A Control Systems Perspective on Entrainment

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SHEFFIELD ROBOTICS

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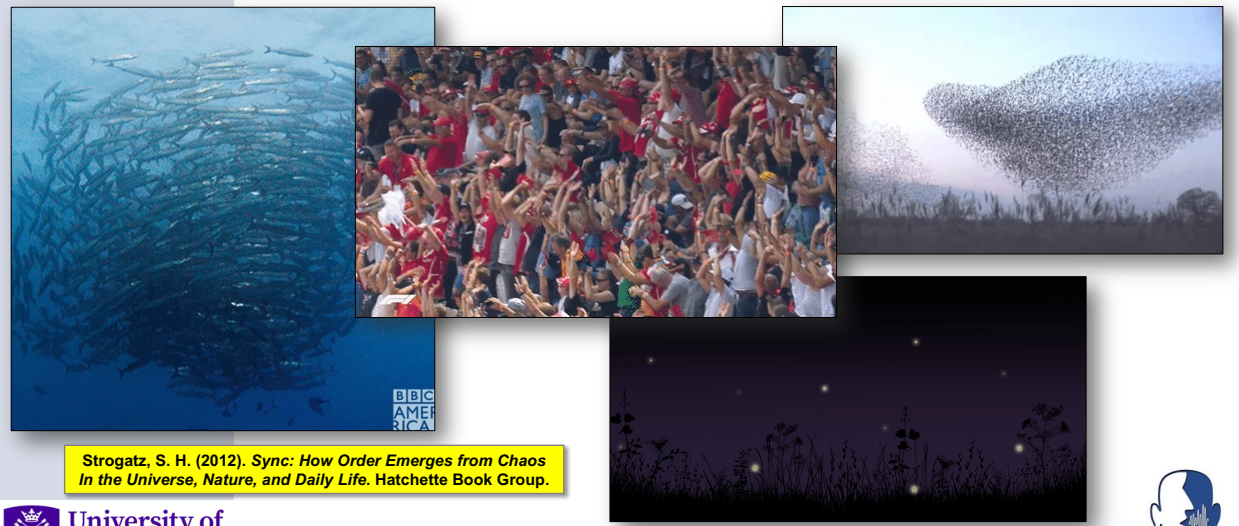
Crowds, Flocks, Swarms & Shoals



Strogatz, S. H. (2012). ***Sync: How Order Emerges from Chaos In the Universe, Nature, and Daily Life.*** Hatchette Book Group.

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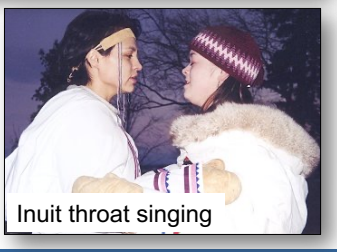
Vocal Synchrony/Entrainment



Cummins, F. (2014). Voice, (inter-)subjectivity, and real time recurrent interaction. *Frontiers in Psychology*, 5, 760.

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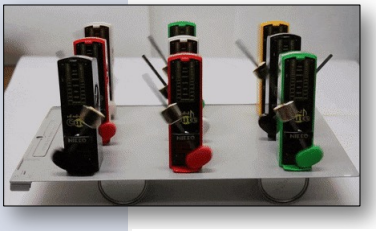
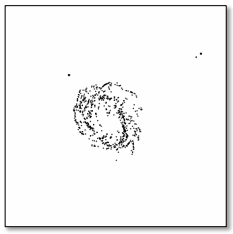
Models *vs.* Mechanisms





Coupled oscillators

- dynamical system
- creates attractor space
- implicit control variables
- suited to non-living systems
- rooted in mathematics
- dynamical systems theory

Interacting control systems

- dynamical system
- creates attractor space
- explicit control variables
- more suited to living systems
- routed in cybernetics
- perceptual control theory

