Exploring complex systems

From RoboCup to computational neuroscience

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Complex systems

Introduction to Complex Systems: Patterns in Nature. YouTube, 2013.

Definition

Systems of many interacting components from which non-trivially global behaviour may emerge

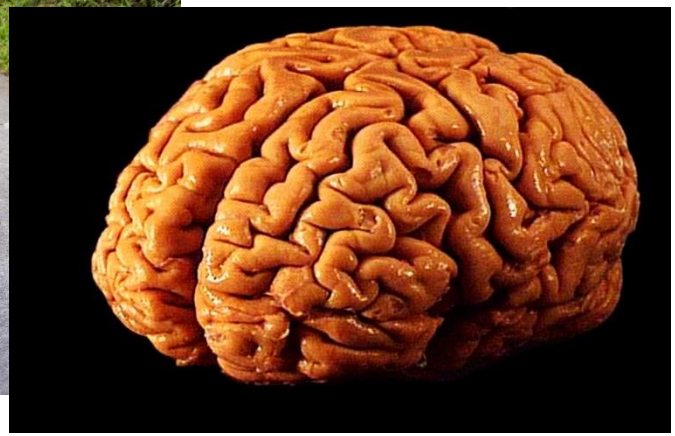
Characteristics

Emergence, Self-organisation, Autonomy, Adaptability, Robustness, Scalability, Unpredictability…

Does Nature compute?

1. Fish compute collective heading

2. Ants compute routes to food



3. Brains process information

But in a very different way:

- Computations are distributed over many "agents"
- Processing self-organised
- Use of coherent information structures

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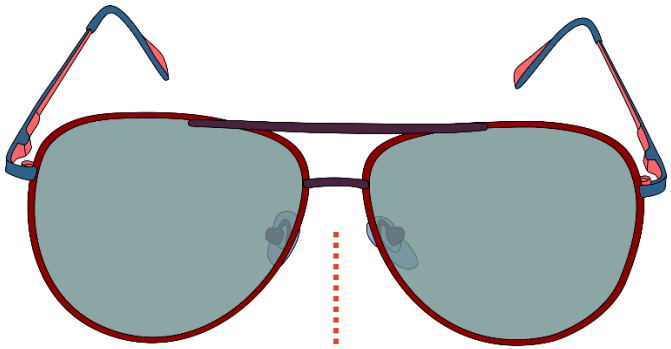
Our research

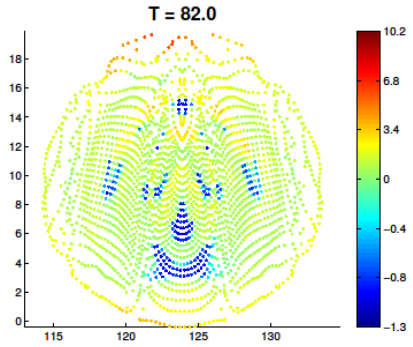
1. Uses information theory
2. To provide "information sunglasses"
3. That reveal information flows in complex systems
4. Which we use to design self-organisation



toolkit

JIDT

http://jlizier.github.io/jidt/



1st example: fish schooling

Schools of Fish. YouTube, 2015.

- When moving in groups, animals collectively process information to coordinate their moves
- Our study quantifies **dynamic information flows** across a school of fish during collective turns
- We provide the first quantification of information dynamics in a biological swarm
- We show that directional changes are related to specific signatures of information-processing

1st example: fish schooling

- *Hemigrammus rhodostomus* placed in a ring-shaped tank
- To move freely for 10 hours, with 455 observed **U-turns**
- Trajectories recorded with HD cameras

