Are ants more organized than us?

Ian O'Dwyer

December 11, 2001

As early as the 1800's, Henri Poincaré recognised that his study of the three-body celestial mechanics problem was leading to what would today be termed a chaotic solution. Poincaré and others struggled to make progress on this problem without the benefit of computers, and it was not until the 1960's that Lorentz discovered the same kind of behaviour as Poincaré, this time in a meteorological setting. Using a computer to solve non-linear differential equations for convection in order to understand the unpredictability of weather forecasting, Lorentz discovered that his solutions would never settle down to a steady-state. The solution always evolved in an irregular, aperiodic fashion [1], that is, the solution was chaotic. The failure of the reductionist approach to explain chaos and complexity (including biological complexity), has led to the emergence of new theories and science, such as that of non-linear dynamics. The study of complexity and social organization has long been of interest, not only to the academic community, but also in the corporate world, where a better understanding of complex social structures and their effect on efficiency and productivity may well be a key element in organizational success or failure. Insect colonies have historically provided useful and interesting insights into complex organizations and whilst human beings are highly autonomous individuals compared to ants, it is still possible to derive some useful clues about human social structures and interactions from them.

The individual ant is not capable of complex behaviour whereas the colony, when viewed as a single entity, is - the sum of the behaviour of the parts does not explain the behaviour of the whole. In this essay I review some studies of insect colonies and examples of complex behaviour built up from simple automata. I then consider how this might be applicable to human social organizations, in particular corporations. To support this discussion, I draw upon an example from the business world, in the form of a virtual network of information sharing teams at IBM.

Many animal social organizations exhibit complexity where the interactions of individuals with other individuals and with their environment leads to emergent patterns of behaviour on the macro level. That is, whilst a colony of ants might be simply a collection of rule-following individuals, the colony itself can also be considered an individual with complex behavioural patterns. The reasons for particular types of emergent behaviour seem clear at a qualitative level, but often defies quantitative description. For example, simple rules for different types of ants may lead to emergent behaviour in the colony. A foraging ant might live by a simple set of rules: 1. Find food and return to the nest, but leave a chemical trail. 2. If you find a trail, follow it. 3. If you have no food and cannot find a trail, then wander randomly until you find one or the other. If all foraging ants follow these simple rules, a particular type of emergent behaviour may be seen in the colony [2]. By having a number of ants follow these simple rules, it is possible to show that the colony can make a decision about which of two food sources is preferred, based on glucose content [3]. No individual ant is capable of this decision, but taken as a complex, self-organizing collective, the colony is capable of such decisions. Below, I discuss several methods of analysing this emergent behaviour, attempting to quantify it and correlating the behaviour of the individuals to the behaviour of the organization as a whole.

In the late 1980's Langton proposed that complex computational abilites emerge at the so-called *edge of chaos*[4, 5]. In relation to insect colonies, Miramontes has more recently proposed [6] that systems of interacting chaotic individuals actually exhibit optimal information processing and adaptive capacity when they are balanced at the border between order and chaos. It has been observed [7] that ant colonies of the genus *Leptothorax* exhibit short term pulses of activity and inactivity within their nests. Further, such ordered periodic activity is not noted in smaller groups of 5-7 individuals, who instead exhibit deterministic chaos in their patterns of activation, but only in the colony as a whole. A typical colony might consist of 100 individuals. Miramontes is able to develop a theoretical model based on the behaviour of the ants which provides evidence for a phase transition from disordered chaos to the ordered periodic state, dependent simply on the density of ants in the nest, and hence the frequency of interactions. By quantifying computational power and adaptability, it is seen that the optimal place for the colony to exist is at the border between order and chaos. In another paper [8], Solé and Miramontes attempt to use fluid neural networks to explain the behaviour of insect colonies, and the periodic behaviour of *Leptothorax* specifically. The basic idea is that the individual ants behave as a neural net of mobile elements. Since the ants are free to move in space, they can be considered a fluid and the colony as a whole can perform network computations. As mentioned previously, this might be in selecting food sources based on sucrose content, a computational task which individual ants are incapable of. Solé and Miramontes go on to develop a theoretical framework based on neural networks which succesfully describes the periodic behaviour of the ants. They are able to show that the maximum information transfer, and thus maximum computational ability, occurs at the boundary between the ordered and chaotic phases. Once again, the key parameter is simply the number of ants involved. Perhaps even more interesting is the fact that this number is not arbitrary, but is controlled by the ants themselves. If the critical density of ants is exceeded, the boundaries of the colony are redefined so that the critical density of ants is once again obtained. This self-organizing system is maintaining itself at optimal computational power, simply by controlling the number of interactions within the nest.

