The world revolves around sheep: how best to deal with stray dogs

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EXTENDED ABSTRACT

The use of an agent-based model (ABM) to depicted flocking behaviour of birds (Reynolds 1987) is a powerful example of how emergent behaviour can appear from a few, simple rules applied using localised information. We developed a demonstration ABM of flocking sheep that included an additional “threat” agent in the form of a dog.

The purpose of this model was two fold:

- Demonstrate the power of a simple agent based model for understanding system behaviour to a group naive to the modelling of complex systems; and
- Test the use of a flocking model to explore the value of information under different environmental conditions.

The first part of this paper outlines experiences gained from using a highly abstract model as a tool to encourage discussion amongst dairy industry stakeholders around developing a model of the complex system that is the dairy industry. Aspects of complexity theory, emergence of complex behaviour from simple rules and the role local information plays in decision-making were all introduced using an easily identifiable context (i.e. shifting sheep with a dog) prior to engaging in further discussions about a more personal context.

The second section is about using the sheep / dog metaphor as a proxy for modelling business decision-making. Our initial experiments revolved around quantifying the value of obtaining and responding to additional information under different environmental conditions, to both an individual agent and its wider community.

Emery and Twist (1965) described four types of environmental element: placid random, placid clustered, disturbed reactive and turbulent fields. Three of these elements were modelled using an abstraction of a flock of sheep (disturbed reactive elements) and a dog (clustered placid or random placid element depending upon model parameters). An experiment was designed to test the value of information to sheep with different abilities to detect the different dogs.

The demonstration, although not visually impressive, gave the stakeholder group a sound understanding as to how agent based models function.. The decision to use sheep rather than anything closer to the groups’ area of expertise helped to maintain focus on the modelling without having more discussion on industry specific details or shortcomings of the model.

Although the abstraction used in this paper is far removed from that of a business system and the approach is in it infancy, this initial study shows promise. The results clearly showed that information is valuable in successfully navigating an environment with placid elements, and more valuable when those placid elements are clustered rather than random. This is because in a clustered environment, it is possible to learn more about the environment, and therefore, to more successfully respond. The change in performance caused by the presence of competitors with a different strategy or ability to gather information was unexpected. The authors need to explore this aspect further to see whether there is evidence from the business world that there is convergence of firm performance within industries even when they pursue different strategies and whether this is caused by heterogeneity amongst competitors. If this evidence does exist, then perhaps the abstraction of sheep and dogs may not be too far removed from the world of business.

1. INTRODUCTION

The use of an agent-based model (ABM) to depict flocking behaviour of birds and fish (Reynolds 1987) is a powerful example of how emergent behaviour can appear from a few, simple rules applied using localised information. A demonstration ABM of flocking sheep that included an additional "threat" agent in the form of a dog was developed.

The purpose of this model was two fold:

- Demonstrate the power of a simple agent based model for understanding system behaviour to a group naive to the modelling of complex systems; and
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2. OPERATING ENVIRONMENTS

2.1. Variety in the environment

Emery and Trist (1965) described four idealised types of environment based on causal structures. Causal structure can be taken to mean the processes that generate variety in an environment and, depending upon the nature of these processes, the environment may be predictable or unpredictable. Variety in an operating environment is a function of the distinguishable elements in the environment and the nature of their interaction (Wright, 1985). The four types of environment described by Emery and Trist (1965) are summarised below.

Placid and random – favourable and threatening events/outcomes are randomly distributed and unrelated to the behaviour of actors in the environment. The random distribution of events means that agents cannot do anything to raise the probability of intercepting favourable events or to lower the probability of intercepting threatening events. An agent can only respond to events as they occur. Uncertainty is derived from the randomness of events.

Placid and clustered – favourable and threatening events are systematically related. The placid nature of the environment still means that the environment is not influenced in any way by the agents. However, agents can actively aim to maximise performance by learning about the nature of the relationships between favourable and threatening events. Uncertainty is derived from incomplete learning.

Disturbed and reactive – favourable and threatening events/outcomes are still systematically related, and competitors are also present in the environment. Competing agents' actions create favourable and threatening events in the environment. Uncertainty is derived from the inability to anticipate the actions of competitors.

