PATTERN-ORIENTED ANALYSIS OF COMMUNICATION FLOW: THE CASE STUDY OF *CICADA BARBARA LUSITANICA*

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ABSTRACT

This paper provides a general perspective concerning the study of flux of information in complex social systems. The recognition of communicative structures through pattern-matching in social systems allows the interpretation and prediction of behaviour in social networks. Applying the pattern-oriented approach suggests the possibility that through modelling, we can discover new previously unknown emergent patterns in complex systems of various kinds. In the present study, we examine the processes of pattern recognition and behaviour involved in cicada mating behaviour and argue that modelling such systems both uncovers and provides an explanation for emergent patterns. Experimental results indicate that cicada's song recognition patterns are related to and explain the configuration of cicada's dislocation and contact patterns.

INTRODUCTION

Recent advances in the study of complex social systems suggest that emergent collective properties appear from interactions between individuals and social structures, at different levels (Sawyer, 2005). In the present study, we examine the processes of pattern recognition and movement involved in cicada mating behaviour and argue that modelling such systems both uncovers and provides an explanation for emergent interaction patterns. This research provides evidence for the importance of characterizing complex social systems through coexisting social structures. As such, we avoid a fundamentalist or bottom-up approach to the study of complex social systems and their emergent features. While we avoid a reductive approach to social systems, we do provide a general perspective concerning the study of flux of information in complex social systems. We anticipate a wide range of applications for this perspective. The recognition of communicative structures through pattern-matching in social systems will allow the interpretation and prediction of behaviour in social networks (Grimm et al., 2005). In particular, our research aims to discuss if the knowledge of the character of the relevant constraints of individuals interacting in a group will allow the detection of an emergent fingerprint, which will signal the presence of a subgroup behaving in a manner identical to some targeted type of social structure. The emergent properties of behaviour in simulated social environments can serve as a fingerprint or template which we hypothesize can serve as the basis for pattern-matching within massive and noisy data sets. To study this hypothesis, we propose to distinguish forms (e.g. patterns) of flow of information, identifying sequences and combinations of those forms. This approach will lead us to interpret and predict emergent properties of social systems, even in the presence of massive and noisy data sets.

On another hand, we assume that knowing only the links between the nodes of the communications network is enough to characterize the flow of information in a social environment. The main advantage of the assumption of this hypothesis is its independence from the semantic properties (content) of communication between agents. While most current treatments of emergent features of group knowers involve propositional or semantic features of the systems under consideration, our strategy is to examine patterns that appear at the level of information-flow per se. We anticipate that social structures with known characteristics and constraints will exhibit behavioural features which are robust enough to detect with pattern observation. This pattern detection will be independent of the content of the communications involved.

Finally, our third research hypothesis stands that collective reasoning throughout the flow of information is an emergent feature of a network which takes place via sequential or parallel combination of a diversity of patterns. We hypothesize that the flow of information, characterising collective reasoning processes, is composed by a sequential or parallel combination of primitive and elementary patterns of communicative acts. The pattern-oriented modelling approach is particularly well-adapted to model the manner in which a diversity of relatively simple patterns can compose sophisticated collective behaviour.

Aiming to test these three hypotesis, our research derives from two main scientific domains: the well known field of multi-agent based simulation (Goldstone and Janssen, 2005) and the research that have been recently labelled pattern-oriented modelling (Grimm et al., 2005).

The main body of the paper is divided into three parts. A brief characterization of the pattern-oriented modelling domain is presented, discussing its relevance to the understanding of complex social systems. Next, a case study from zoology is used as the basis for the implementation of a multi-agent simulation environment illustrating some of the general features of our approach. In the simulations we compare the input communication patterns and resulting emergent movement patterns from different species of cicadas. Experiments using this model are described. The text ends with a discussion of our experimental results, followed by further research.