A different view of insect colony organization and behaviour is given in a recent study by Anderson et al [9]. The typical method by which such colonies are studied is to focus on task function, catalog behaviours and conduct function oriented behavioural studies. In order to gain new insight, Anderson et al deconstructed the society not based upon function, but based upon structure and the demands of the tasks the colony must perform. In their own words, "...how does the set of skills needed to complete a task influence the organization of workers around that task?" [9]. This approach seems to have relevance and applicability to human organizations, even if the degree of autonomy varies widely between insects and humans. By identifying four types of task: individual, group, team and partitioned, and studying the relationships between these and their hierarchical structure, it may be possible to objectively evaluate the complexity of an insect society. Each task type is seen as a level in the hierarchy of complexity, with individual tasks being the least complex and partitioned and team tasks being the most complex. Group tasks require concurrent participation by many workers for their completion, with each worker performing the same task. A team task requires two or more tasks to be performed concurrently and in a coordinated manner by the workers and hence requires a much higher degree of complexity than group or individual tasks. Partitioned tasks are tasks which are sequential and again involve a high level of complexity and require the highest degree of cooperation. For example, one group of termites might climb grass stalks and cut the off pieces of grass and drop them to the ground to be collected by another group of termites. There is not only a high degree of separation of tasks and cooperation required, but there is a definite act of transfer either directly or indirectly from one group of individuals to the other. This picture is further complicated by the possibility of tasks being nested within other tasks, such as a partitioned task being a sub-task of a team task.

Having established this view of the insect colony, which bears a striking resemblance to many human organizations, it is possible to assign complexity scores to various tasks performed by the insect colony. For example, 3 points for a team or partitioned task or sub-task, 2 points for a group task or sub-task and 1 point for an individual task. In this scheme, a team task with two partitioned sub-tasks and a group subtask would score 11 complexity points. The scale is a measure and as such does not imply that a task which scores 10 points is twice as complex as a task that scores 5 points. Such a scoring system is generic and independent of taxon, which means that if we have sufficient detail of the way any task is handled by any particular taxon, then a complexity score can be assigned and the complexity of the task quantitatively assessed. Of course, there are various assumptions in this model which may cause the measure to be inaccurate. It is assumed that we are observing all of the complexity associated with the task and not overlooking some factor, due to our own perceptions of complexity. Another potential problem is in the use of human language to describe tasks, which may lead one individual to assign a different complexity score to a task than another, making the whole scoring mechanism arbitrary. Indeed, the whole system relies on the fact that behaviours genuinely possess an underlying structure and that the apparent structure of the tasks we observe is not imposed by the observer.

In a further paper, Anderson and Franks [10] extend this analysis of teams to include animal groups other than insect colonies. In particular, vertebrate teamwork is considered, and this may be the first tentative step towards understanding emergent behaviour in complex human organizations. There are numerous differences between vertebrate and insect groups and teams, but there are also some similarities, and it is these which may hold the key to a better understanding of human organizational behaviour. Vertebrate teams appear to be based on individual recognition, and there is no evidence of this in insect colonies. Vertebrate teams often involve a degree of trust, for example in big cats, hunting is a team effort, although the kill is often made by one animal. The other individuals must simply trust that they will receive their share in the profit. By contrast, insect colonies appear to be much less selfish, with individuals essentially working towards the group goals with little thought of personal reward. A typical vertebrate group is much smaller than a typical insect group: a pride of big cats may be composed of 5-10 individuals compared to an ant colony of 2000 or more individuals. The insect colony contains much more redundancy, thus each individual is far less crucial to the functioning of the group than in the smaller vertebrate group, where redundancy is very low.