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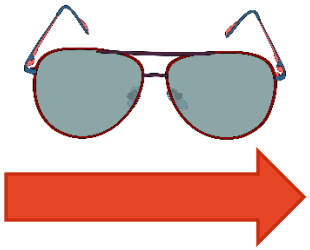
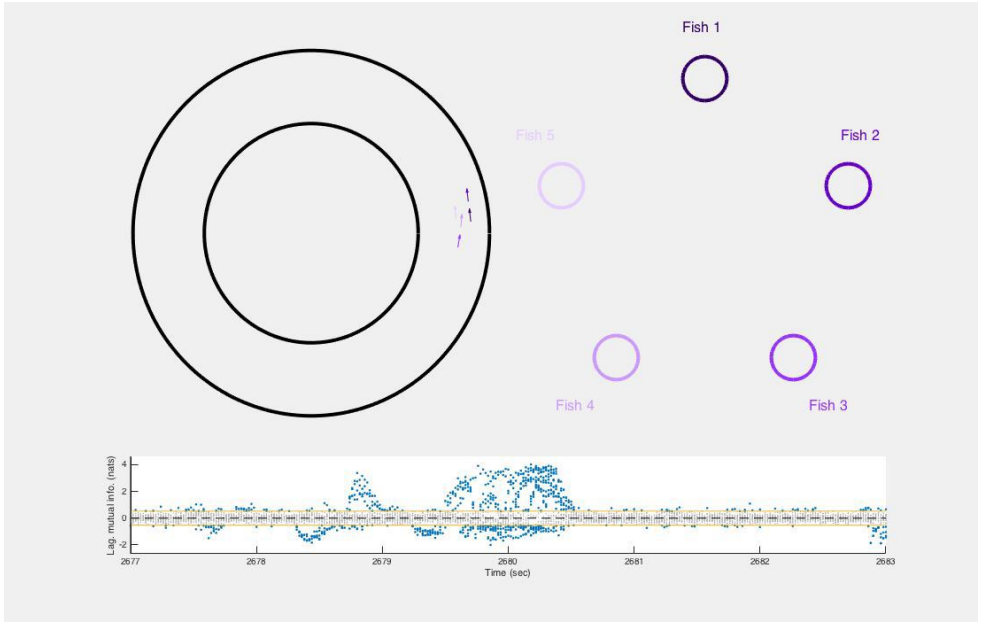
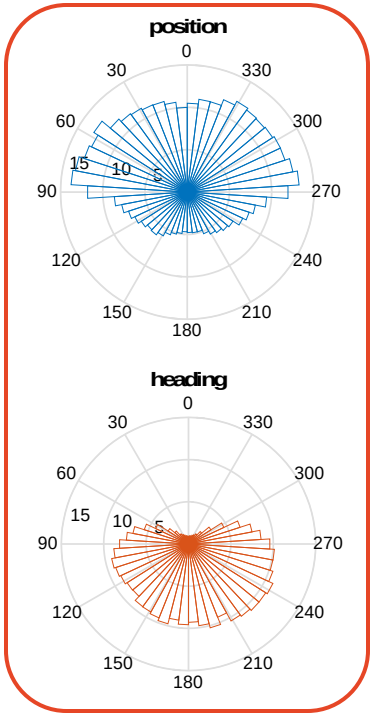
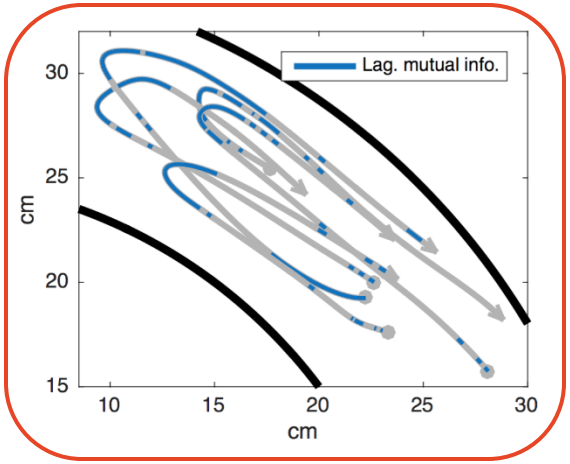
E. Crosato, L. Jiang, V. Lecheval, J.T. Lizier, X.R. Wang, P. Tichit, G. Theraulaz, M. Prokopenko. *Measuring information dynamics in a school of fish.* Submitted to NatureCommunications.