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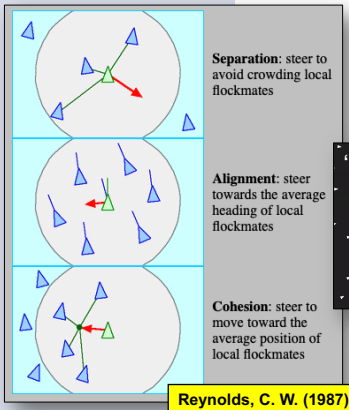
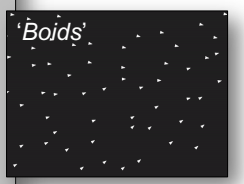
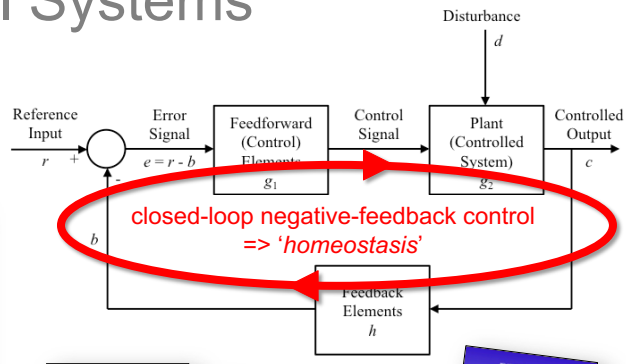
Control Systems

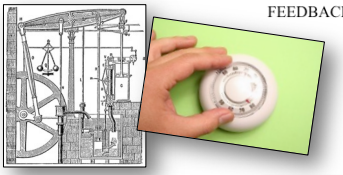


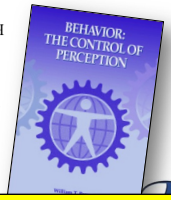


Reynolds, C. W. (1987). Flocks, herds, and schools: a distributed behavioral model. *Computer Graphics*, 21(4), 25–34.



closed-loop negative-feedback control
=> '*homeostasis*'





Powers, W. T. (1973). *Behavior: The Control of Perception*. NY: Aldine: Hawthorne.

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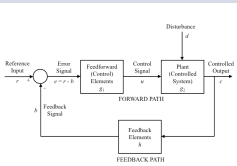
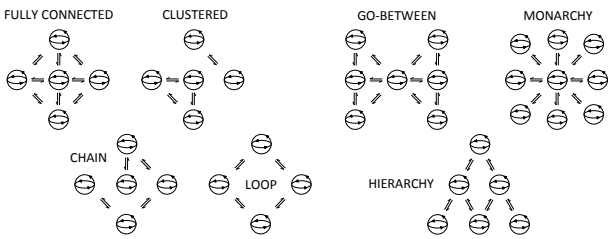
Research Questions



- What happens when two (or more) control systems interact?
- What are the control variables, and how do they influence behaviour?
- How is the emergent behaviour influenced by the topology of the network?



