R.Margalef:
Dual thinking in ecological theory

Frederic Bartumeus
Investigador ICREA

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CEAB-CSIC & CREAF

R.Margalef & Maths

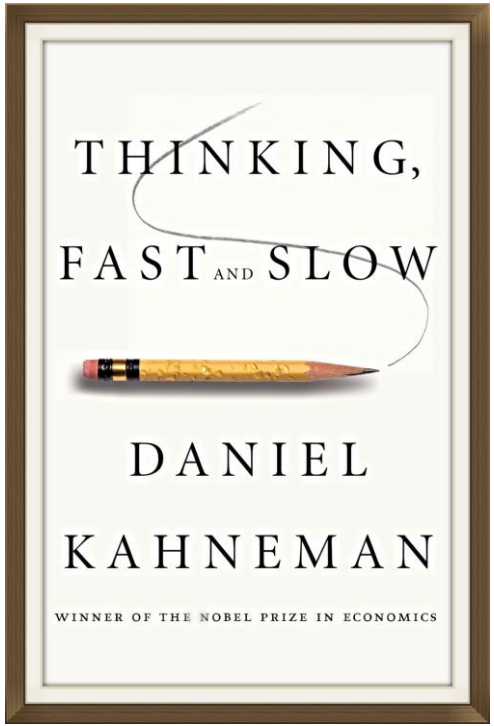
“As a language, mathematics permits the biologist to formulate his working hypotheses in the form of mathematical models capable of quantitative corroboration.”

“Expression by means of mathematical symbols frees us from the dangers of the rhetorical inertia of our verbal reasoning and allows us to advance more surely and rapidly in the development of our science.”

R.Margalef & Maths

“The reduction of vital facts to mathematical symbols presupposes and abstraction and a consequent loss of a series of attributes of whatever is being considered.”

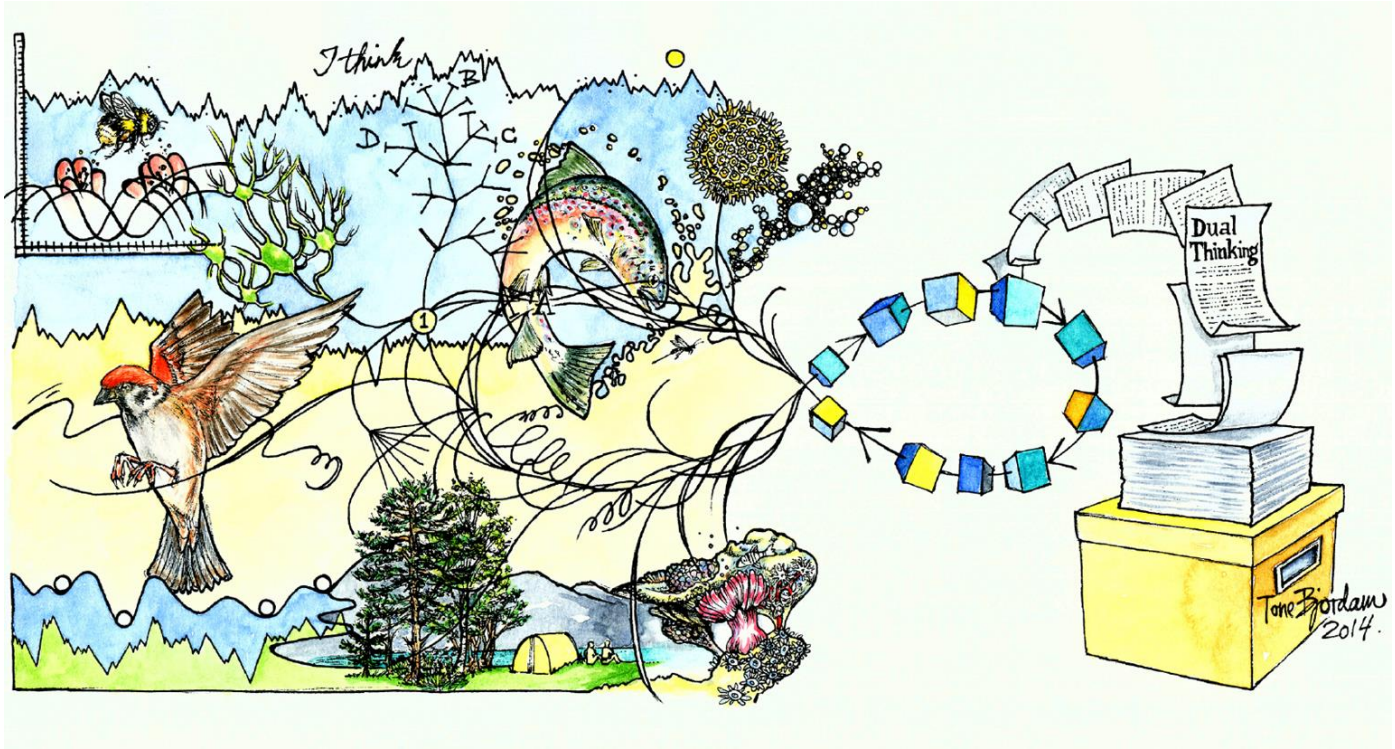
“Therefore, every mathematical representation will be incomplete, reflecting only one viewpoint of the situation with which Nature confront us, and indeed, it will be frequently be possible to construct independent mathematical models on a single set of data according to the attributes we choose to consider.”