It is interesting to note that when considering human corporations, the size can be very large, in some cases 75,000 individuals, so there may be more parallels with insect colonies then with the smaller vertebrate groups. Of course, just as in insect colonies, teamwork has always been highly prized by companies and other social organizations throughout history, but do the most successful organizations exist at the phase boundary between order and chaos? If this is true, and if comparison with insect colonies can be extended, perhaps this allows them to process information faster and to be more adaptive than other organizations which are further from the phase boundary. Clearly, the prospect of existing close to, or even in, chaos may not be welcome to many organizational leaders, but perhaps this is a prerequisite which must be embraced if an organization is to be successful.

At IBM, individuals are spread across the globe, many working from home, using their computers to keep in touch with the organization. This has led to online collaborations in the form of *virtual teamrooms*, where small groups of individuals in different parts of the organization meet in cyberspace to discuss projects and ideas. There are 75,000 of these informal teamrooms and just 55 formal ones. Enormous amounts of knowledge are being created by small, self-organizing teams within the organization, over which the organization exerts little or no direct control. Indeed, the organization as a whole is largely ignorant of the knowledge being generated. However, as soon as a currently unknown piece of information or knowledge is required, it can be sought. IBM has developed a search engine which can trawl through these virtual teamrooms and search for particular keywords on the required subject. Only keywords are recovered and then email is sent to the individuals from the teamroom asking them if they have the required expertise. The fascinating aspect of this process is that the individuals are not required to respond, they need only do so if they find it appropriate. For example, if the person requesting the information has a reputation for not sharing credit and the individual contacted feels their idea might be stolen, they do not respond to the request. If they feel comfortable working with the person making the request, they can respond and collaborate. In this way, individuals who would normally prosper through 'cheating' and taking credit for others ideas are starved of the information and ideas they require to do this. Going back to the animal kingdom, we see that this prevents the kind of behaviour a greedy lion may exhibit, stealing the kill from its fellow hunters, and encourages modes of behaviour which are more similar to those found in the insect colonies. The small sub-groups found in the teamroom environment equate well with the type of small team used for various tasks in insect colonies. Just as in the insect colonies, a self-organizing, complex system develops from these small teams and IBM exhibits emergent behaviour which is a result of chaotic behaviour at the individual level.

It would be virtually impossible for a company as large as IBM to form such a complex network intentionally, but by tapping into this self organizing resource, IBM is able to take advantage of the intellectual capital at its disposal, whilst simultaneously encouraging the chaotic nature of the process delivering the information. Given the discussion above, it seems highly likely that an increasing number of social structures and organizations will encourage similar chaos, in order to benefit from the order which results. As research into complex biological systems, such as insect colonies, continues, it is probable that we will achieve ever greater insights into chaotic and unpredictable organizational behaviour in humans. Those who lead large human organizations may well find that new and unexpected forms of leadership emerge, generating new relationships and interactions throughout the organization.

References

[1] http://www.physics.gatech.edu/chaos/tutorial/history3.htm

[2] http://www.lse.ac.uk/LSE/COMPLEX/Seminars/2001/report_19march01.htm

[3] G. Nicolis and I. Prigogine, Exploring Complexity (Freeman, New York, 1989)

[4] Langton, C., Physica D 42 (1990) 12

[5] Langton, C., Physica D 22 (1986) 120

[6] Miramontes, O., Order-Disorder Transitions in the Behaviour of Ant Societies. Complexity 1(3):56-60 (1995)

[7] Cole, B.J. & Cheshire, D., Mobile cellular automata models of ant behaviour: movement activity of Leptothorax Allardycei. The American Naturalist, 148, 1:1-15 (1996)

[8] Solé, R.V. & Miramontes, O., Information at the edge of chaos in fluid neural networks. Physica D, 80 (1995) 171-180

[9] Anderson, C., Franks, N.R. & McShea, D.W., The complexity and hierarchical structure of tasks in insect societies. Animal Behaviour, 2001, 62, 643-651

[10] Anderson, C. & Franks, N.R., Teams in animal societies. Behavioural Ecology, 12 5:534-540 (2001)