body temperature is higher. Further, the queen needs to have a warm and stable environment. Also, scout bees search for a new location to start a hive better when they are warm. In this project, you will implement these additional aspects. You study their contribution to survival and whether and how strategies of thermoregulation need be adjusted.

#### *References*

- Sumpter, D. J. T., & Broomhead, D. S. (2000). Shape and dynamics of thermoregulating honey bee clusters. *Journal of theoretical Biology*, 204(1), 1-14.
- Hepburn, H. R. (2006). Absconding, migration and swarming in honeybees: an ecological and evolutionary perspective. *Life cycles in social insects—behaviour, ecology and evolution*. St. Petersburg University Press, St. Petersburg, 121-136.

### **Netlogo: Thermoregulation in Honeybees - variability increases stability**

According to Jones, Myerscough, Graham and Oldroyd (2004), there are benefits to genetic diversity in honey bee colonies. One benefit is increased stability in thermoregulation. In colonies sired by several males, temperatures were found to be more stable and beneficial than in colonies sired by only one male. In this project, you study the effect of diversity of (worker) bee behavior on thermoregulation. Can you



replicate these empirical findings?

#### *References*

Jones, J. C., Myerscough, M. R., Graham, S., & Oldroyd, B. P. (2004). Honey bee nest thermoregulation: diversity promotes stability. *Science*, 305(5682), 402-404.  
Oldroyd, B. P., & Fewell, J. H. (2007). Genetic diversity promotes homeostasis in insect colonies. *Trends in ecology & evolution*, 22(8), 408-413.

#### **Netlogo: Brood sorting in *Temnothorax* ants**

When *Temnothorax* ants move to a new nest, they sort their brood into concentric rings: Eggs and small larvae in the middle, the middle-sized larvae around it, then pupae and pre-pupae, and most peripherally, large larvae. Try to build a Netlogo model that can explain such behavior.

#### *References*

Sendova-Franks, A.B., Scholes, S.F., Franks, N.R. & Melhuish, C. (2004). Brood sorting by ants: Two phases and differential diffusion. *Animal Behaviour*, 68, 1095-1106.

#### **Netlogo: Wallbuilding in *Temnothorax* ants**

*Temnothorax* ants live in tiny fissures in rocks, where they build walls to protect their nests. In the model of Theraulaz *et al.*, the entrances to these walls are the result of stigmergic effects during building. However, if this is the only effect at work, the entrances eventually close up, as ants keep adding more and more stones to their wall. See if the NetLogo model of this wallbuilding behavior can be extended so that the entrances stay open.

#### *References*

Chapter 17, Wallbuilding by ants, in: *Self-organisation in biological systems*, by Camazine *et al.* 2001, Princeton University Press (also on Nestor).

#### **Netlogo: Task division among bumble bees**

The model about the task division in bumblebees (Hogeweg & Hesper 1983) is based on bees going more often to the centre if they are higher in dominance rank and more often to the periphery if they are lower. The aim of this project is to see whether the spatial structure can be emergent (like in DomWorld). Thus, implement dominance interactions and chasing and fleeing in space and see how this affects dominance development and task division.

#### *References*

Hogeweg, P. & Hesper, B. 1983. The ontogeny of the interaction structure in bumble bee colonies: a MIRROR model. *Behav Ecol Sociobiol*, 12, 271-83.

**Any ideas of yourself are highly welcome!**