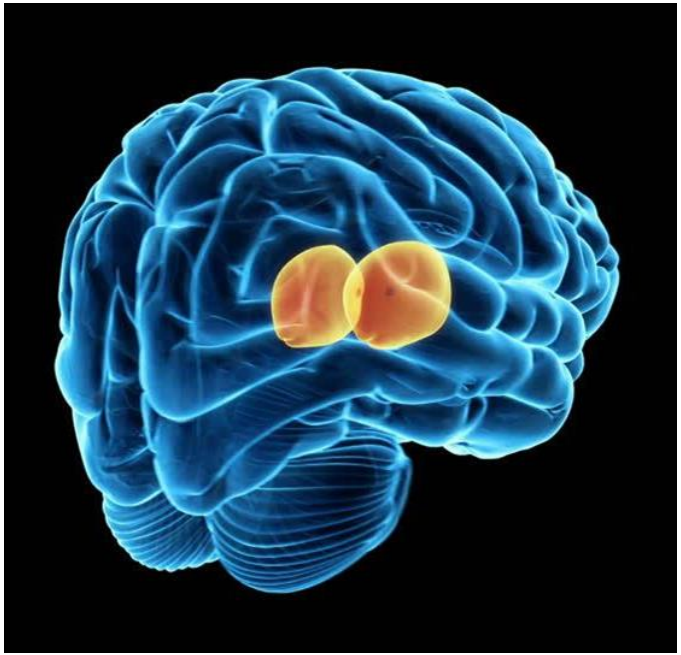
Cognition

System I: Intuition, "the Associative Machine"
it works largely unconsciously and relies on instantaneous underlying associations

System II: Reasoning, "the Rational Machine"
relies on the much slower process of reasoning



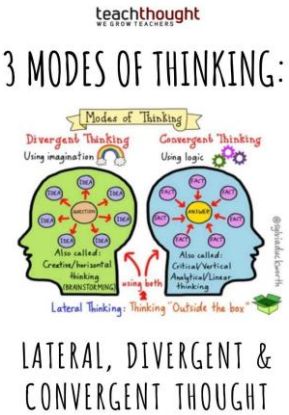
The forgotten half of scientific thinking, Scheffer et al (2014)
Dual thinking for scientists, Scheffer et al. (2015)

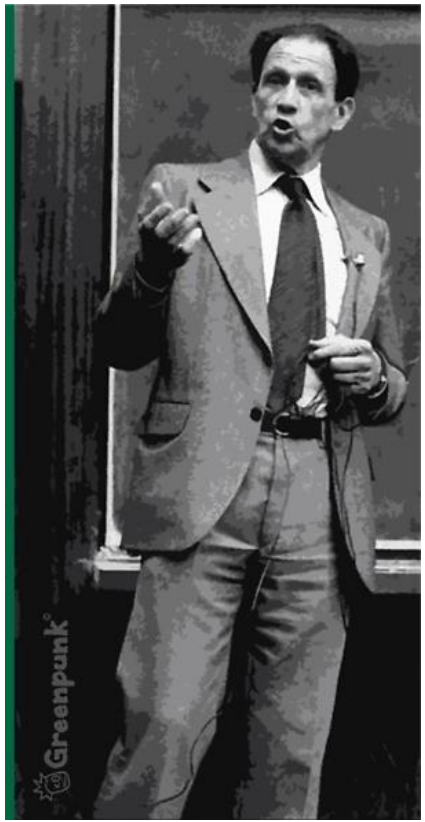


de Manzano et al. (2010)