Turbulent field – interactions between agents are sufficient to cause changes in the environment, and changes can have unpredictable consequences. Change is endemic, and signals present in turbulent fields are often unreliable, ambiguous and misleading. Uncertainty is derived from the complexity of the relationships between agents, and between agents and the environment, and from the continual change occurring in the environment. Turbulent fields are characterised by often appearing predictable for quite long periods, but suddenly changing without notice. Turbulent fields are analogous with emergent properties of complex systems.

2.2. Management responses to variety

Each of these four idealised environments is likely to be present in the different aspects of any real operating environment. Variety in an operating environment reduces the level of control the manager has over performance (Wright, 1985). Performance of the aggregate of individuals is an emergent property of the complex system. Wright (1985) went on to propose that the degree to which performance of an organisation can be controlled depends upon the causal nature of the variety exhibited by elements in the operating environment impacting significantly on performance. The greater the number of options the manager has available to respond to variety in the environment, the greater the degree of control the manager can exert over individual performance (Kaine et al., 1994).

Strategic planning is the development of a pattern of action based on predictions about events focused on the means to achieve long-term ends, and such planning usually occurs infrequently and irregularly. Wright (1985) suggested that strategy formulation is provoked by the emergence of new opportunities, threats, ideas, and other irregular stimuli in the environment.

The success of an organisation depends upon the manager's ability to make good decisions that move the organisation towards goal attainment (Harrison and Pelletier, 2000). The decisions managers make are dependent upon their values; their attitudes towards, and perceptions of, the operating environment; and psychological factors.

Psychological factors could include intelligence and analytical skills, dogmatism, communication and information seeking, and ability to deal with abstractions. The communication and information seeking factor is central to management. Surveys of managers and the tasks they do (e.g., Duncan, 1999) showed that managers at all levels spend most of their time communicating with people both within the organisation (superiors and subordinates) and outside (customers, suppliers, service providers, competitors), either gathering information, obtaining responses to ideas, or disseminating information.

Perceptions of, and attitudes towards, the operating environment are dependent on the individual manager, and are influenced by the manager's experience, learning and knowledge (Rotter, 1966).

The key perception of management is the perceived degree of control over various aspects of the business. Different experiences, learning and knowledge mean managers will differ in their perceptions of the nature of the operating environment and which elements of the operating environment they can influence or control. Differences in perceived control will lead to different business objectives, and different strategies employed to meet these objectives (Kaine et al., 1994). Kaine et al. (1994) suggested that differences arise in farm business performance due to the different strategies used by managers resulting from differences in their perceptions. The concept of locus of control proposed by Rotter (1966) is a measure of an individual's perception of their ability to change a situation, and refers to the individual's beliefs about success and failure.

Khatri and Ng (2000) showed that intuitive synthesis was also related to business performance. They found that managers operating in unstable environments used intuition, together with rational analysis, in strategic decision-making, and that those managers using intuition achieved better financial performance for their company than those managers who relied solely on rational analysis. The value of intuition in unstable and unpredictable environments is derived from the inherent lack of reliable information on which to base rational analysis. In more stable and predictable operating environments, intuition should be used less, and may in fact have a negative affect on business performance (Khatri and Ng, 2000).

Variation in performance is inevitable as there are elements of the operating environment genuinely outside a managers' control, but managers should develop a strategy to minimise this variation by controlling those aspects of the business or environment identified as controllable, and avoiding or reducing contact with those aspects identified as uncontrollable. To achieve best performance, managers should have perceptions and strategies that follow the causal structure of variation in the environment (Kaine et al., 1994).

This suggests that knowledge about the state of elements that are not affected by other elements and can be predicted, i.e. placid clustered elements, is most valuable to managers. Knowledge about placid random elements is less valuable because they cannot be predicted. Similarly, for elements that are turbulent fields or disturbed reactive elements, knowledge will be less valuable to managers.

3. METHOD

3.1. Demonstration

In order to demonstrate to the stakeholder group how a few simple rules could generate complex behaviour a simple sheep flocking simulation was constructed. The simulation contained 50 "sheep" that applied three rules (Reynolds, 1999) to generate flocking behaviour (separation, alignment & cohesion). In order to make things a little more interesting, a "dog" was added, leading to an additional rule – "flee from the dog when it is near by". This gave the user the ability to perturb the system in a manner familiar to anyone who has witnessed a dog running through a mob of sheep.

Figure 1 shows a series of screen captures from the simulation.

3.2. Model

The "sheep" are depicted in white (with black heads to show direction) and the "dog" is brown (a highlighted green area was added for clarity). The sequence shows the "dog" splitting up the mob, by running through the middle of it, followed by the mob reforming after the "dog" moves away.