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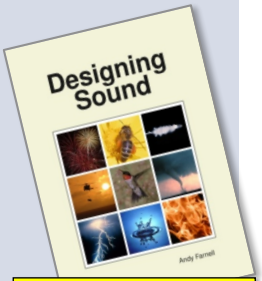
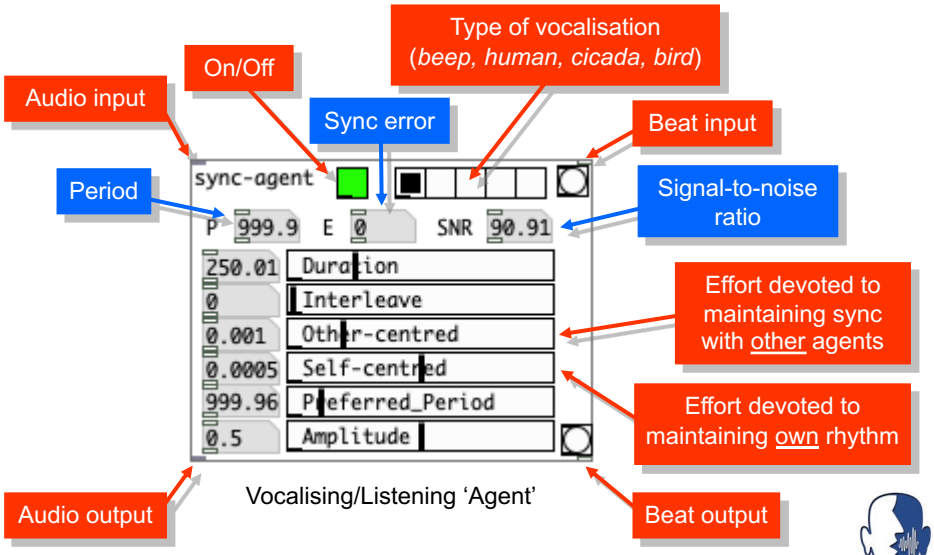
Simulation Environment



Farnell, A. (2008). *Designing Sound*. London: Applied Scientific Press Limited.



Vocalising/Listening 'Agent'

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Simulation Environment

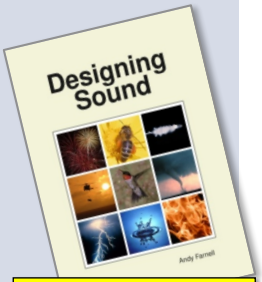
Main controls

Degree of 'entrainment'

'Beats'

'Leader' agent

'Follower' agent



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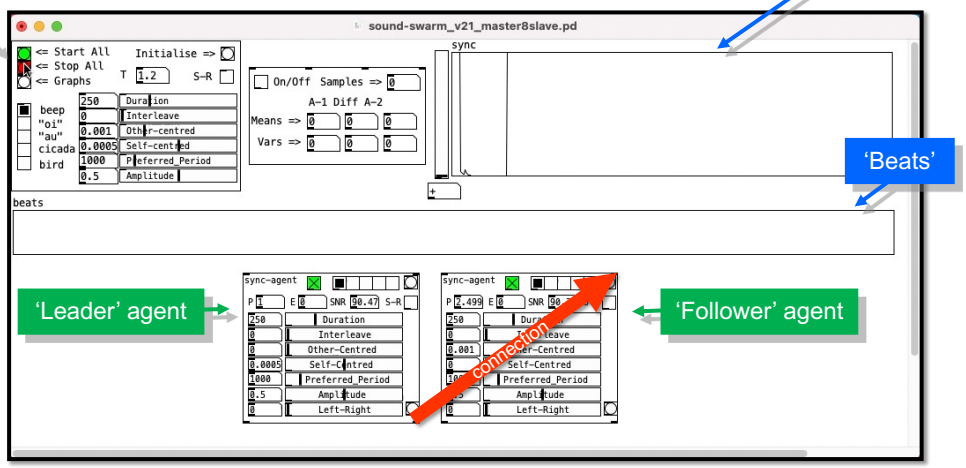