Creativity & Divergent Thinking

Low levels of dopamine-D2 receptor in the thalamus

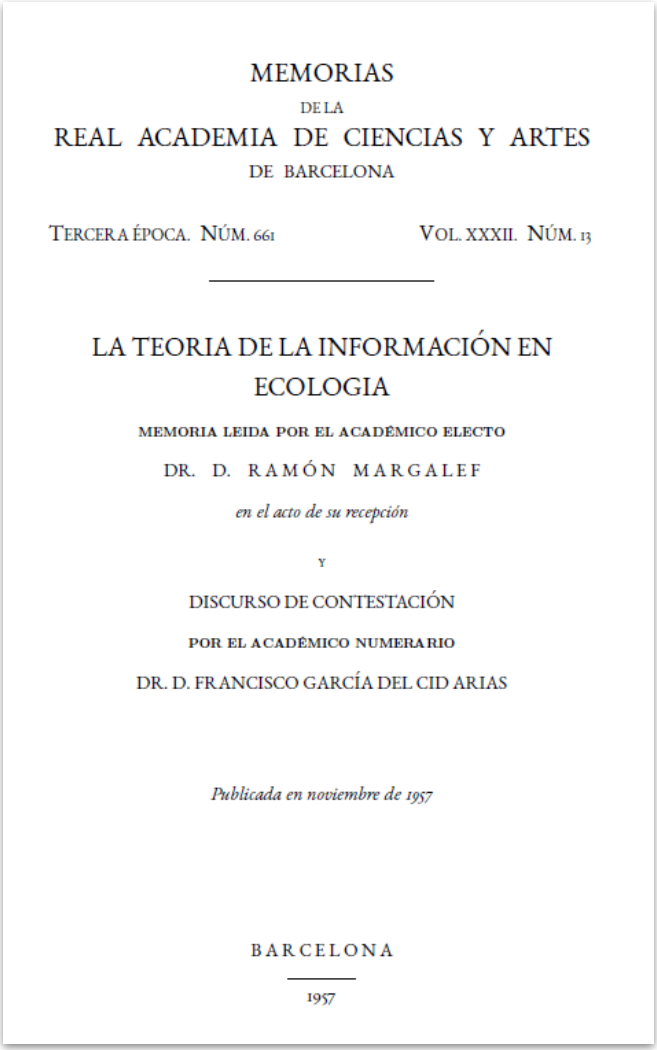




R.Margalef: a dual thinker

A) An associative machine with “rudimentary knowledge of mathematics”.
B) An associative machine “aware of the limits of mathematics”.

“I am fully conscious of the risk of displeasing both mathematicians and biologists”.
Mem. Real. Acad. Ciències i Arts, Barcelona 1957



MEMORIAS
DE LA
REAL ACADEMIA DE CIENCIAS Y ARTES
DE BARCELONA

TERCERA ÉPOCA. NÚM. 661 VOL. XXXII. NÚM. 13

LA TEORIA DE LA INFORMACIÓN EN ECOLOGIA

MEMORIA LEIDA POR EL ACADÉMICO ELECTO
DR. D. RAMÓN MARGALEF
en el acto de su recepción
Y
DISCURSO DE CONTESTACIÓN
POR EL ACADÉMICO NUMERARIO
DR. D. FRANCISCO GARCÍA DEL CID ARIAS