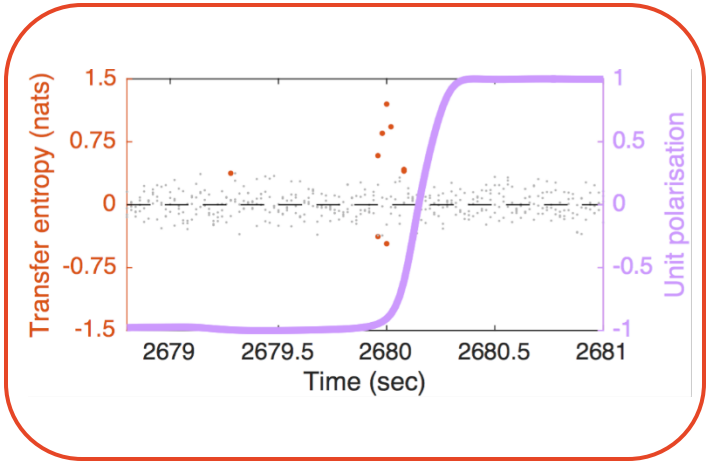
1st example: fish schooling





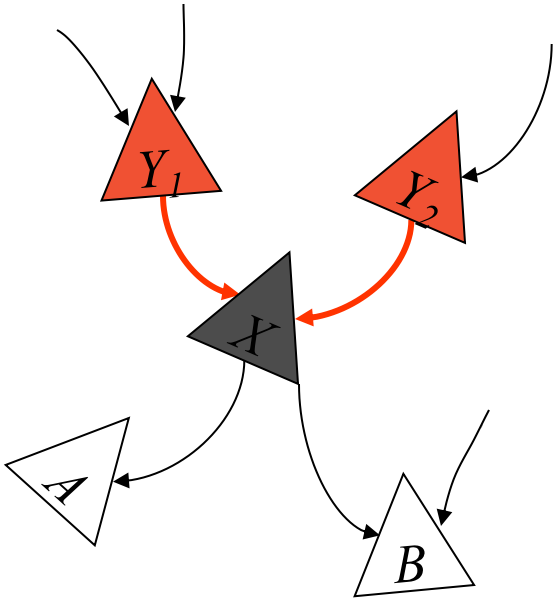




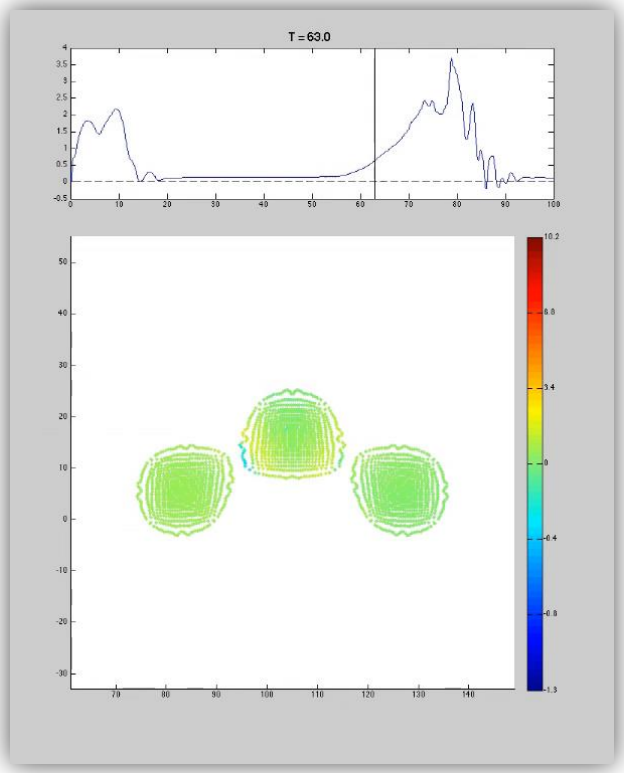


2nd example: simulated swarms

Reveal emergent information cascades



Nearest neighbour interactions

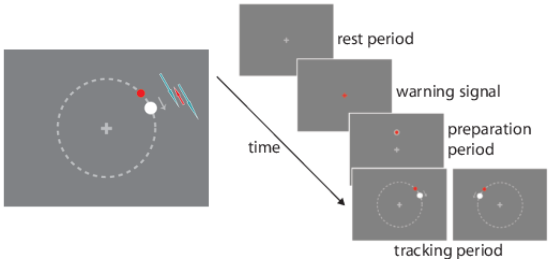


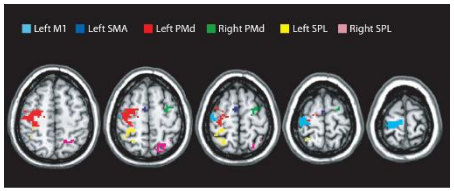
Coherent information waves

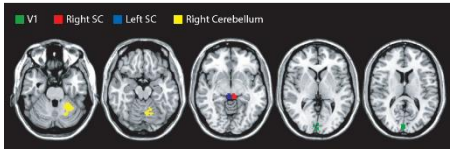
X.R. Wang, J.M. Miller, J.T. Lizier, M. Prokopenko and L.F. Rossi. *Quantifying and Tracing Information Cascades in Swarms*. *PLoS ONE*, vol. 7, no. 7, e40084, 2012.