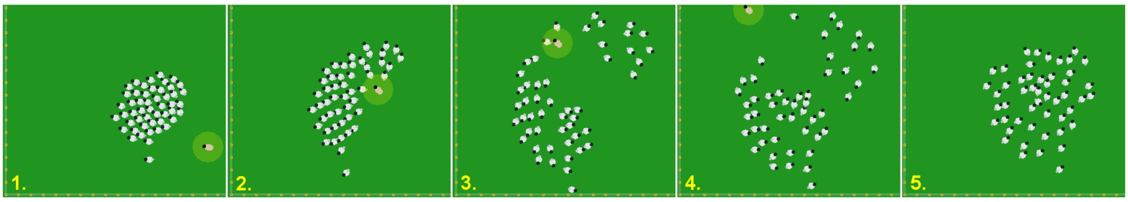

Figure 1. Complex behaviour, 3 flock rules + dog avoidance

Image sequence from Figure 1:

1. Sheep tightly mobbed (dog approaching)
2. Sheep fleeing dog (dog entering mob)
3. Sheep wheeling in behind dog (dog exiting mob)
4. Sheep mob reforming
5. Sheep back in a loose mob

This example clearly shows how a complex high level behaviour of the mob can emerge naturally from a few very simple behaviour rules being applied at a local/individual level. Of course, human decision-making (as individuals) have far more sophisticated behaviours than sheep, but the theory behind agent-based modelling is that the behaviour of an entire industry segment will nevertheless emerge naturally from the behaviour of its individual members, just as the behaviour of the mob of sheep did in our demonstration.

3.3. Experimental design

A three by three experimental matrix was constructed from the combination of three sheep populations with differing lengths of vision, R and 2R and three dog states (no dog, placid random dog and placid clustered dog). Each of the nine experiments were repeated 50 times from randomly allocated initial agent positions. At each time step the agents order was also randomised.

The experiment was completed using a 500x500 continuous bounded "paddock" with 100 sheep and one dog agent. Each iteration was run for 1000 time steps.

The threat (dog) had two distinctly different movement patterns that were in no way related to the other elements of the environment.

- Clustered - used a series of fixed points which formed a simple pattern covering one corner of the simulation space. Each of these points was visited in sequence using an "Arrival" behaviour. This resulted in the dog travelling directly between each of the points in space.
- Random - selected a point at random inside the space and a "Seek" behaviour steered the dog towards the point. When the dog reached this point, another point was randomly allocated and sought. This resulted in the dog taking a smoother path between each point.

Sheep were allocated a vision distance (radius) within which the presence of a dog could be detected. Upon detection of a dog a sheep would change its behaviour from "flocking" to "flee" in an attempt to escape the threat (dog). The behaviour switched back to "flocking" when the threat was evaded (i.e. no longer inside the detection radius). All sheep had the same flocking parameters.

3.4. Performance measures

Two measures of sheep performance were calculated and a measure of efficiency was calculated from these:

- Distance from dog (measured & summed each time step) was the primary goal
- Work (sum of the steering force vectors applied each time step)
- Efficiency (Distance / Work)

The greater the distance sheep were from the dog, the higher the level of performance. The less work required, the higher the performance. Formulated hypotheses related to the performance of sheep with different levels of knowledge about their environment as the elements present in the environment were changed.

H1: The presence of sheep with a different level of knowledge does not influence the overall performance of sheep with a particular level of knowledge.

H2a: In an environment with disturbed reactive elements and a placid random element, sheep with greater knowledge about their environment will perform better than sheep with less knowledge.

H2b: In an environment with only disturbed reactive elements sheep performance will be better than sheep in an environment with disturbed reactive elements and a placid random element.

H3a: In an environment with disturbed reactive elements and placid clustered element, sheep with greater knowledge about their environment will perform better than the sheep with less knowledge.

H3b: In an environment with only disturbed reactive elements, sheep performance will be better than sheep in an environment with disturbed reactive elements and a placid clustered element.

H4: In an environment with disturbed reactive and placid clustered elements, sheep performance of will be better than sheep in an environment with disturbed reactive and placid random elements.

Hypotheses 1, 2a, 3a and 4 were tested using distance, work and efficiency, while hypotheses 2b and 3b were tested using only work.