Publicada en noviembre de 1957

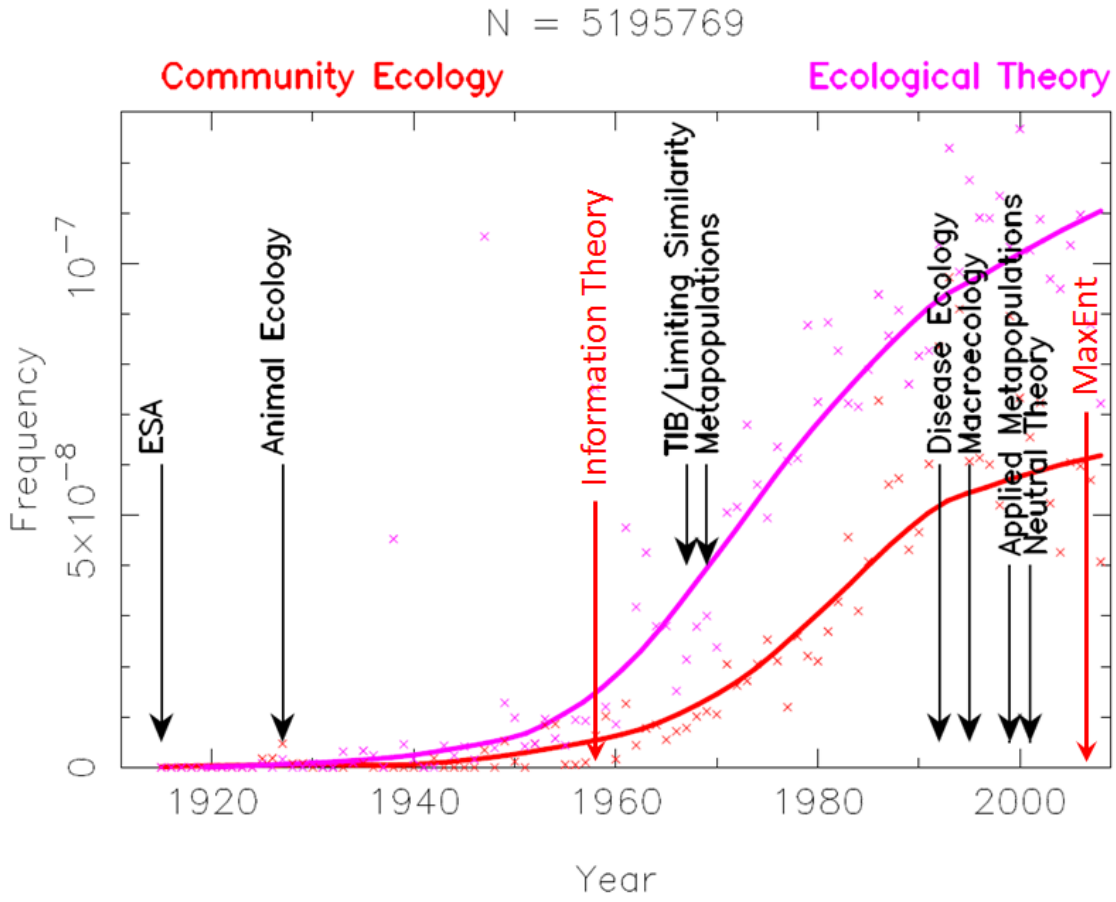
BARCELONA
1957

Information Theory in Ecology

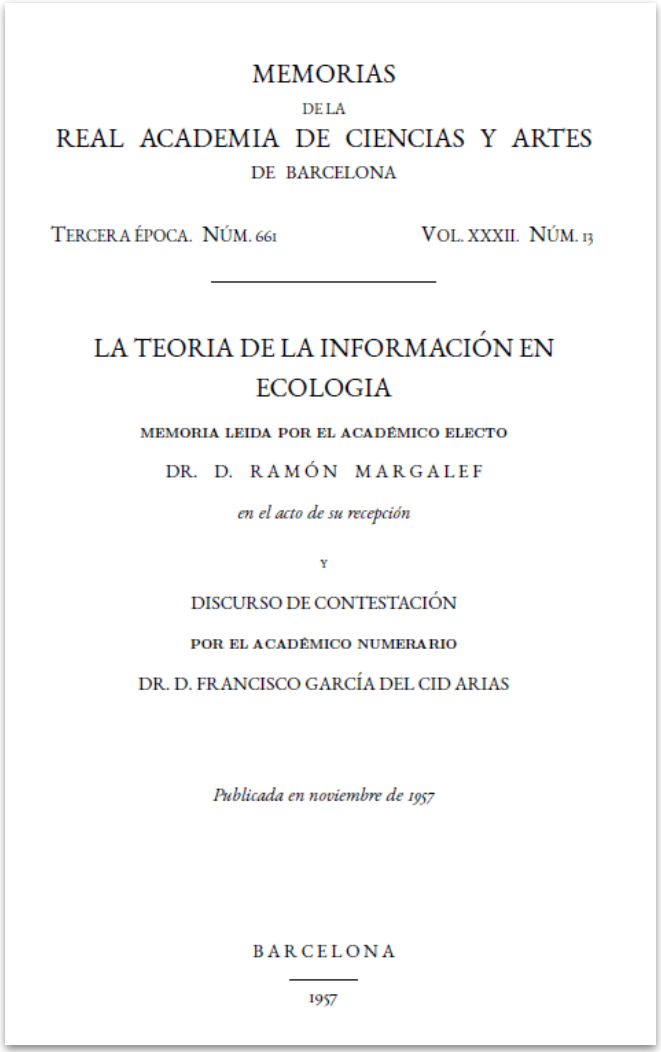
"The usual indices of diversity have the drawback of attempting to adjust a natural distribution to ***a simple mathematical expression of more or less arbitrary form****, and this does not always work"*