Two agents: leader + follower

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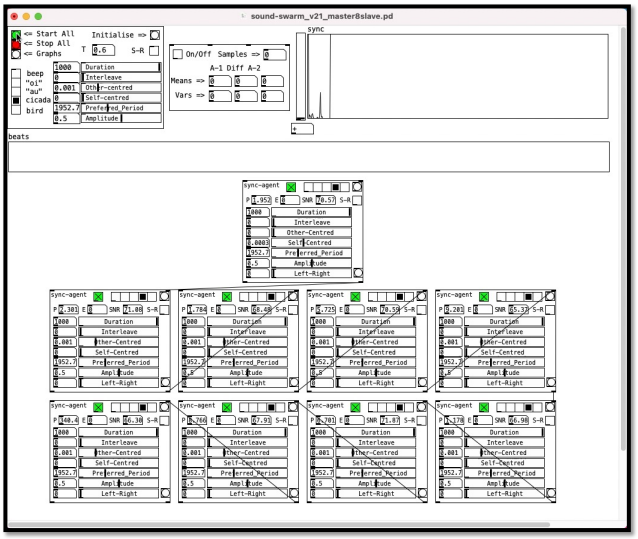
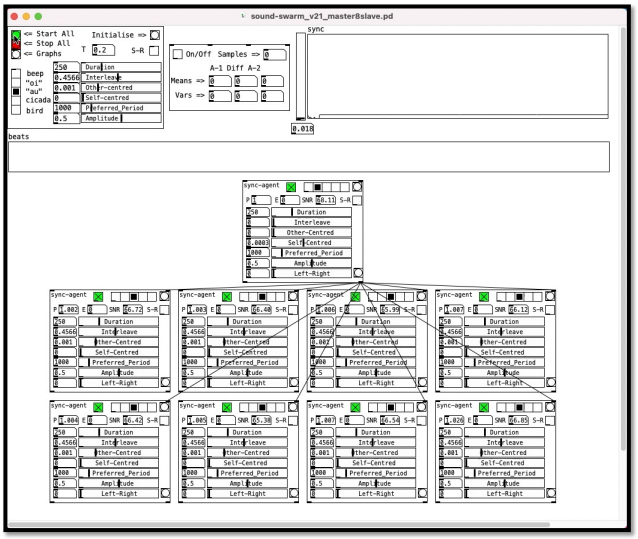
Simulation Environment



Chain of nine agents

Farnell, A. (2008). ***Designing Sound.*** **London: Applied Scientific Press Limited.**

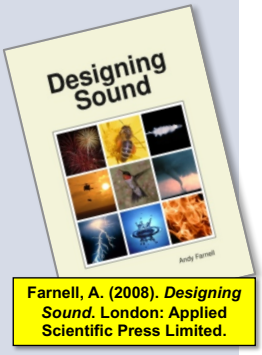
Simulation Environment



One leader, eight followers

Farnell, A. (2008). ***Designing Sound.*** **London: Applied Scientific Press Limited.**

Simulation Environment



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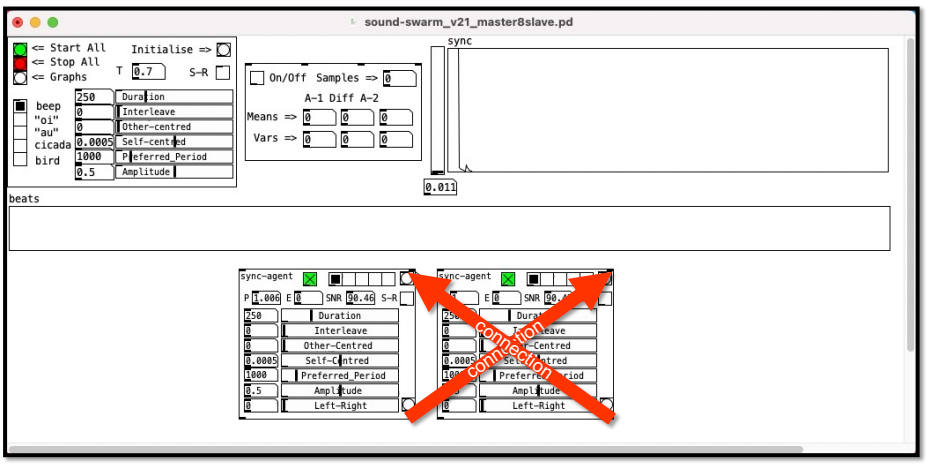

Interacting agents
(*mutual entrainment*)