PATTERN-ORIENTED MODELLING

The bottom-up approach to modelling social simulations is characterised by compiling relevant information about entities at an elementary level of abstraction, representing heterogeneous individual behaviours, implementing these diverse behaviours in a computer simulation, and observing the emergence of system-level properties (Sallach et al., 2006). This approach lacks an explicit methodology for dealing with the variety of structures and levels of abstraction that are characteristic of complex social systems. In reality, finding the optimal level of representation in the structure of a bottom-up model is frequently an extremely difficult task. This is the major challenge facing social simulation processes, since the choice and adoption of a given level of abstraction will have a strong qualitative influence on the results of a simulation. Conceptual multi-agent based simulation models often reflect, in an excessive way, the modeller's point of view, with its specific interests, beliefs, and scales of perception. The problem of the subjectivity of the modeller's perspective is compounded by the many degrees of freedom characterising complex social systems. However, no matter what level of abstraction one adopts in the analysis of complex social systems, one will inevitably be involved in the business of identifying patterns. Hence, the pattern-oriented approach to modelling is likely to be a source for good general solutions for studying complex social systems (Küppers and Lenhard, 2005).

Pattern-oriented modelling has been recently presented as a unifying framework for the study of complex social systems (Grimm et al., 2005). In pattern-oriented modelling, multiple observed patterns, at different abstraction levels and scales, are used additively to optimize the model structure or to test and contrast models of agent behaviour (see figure 1).

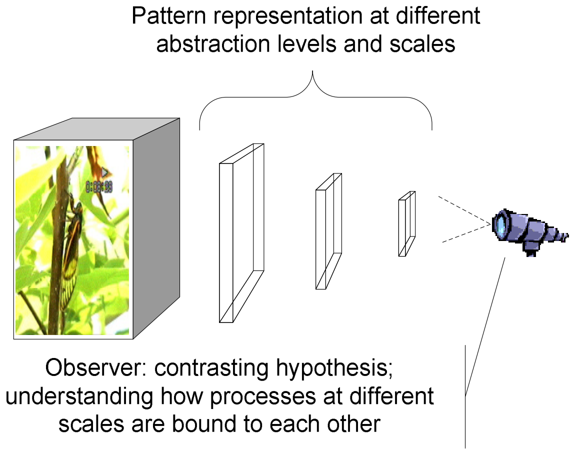

Figure 1: Pattern Representation at Different Abstraction Levels

Using patterns to contrast alternative models is a way to generate better explanations of how real systems are organized. Experiments contrasting hypotheses will lead to an accumulation of theory concerning modelling specific domains (DIVERSITY, 2007), e.g. innovation diffusion processes (Louçã and Meneses, 2007). At the same time, taking into account different levels of abstraction can help us to understand how processes at different scales and hierarchical levels are related. Complex systems are regularly characterized by patterns at different levels of abstraction. Ecosystems, for example, are defined by species diversity, spatial structure, and resource dynamics – these characteristics can all be represented by intricate patterns describing essential ecosystemic processes and structures (Grimm et al., 2005). For these reasons, we claim that the pattern-oriented modelling approach is particularly adapted to the study of primitive communication mechanisms through the combination of a diversity of patterns. The adoption of this approach will allow us to test our research hypothesis.

THE CASE STUDY OF *CICADA BARBARA LUSITANICA*

A case study in zoology has been developed, concerning the design of patterns in insect communication. The case study was composed with experimental results obtained at the Faculty of Sciences - University of Lisbon, concerning live experiments of stereotyped singing response behaviours of cicadas (Fonseca & Revez, 2002). We have used this previous results to design a multi-agent simulation platform allowing to represent the behaviour of two cicada species, *Cicada barbara lusitanica* and *Cicada orni*.

Previous experimental results concerning cicada communication

Insect songs may encode specific information about the identity of species, which can be used by individuals to discriminate conspecific from heterospecific sympatric species. Figures 2 to 4 depict examples of temporal and frequency calling song configurations from two different cicada species. The temporal configuration of Cicada barbara song, characterized by an uninterrupted pulse, illustrates a continuous pattern (figure 2). On another hand, the temporal configuration of *Cicada orni* song shows a clear discontinuous pattern (figure 3). Also, frequency analysis can be used to compare both calling song configurations (figure 4). All figures represent calling songs over a period of 5 seconds.

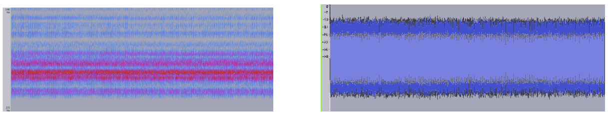

Figure 2: *Cicada barbara* Calling Song Analysis: Spectrum and Waveform db

Figure 2 shows that the *Cicada barbara* calling song has a broad spectrum (image on the left), although some frequencies are more intense than others. The waveform analysis shows that the calling song is continuous, with no pauses.