"Information theory provides a way to escape this difficulty, adopting as an index of diversity ***a more exact expression of the information contained in the structure of a community****"*

"Information ***as a measure of order/organization****"*



Adapted from D. Alonso (2018). Source: ngrams Google database



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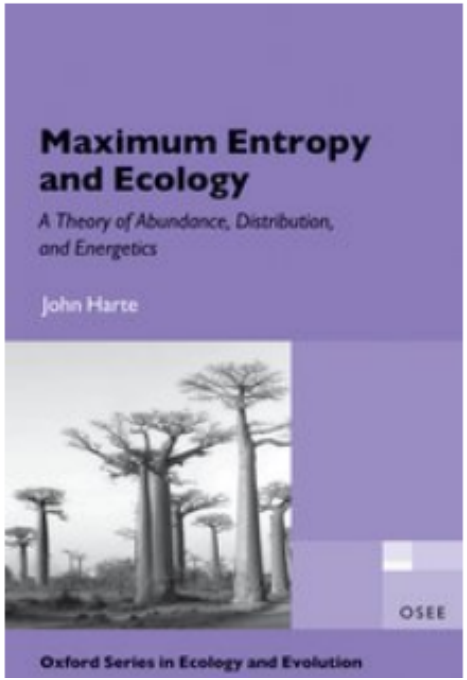
Information Theory in Ecology

- Maximum Entropy Principle
- Transfer Entropy
- Causal Entropic Force

MaxEnt Principle: foundational or statistical inference?



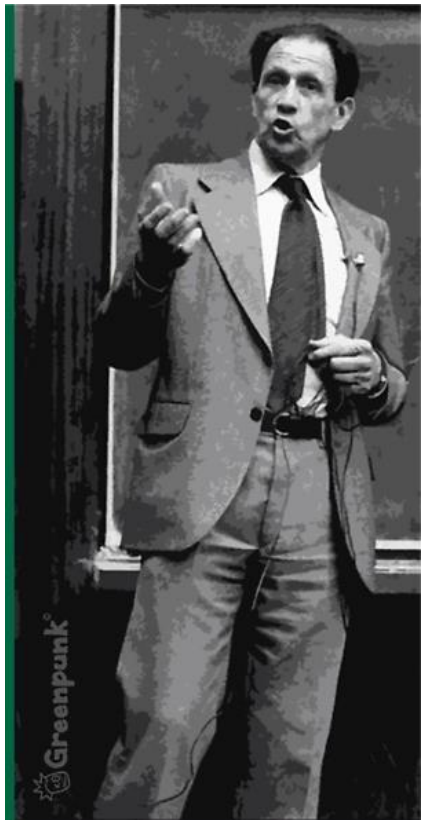
Maximum Entropy and Ecology

A Theory of Abundance, Distribution, and Energetics

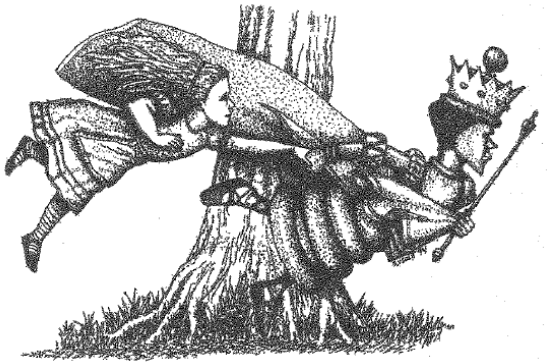
John Harte

Oxford Series in Ecology and Evolution

- Integrates ecology and maximum entropy to provide a comprehensive, predictive, and parsimonious theory that describes the major observed patterns in macroecology (2011)