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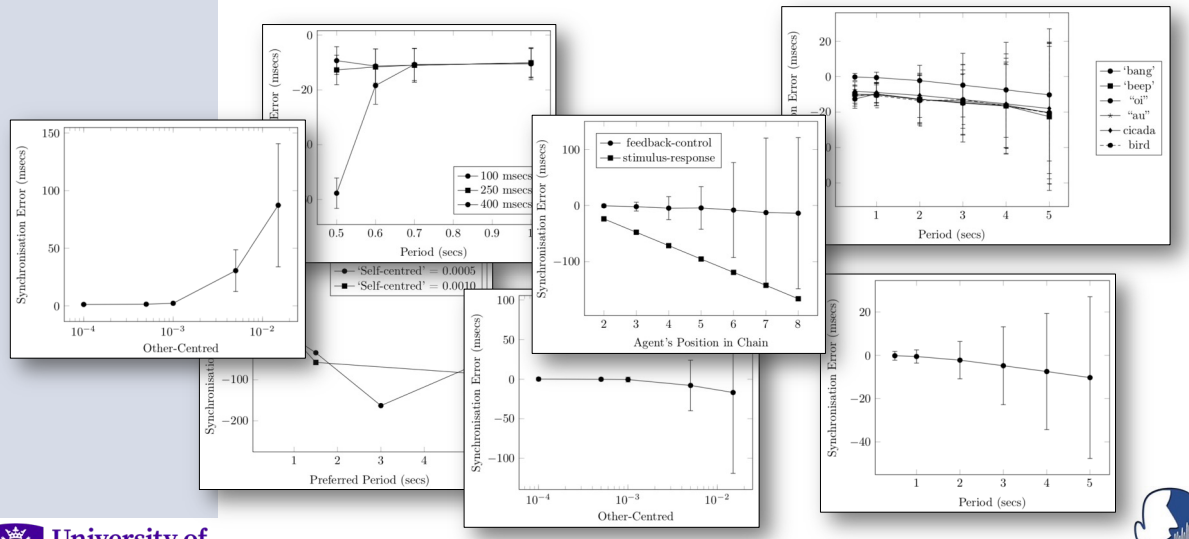
Experimental Outcomes



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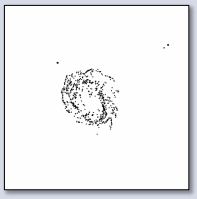
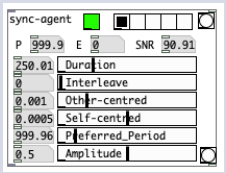
Conclusions



It has been demonstrated that:

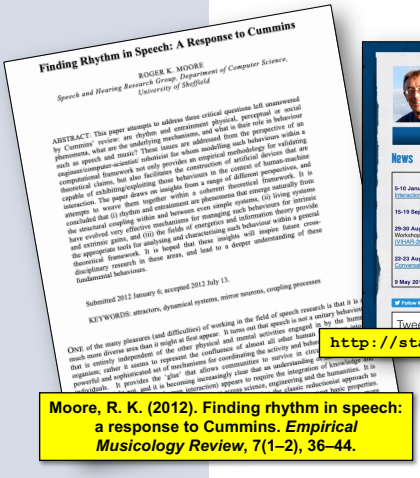
- interacting closed-loop negative-feedback control systems provide an interesting paradigm for modelling entrainment
- the approach offers insights into how different intra-agent control variables and inter-agent connections influence the emergent behaviours



It should be possible to show:

- how 'turn-taking' emerges as an emergent compensatory response to the automatic regulation of intelligibility
- how cooperative *vs*. competitive interaction conditions vocalisations
- how communicative behaviour emerges from vocal interaction

Where to Find Out More


Finding Rhythm in Speech: A Response to Cummins

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Speech and Hearing Research Group, Department of Computer Science, University of Sheffield