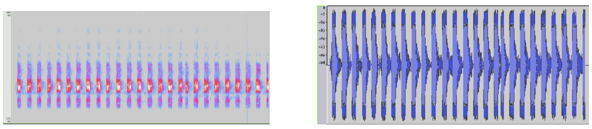

Figure 3: *Cicada orni* Calling Song Analysis: Spectrum and Waveform db

The *Cicada orni* spectrum depicts a clearly discontinuous calling song. This particular species of cicada uses a calling song characterized by pulses and pauses. The spectrum occupies a narrower band than that of *Cicada barbara*. Nevertheless, it is very intense in some frequencies. The wave form represents the discontinuity in the calling and regular pauses (e.g., silence) are evident.

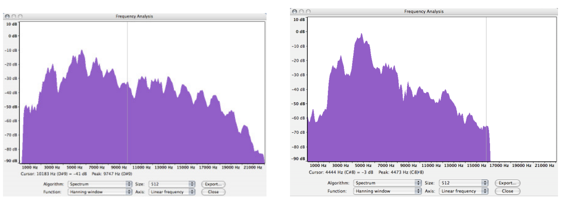

Figure 4: *Cicada barbara* (left) and *Cicada orni* (right) Calling Song Analysis: Frequency

The frequency analysis of *Cicada barbara* confirms the spectrum at a narrow time band. The *Cicada barbara* calling song has several high frequencies. On another hand, *Cicada barbara* males are able to produce sounds at regular intervals of the spectrum. The analysis of a pulse period in *Cicada orni* calling song reveals that very few frequencies are significant, as opposite to the *Cicada Barbara* results. This might provide evidence that the use of temporal patterns (pulse-pause) to achieve recognition allows for use of a narrower band. By contrast, *Cicada barbara* might have to produce a broader spectrum of frequencies as it will not use temporal patterns (the song is continuous). Calling song configurations are generally used by cicadas to distinguish their own species, as concluded by Fonseca and Revez (2002) in their experiments.

Fonseca and Revez have used the stereotypical singing response behaviour of males to analyse song discrimination in *Cicada barbara lusitanica*. Experiments were conducted outdoors in a cylindrical cage, where stimuli were individually presented to males by a loudspeaker. Singing activity by males was taken as a positive response to stimuli. The set of test stimuli included stereotypical songs *Cicada barbara* and *Cicada orni*, presented in random order. Studies of different song parameters in species recognition have been conducted. Specifically the temporal pattern and the frequency spectrum of the signal. Both the temporal pattern and the frequency spectrum of the signal have been shown to be involved in species discrimination by *Cicada barbara*. The main experimental result of the experiments was that specific manipulation of the gross temporal pattern of the song significantly affected song discrimination.

Experiments were designed in order to answer several questions. Concerning the first one – are *Cicada barbara* males able to discriminate the conspecific song from the calling songs of the other sympatric cicada species? - experiments showed that pulsed songs were less attractive then trilled songs, suggesting a role of the temporal pattern in song discrimination. Next experiments attempted to discover which parameters of the temporal pattern are used by *Cicada barbara* males to discriminate their song from the one from *Cicada orni*. The following parameters of temporal pattern were manipulated: sound pulse duration; pause duration and the duty cycle (i.e. pulse duration/pulse period). Results showed that pulse duration and duty cycle have no influence on signal discrimination by *Cicada barbara*. On another hand, pause duration influences signal discrimination. However, temporal cue alone is not sufficient to discriminate the conspecific song from the songs of some other sympatric species. Finally, experiments were made to understand whether differences in frequency spectrum can serve to enhance song discrimination between two trilled songs, indicating that *Cicada barbara* males responded better to some frequencies than to others.

The conclusions of the Fonseca and Revez set of experiments was that *Cicada barbara* males stopped responding to stimuli in which the temporal pattern approached the characteristic *Cicada orni* song, a sympatric and closely related species; also, *Cicada barbara* males were more stimulated by some frequencies then others, being able to discriminate frequencies differing only by 1 kHz. Thus, even if *Cicada barbara* is sympatrically distributed with other cicada species, including the closely related *Cicada orni*, the species is always able to distinguish his own songs. Generalising these results, Fonseca and Revez stated that both frequency spectrum of the signal and temporal pattern carries information about the species-identity of a calling male, but the use of only one parameter might not be sufficient. The pre-copulatory isolating mechanism based on song analysis, used to maintain species integrity, uses one or/and another parameter according to the species environment.