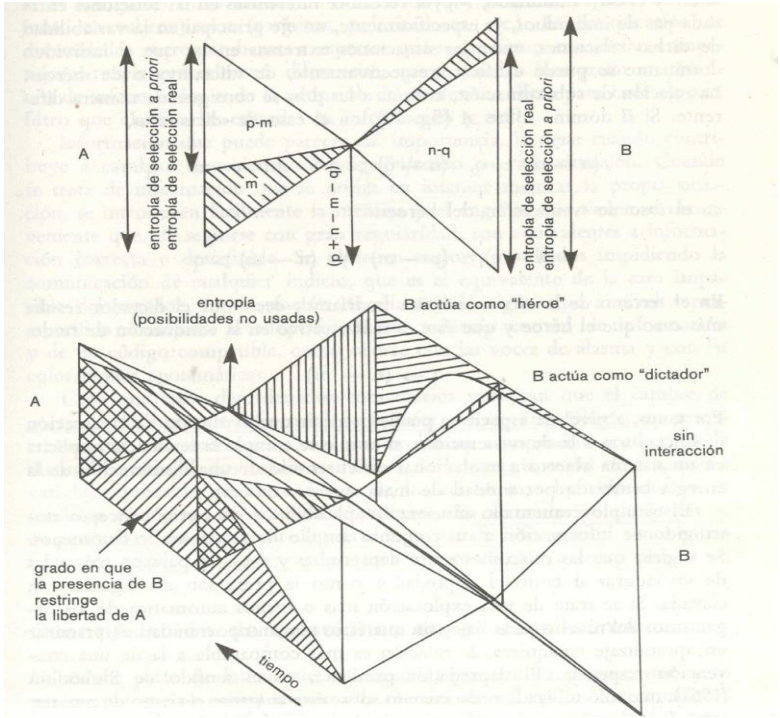
Transfer Entropy in ecological interactions



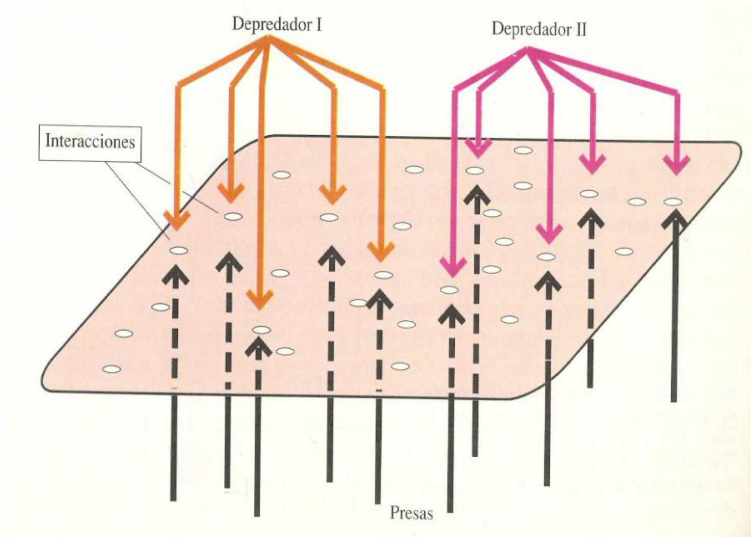
The “red Queen” hypothesis, van Valen (1973)
Solé RV y Manrubia S. (1996)

“Nothing in Biology Makes Sense Except in the Light of Evolution”
T.Dobzhansky (1973)