3rd example: brain regions

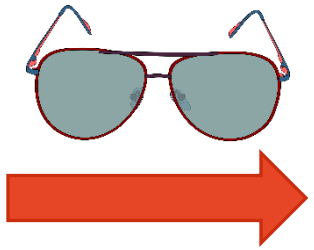
Infer hidden directed relationships

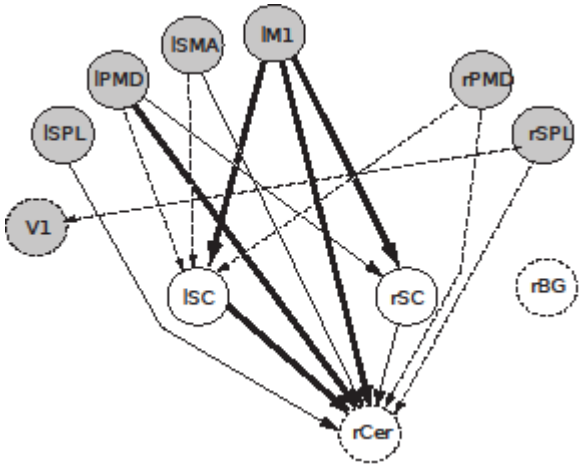






fMRI recordings during visual tracking task



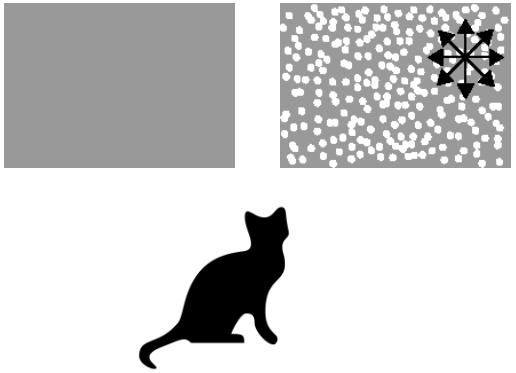


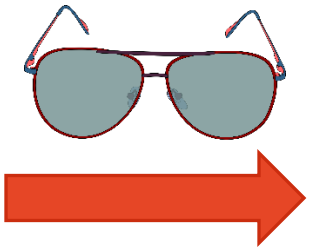
Inferred directed brain network

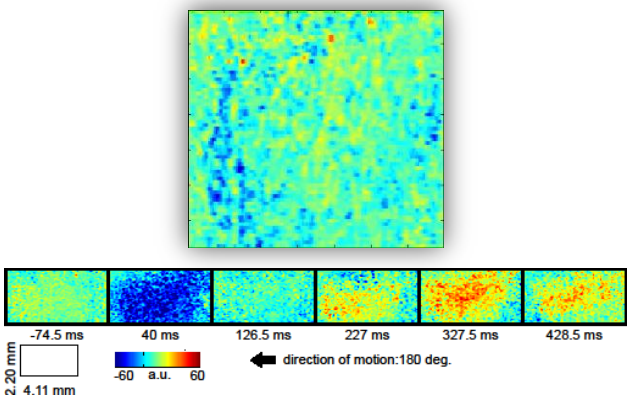
J.T. Lizier, J. Heinzle, A. Horstmann, J.-D. Haynes, M. Prokopenko. *Multivariate information-theoretic measures reveal directed information structure and task relevant changes in fMRI connectivity*. Journal of Computational Neuroscience (in Special issue on "Methods of Information Theory in Neuroscience Research"), vol. 30, pp. 85-107, 2011.