4. RESULTS

4.1. Demonstration

A live demonstration, although not visually impressive, created a good feel for how agent based models function at a higher level. The authors believe this was due mainly to;

- Simple, easily understood rules.
- A topic familiar to the participants.
- A feeling of trust built through performing a live interactive demonstration.
- An appropriate level of abstraction.

While it was generally agreed by the group that the model rules did not take everything into account, the general consensus was the system still exhibited the important characteristics of a mob of sheep being worried by a dog.

The choice of using sheep rather than anything closer to the groups' area of expertise helped to maintain focus and discussion towards the modelling without emphasising industry specific details. This was an issue identified during earlier projects. Presenting with an overly simplified model for demonstration purposes to a group of experts often meant that they focused on the shortcomings of the model rather than having a discussion about the real world system.

4.2. Experiment

The introduction of any dog (placid random or placid clustered) to the system increased the mean amount of work done by the sheep, supporting H2b and H3b, but the random dog caused sheep to work more than the dog exhibiting placid clustered behaviour, supporting H4 (see Table 1). Similarly, sheep were able to achieve a greater mean distance from a dog exhibiting clustered behaviour than from the random dog, further supporting H4 (see Figure 2). Thus, the efficiency with which the sheep avoided the clustered dog was also higher.

Sheep with vision 2R were more successful than sheep with vision R at avoiding the placid random dog. Thus, H2a was supported regardless of whether sheep with only one length of vision were

Table 1. Mean distance, work and efficiency of sheep under different environmental conditions

	Sheep Vision	No Dog	Placid Clustered Dog			Placid Random Dog		
		Work	Distance	Work	Efficiency	Distance	Work	Efficiency
Single Sheep Type	R	175	222860**	249**	1064**	202330**	309**	730**
	2R	175	248970**	378**	768**	228685*	502**	494**
Two Sheep Types	R	177	219922**	261**	983**	199943**	325**	663**
	2R	175	246873**	354**	840**	227130*	488**	515**

Note: ** 99% significance; * 95% significance present or sheep with both R and 2R (see Figure 3). However, the greater distance from the dog was obtained at the cost of significantly greater work, and therefore less efficiently, which does not support H2a when considering these other factors.

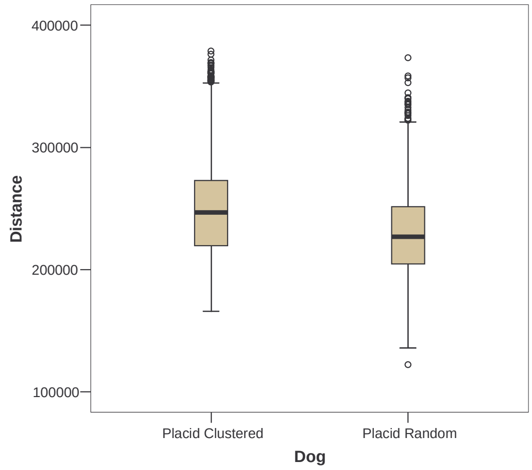

Figure 2. Distance of sheep with vision 2R from different dogs.

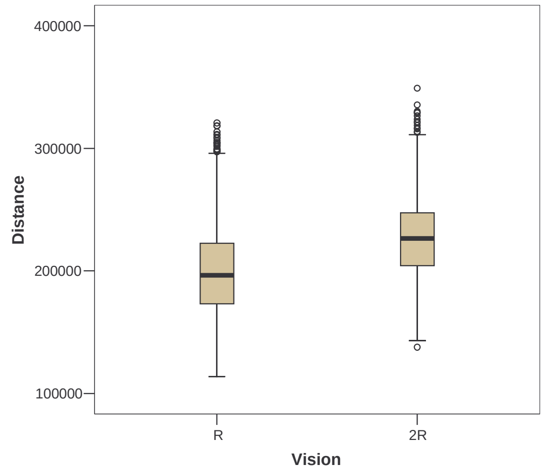

Figure 3. Distance of different sheep from placid random dogs

H3a was supported because sheep with vision 2R out-performed sheep with vision R in avoiding the placid clustered dog (see Figure 4). Again, this higher performance was obtained at the cost of significantly greater work (see Figure 5).

When the two types of sheep were run together, the distances to the dog for each type of sheep were significantly different to when run separately. These differences were significant but not substantive. This neither supports nor refutes H1. However, the amount of work significantly and substantively changed when the two types of sheep were run together. Sheep with vision R worked more and became less efficient while sheep with vision 2R expended less work and became more efficient, disproving H1.