Transfer Entropy in predator-prey systems

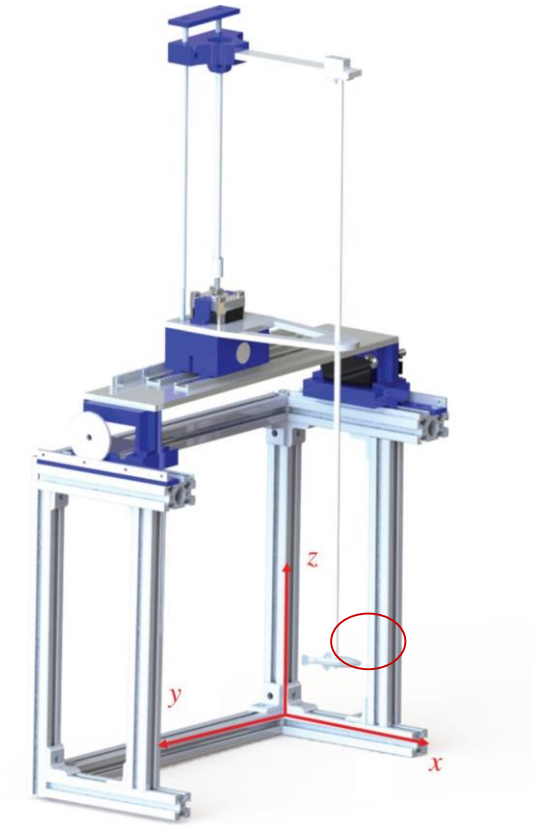


Margalef R (1980), La Biosfera, pag.115



Margalef R (1992) Planeta Azul, Planeta Verde.

Transfer Entropy in predator-prey systems

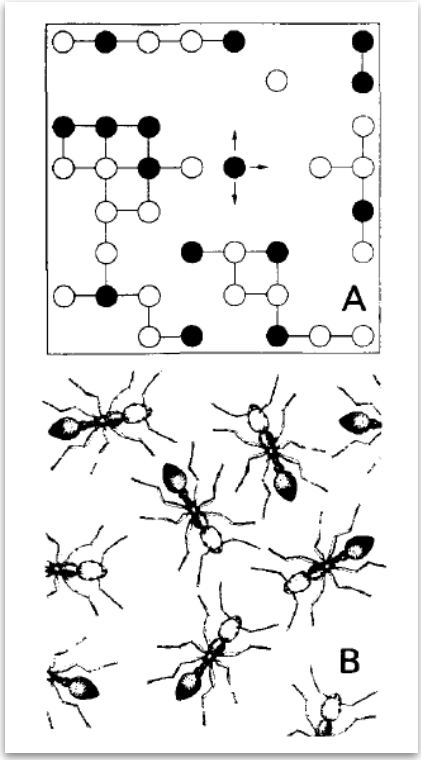


Information theory and robotics meet to study predator-prey interactions

*Neri D et al (2017) Chaos **27**, 073111*

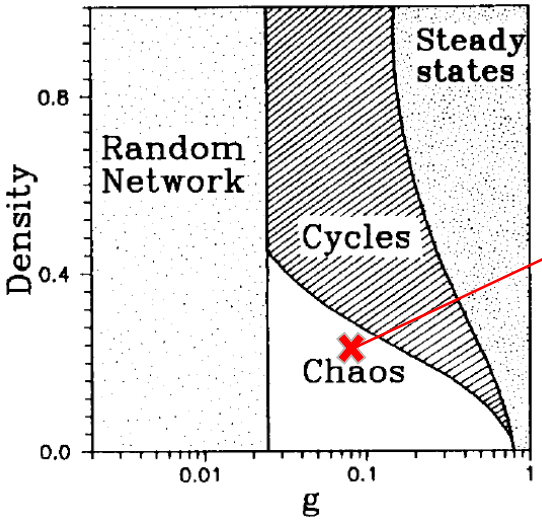
$$T_{Y\to X} = \sum_{x_{t+1},x_t,y_t} p(x_{t+1},x_t,y_t)\,\log_2 \frac{p(x_{t+1}|x_t,y_t)}{p(x_{t+1}|x_t)}$$