4th example: brain stimuli

Identify spatiotemporal fluctuations in information flow

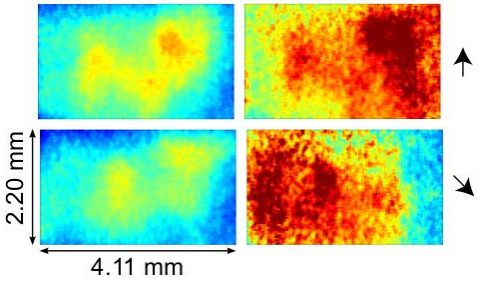






Recording visual cortex under stimuli of dots moving in different directions

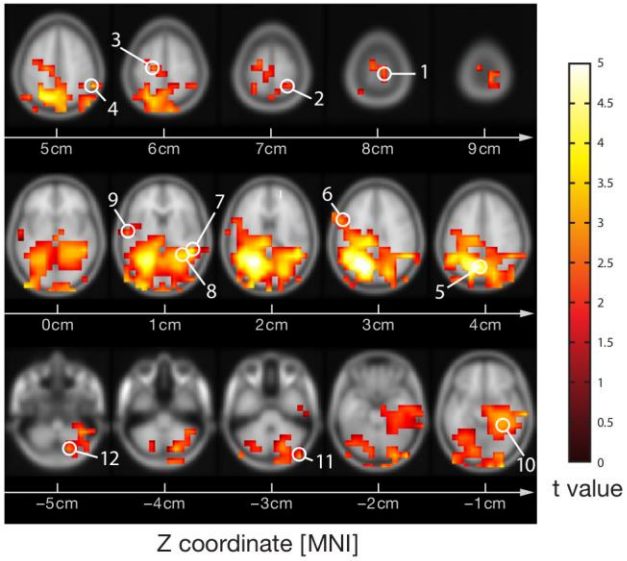
Identifies stimulus change ↑ and different directions of movement ↓



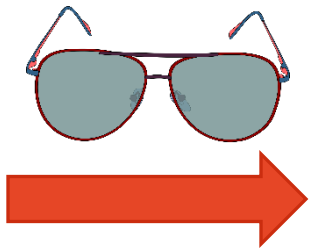
M. Wibral, J.T. Lizier, S. Voegler, V. Priesemann and R. Galuske. *Local active information storage as a tool to understand neural information processing*. Frontiers in Neuroinformatics, vol. 8, no. 1, 2014;

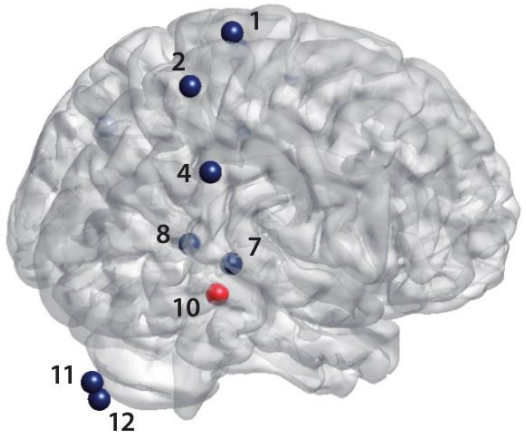
5th example: Autism Spectrum Disorder

Contrast information flow under different conditions



Resting stage MEG recordings





significant
no significant

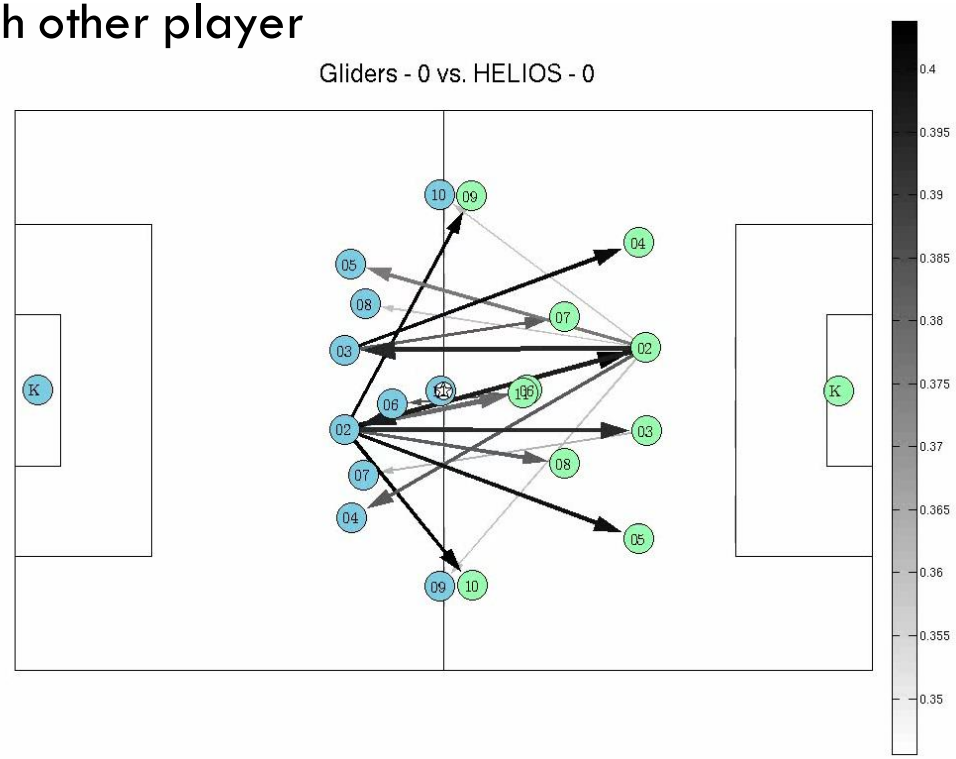
decrease of active information storage for ASD patients in hippocampus