Multi-agent based simulation of cicada communication

Fonseca and Revez experiments and conclusions were used to implement a multi-agent simulation of cicada communication behaviours.

Input patterns: species recognition

The model considers the existence of two patterns used to species recognition by *Cicada barbara* and *Cicada orni*: temporal (pulse and pause duration) and frequency patterns.

Cicada barbara and *Cicada orni* individuals are randomly placed in a finite environment. Males are static and females move, attracted by songs from their conspecific males. Each female cicada has a given initial energy, used to travel in the environment. When a female meets a male, two things can occur: either they belong to the same species and in this case their energy is set to a maximum level, or they belong to different species and then their energy is set to a minimum level. The key issue of the simulation is the pattern-matching mechanism used by females to recognise a calling song. Several simulation experiments were modelled and executed using temporal patterns, frequency patterns separately and simultaneously.

Results of the simulation are illustrated by figures 5 and 6. Figure 5 compares the number of contacts achieved by *Cicada barbara* individuals in three situations: using uniquely the temporal pattern (which is, in the case of *Cicada barbara*, a continuous song – see figure 2), using the frequency pattern and using both temporal and frequency patterns.

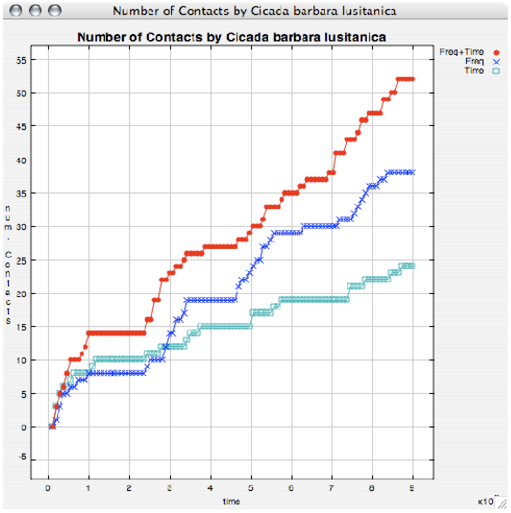

Figure 5: Running the Simulation with Different Singing Recognition Patterns Used by *Cicada barbara*

Figure 6 presents the same comparison concerning the number of contacts achieved by *Cicada orni* individuals, using its species specific pattern values. For example, *Cicada orni* temporal patterns is a trill pulse-pause with values around 40ms – 120ms (see figure 4).

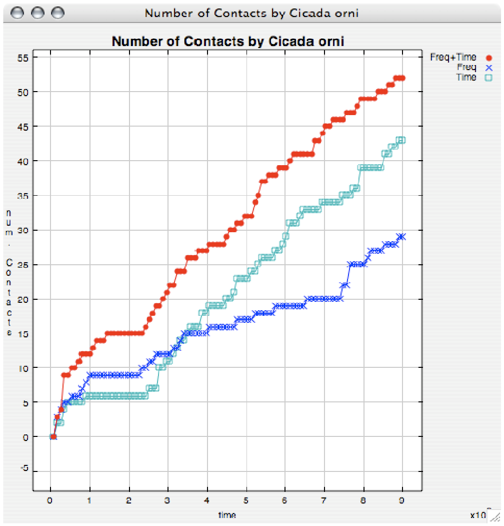

Figure 6: Running the Simulation with Different Singing Recognition Patterns Used by *Cicada orni*

From the observation of graphs we can conclude that, in *Cicada barbara* species the frequency pattern leads to a better performance, in *Cicada orni* is the contrary, and in both species the combination of the two patterns result in a more accurate perception about the origin of some calling song.

Output patterns: cicada female paths

These simulations can also be analysed from the point of view of cicada’s behaviour. Let’s consider the coexistence, in a cicada’s field, of the following behaviour types:

Type I – cicadas don’t use a recognition pattern and follow a song randomly;
Type II – cicadas use a temporal recognition pattern;
Type III – cicadas use a frequency recognition pattern;
Type IV – cicadas use both recognition patterns.

Cicada’s paths are identified by colour marks in cells. Initially all cells are white, and they became darker when crossed by females in their way to meet males of the same species.