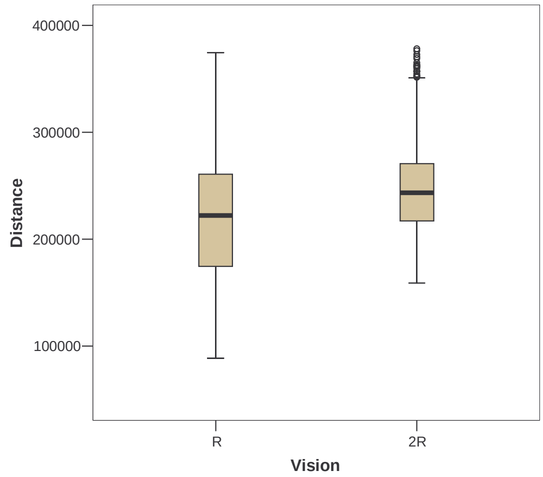

Figure 4. Distance of sheep from the placid clustered dog.

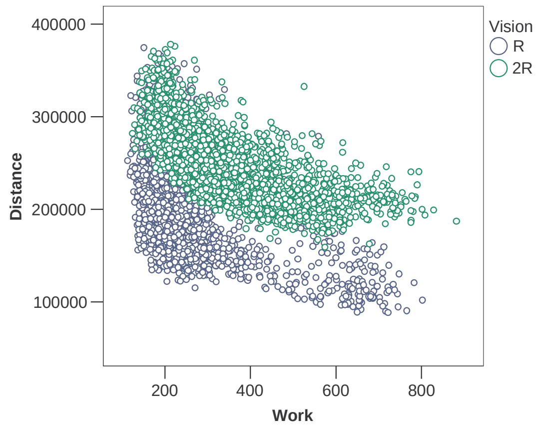

Figure 5. Distance and work for the two types of sheep run with the placid clustered dog.

5. DISCUSSION

The flocking model involving sheep with different lengths of vision and a dog behaving in different ways appears to have been a useful abstraction of understanding the value of information to disturbed reactive agents operating under different environmental conditions. The performance of sheep in the environment with a placid clustered dog were able to perform better than those in an environment with a placid random dog because they could learn about the dog, and therefore develop a strategy for better avoiding the dog. In addition, those sheep with longer vision, or more information about their environment, performed better than those sheep with less information, but to achieve this higher performance they did expend more work. This shows that there was a benefit to be gained by having more information, but there is further need to better calculate costs and benefits so as to determine the value of information.

Another interesting emergent property observed was the interaction between the two types of sheep when run together. The amount of "running around" by sheep with vision 2R was dampened by the presence of sheep with shorter vision because these sheep were less responsive to the dog (later in detecting its presence), which meant that the flocking behaviour dominated the flight behaviour for longer. Conversely, the sheep with vision R ended up "running around" more as they responded to the earlier movements away from the dog of those sheep with vision 2R. Those sheep with shorter vision did benefit a small amount by being significantly (but not substantively) further away from the dog. This raises the question of the value of observing competitors following different strategies. The answer to this question will depend upon the other strategies being followed by individual agents (in this case the three flocking strategies).

6. CONCLUSION

Although the abstraction used in this paper is far removed from that of a business system, there are some useful insights to be gained. Clearly information is valuable in successfully navigating an environment with placid elements, and more valuable when those placid elements are clustered rather than random. This is because in a clustered environment, it is possible to learn more about the environment, and therefore, to more successfully respond. The change in performance caused by the presence of competitors with a different strategy or ability to gather information was unexpected. The authors need to explore this aspect further to see whether there is evidence from the business world that there is convergence of firm performance within industries even when they pursue different strategies and whether this is caused by heterogeneity amongst competitors. If this evidence does exist, then perhaps the abstraction of sheep and dogs may not be too far removed from the world of business.

7. REFERENCES

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APPENDIX A: MODEL PARAMETERS

Sheep	
Max speed	10
Mass	0.1
Max force	1
Vision radius (R)	75
*Dog detection radius	[R,2R]
Available behaviours	Flocking, Flee
Dog (as per Sheep)	
Max speed	20
Vision	N/A
*Available behaviours	[Seek, Arrival]
Flocking behaviour	
Separation	0.9
Alignment	0.5
Cohesion	1.0

*denotes experimental parameters. All others were fixed for all the experiments.