C. Gomez, J.T. Lizier, M. Schaum, P. Wollstadt, C. Gruetzner, P. Uhlhaas, C. Freitag, S. Schlitt, S. Boelte, R. Hornero and M. Wibral. *Reduce Predictable Information in Brain Signals in Autism Spectrum Disorder*. Frontiers in Neuroinformatics, vol. 8, no. 9, 2014.

6th example: multi-agent dynamics

Sink Diagrams via Information Theory

We build a network of interactions by determining which player is most *responsive* to which other player

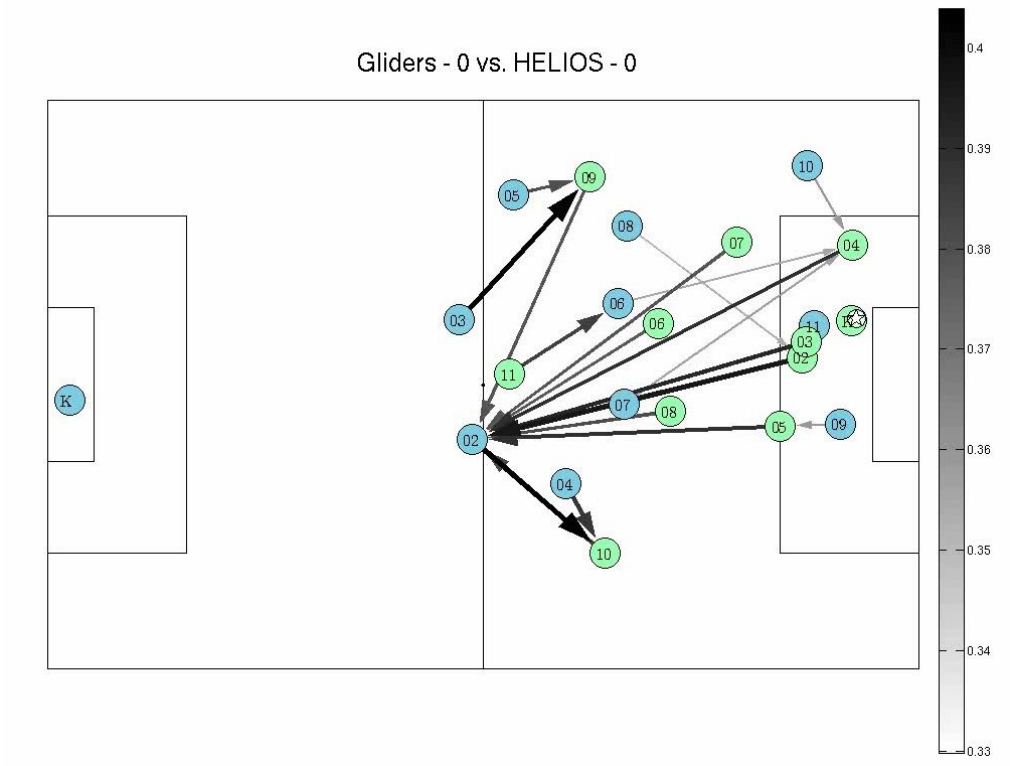


O.M. Cliff, J.T. Lizier, X.R. Wang, P. Wang, O. Obst and M. Prokopenko. *Quantifying long-range interactions and coherent structure in multi-agent dynamics*. Forthcoming in Artificial Life 23:1.

6th example: multi-agent dynamics

Base Diagrams via Information Theory

We build a network of interactions by determining which player each player *drives* the most



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Thank you

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