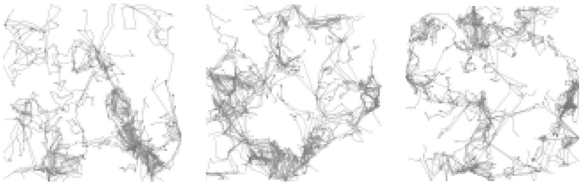

Figure 7: Results of Three Simulations Showing Type I Paths

Figure 7 represents the result of three simulations, characterized by marks from Type I, e.g. cicadas not using a detection pattern. Each female cicada is not moving far from a small radius, and her direction changes randomly. The result is a set of small and diffuse zones of dark cells, with no clear tracks.

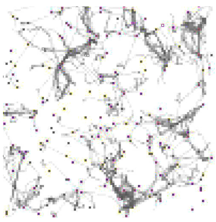

Figure 8 : Males Positions Concerning Type I Paths

Figure 8 shows the position of cicadas males relative to Type I paths. These act like nodes of a network. Dark cells surround males.

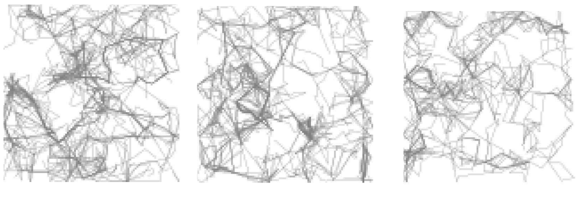

Figure 9: Results of Three Simulations Showing Type II Paths

Type II, concerning cicadas using the frequency pattern, shows a longer dislocation of females and the existence of clear tracks.

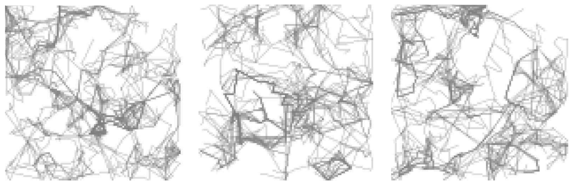

Figure 10: Results of Three Simulations Showing Type III Paths

In what concerns Type III (figure 10), where cicadas use the temporal pattern, tracks are also well defined.

Figure 11: Results of Three Simulations Showing Type IV Paths

Type IV paths, regarding cicadas using both patterns, represent a thinner network, composed by a diversity of tracks.

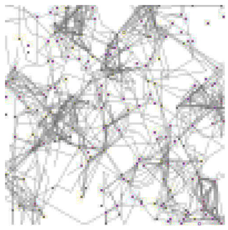

Figure 12: Males Positions Concerning Type I Paths

The analysis can be completed with the observation of figure 12, showing a star-like pattern concerning males positions.

These experiments support the conclusion that, when cicadas use song recognition patterns, females dislocation is structured, covering the field with clear tracks. The particular case of simultaneously using both recognition patterns results in a thin network, with more tracks and more rapid access to males of the corresponding species. On another hand, when there is no use of recognition patterns, dislocations are short and direction random, with no clear existence of tracks.

CONCLUSIONS

Modelling and implementing a social simulation, using experimental data from Fonseca and Revez (2002), allowed us to test our previous research hypothesis. Relating recognition patterns with path patterns, we conclude that the use of recognition patterns is connected to the existence of clear track structures, occupying the field in a uniform way. Otherwise, when cicadas don't use recognition patterns, results are characterised by small diffuse shades, with no clear tracks.

The simulation permitted observation of an emergent star-like behavioural fingerprint concerning female movement towards singing males, in which several females move simultaneously towards a singing male - movement which takes the form of an implosion. This implosion ceases when the male stops singing with the arrival of the first female. With the cessation of his song, the females move away simultaneously - movement which takes the form of an explosion. In an environment with an important diversity of sound signals (e.g., noisy), the characteristic behavioural pattern (the emergent fingerprint of the song) can easily be recognized. This will confirm the second research hypothesis, saying that considering only the links between the nodes of the network is enough to characterize the flow of information. Finally, concerning the third hypothesis, stating that collective reasoning throughout the flow of information can take place combining a diversity of patterns, the case study supports the conclusion that a combination of diverse pattern recognition processes is optimal. In this specific example, recognition of temporal and frequency patterns are used to achieve recognition between cicadas of the same species, thereby improving its chances of successfully reproducing.

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