ABSTRACT. This paper attempts to address three critical questions left unanswered by Cummins' review: are rhythm and entrainment physical, perceptual or social phenomena, what are the underlying mechanisms, and what is their role in behaviour such as speech and music? These issues are addressed from the perspective of an engineer/computer-scientist roboticist for whom modelling such behaviours within a computational framework not only provides an empirical methodology for validating theoretical claims, but also facilitates the construction of artificial devices that are capable of exhibiting/exploiting those behaviours in the context of human-machine interaction. The paper draws on insights from a range of different perspectives, and attempts to weave them together within a coherent theoretical framework. It is concluded that (i) rhythm and entrainment are phenomena that emerge naturally from the structural coupling within and between even simple systems, (ii) living systems have evolved very effective mechanisms for managing such behaviours within a general and extensible framework. It is hoped that these insights will inspire future cross-disciplinary research in those areas, and lead to a deeper understanding of these fundamental behaviours.

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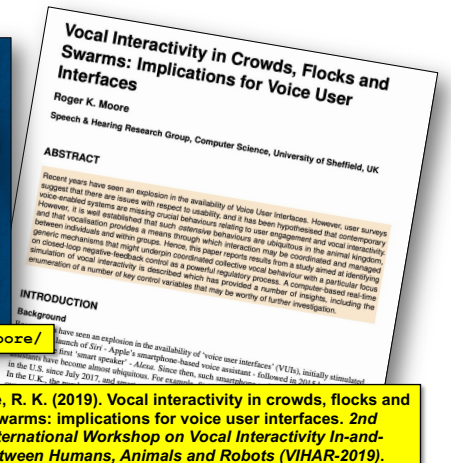
KEYWORDS: attractors, dynamical systems, mirror neurons, coupling processes

ONE of the many pleasures (and difficulties) of working in the field of speech research is that it is


Vocal Interactivity in Crowds, Flocks and Swarms: Implications for Voice User Interfaces

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ABSTRACT

INTRODUCTION

Background

http://staffwww.dcs.shef.ac.uk/people/R.K.Moore/

Moore, R. K. (2012). Finding rhythm in speech: a response to Cummins. *Empirical Musicology Review*, 7(1–2), 36–44.

Moore, R. K. (2019). Vocal interactivity in crowds, flocks and swarms: implications for voice user interfaces. *2nd International Workshop on Vocal Interactivity In-and-between Humans, Animals and Robots (VIHAR-2019).*

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- The coordinated behaviour of large numbers of independent living organisms has been the subject of scientific enquiry for many years. For example, studies have been conducted into the flocking of birds, the synchronised flashing of fireflies, the dynamics of human crowd movement, waves of coordinated clapping by audiences, and spatial sorting in shoals of fish. An important aspect of such synchronous behaviours is that they involve parallel coupled simultaneous action, as opposed to sequential action-reaction. Such collective behaviours can thus be viewed as rhythmic entrainment, constituting a form of accommodation between individuals in a population.

- The most popular paradigm for modelling coordinated collective behaviour is based on coupled oscillators. However, it is only one way of formulating a complex non-linear attractor space, and it overlooks a number of potentially important conditioning variables. The work reported here investigates an alternative approach based on closed-loop negative-feedback control – a powerful regulatory mechanism with roots in 'cybernetics' and commonly deployed for stabilising engineering systems. The main differences between this approach and coupled oscillators is that the convergence criteria can be made more explicit, thereby offering the potential to gain a deeper understanding of the implications of particular parameters/settings on the emergent collective behaviours.

- This paper reports on a computer-based simulation in which a number of vocalising (and listening) 'agents' may be connected to each other in arbitrary network topologies. Each agent comprises two feedback-control loops: one to regulate the interaction with other agents and another to regulate the agent's own behaviour. The first of these control loops aims to maintain synchrony between an agent's own vocalisations and those from agents that it can 'hear'. The second control loop attempts to maintain the agent's own preferred vocal rhythm. The emergent outcomes demonstrate various forms of entrainment as a function of particular parameter settings.

- closed-loop control; vocal synchrony; computational modelling

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