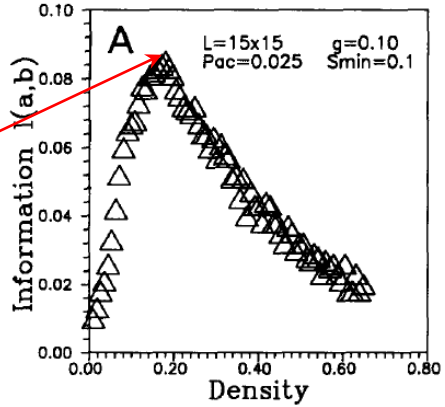
Transfer Entropy in multi-agent systems



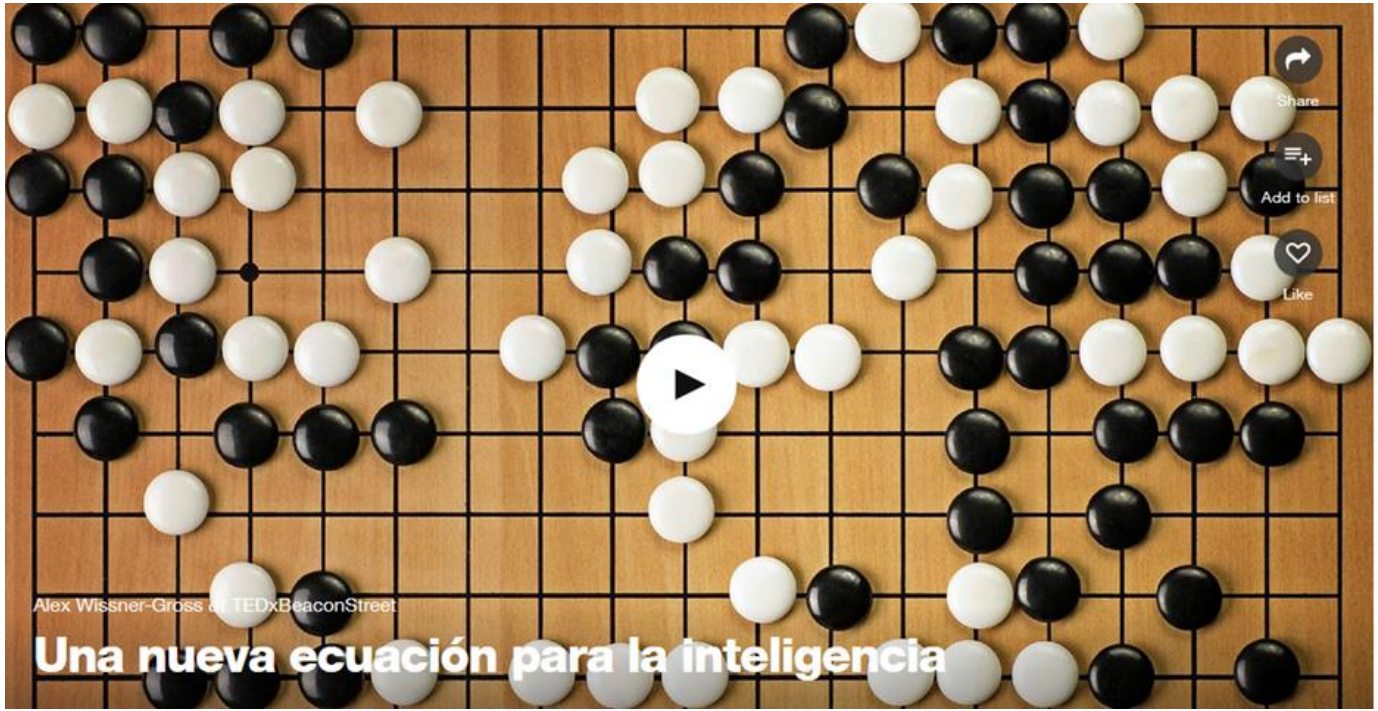
Information at the edge of chaos in fluid neural networks

Solé RV and O,Miramontes (1995) Physica D 171-180





Causal Entropic Force

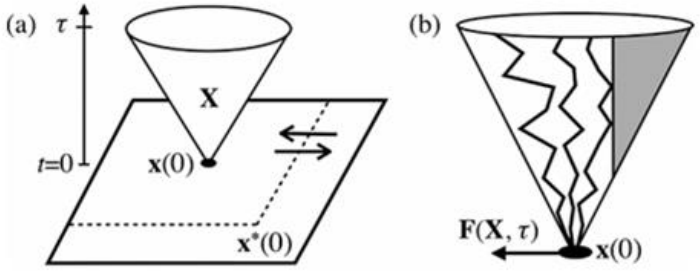


https://youtu.be/ue2ZEmTJ_Xo

Wissner-Gross and Freer PRL (2013)

Causal Entropic Force

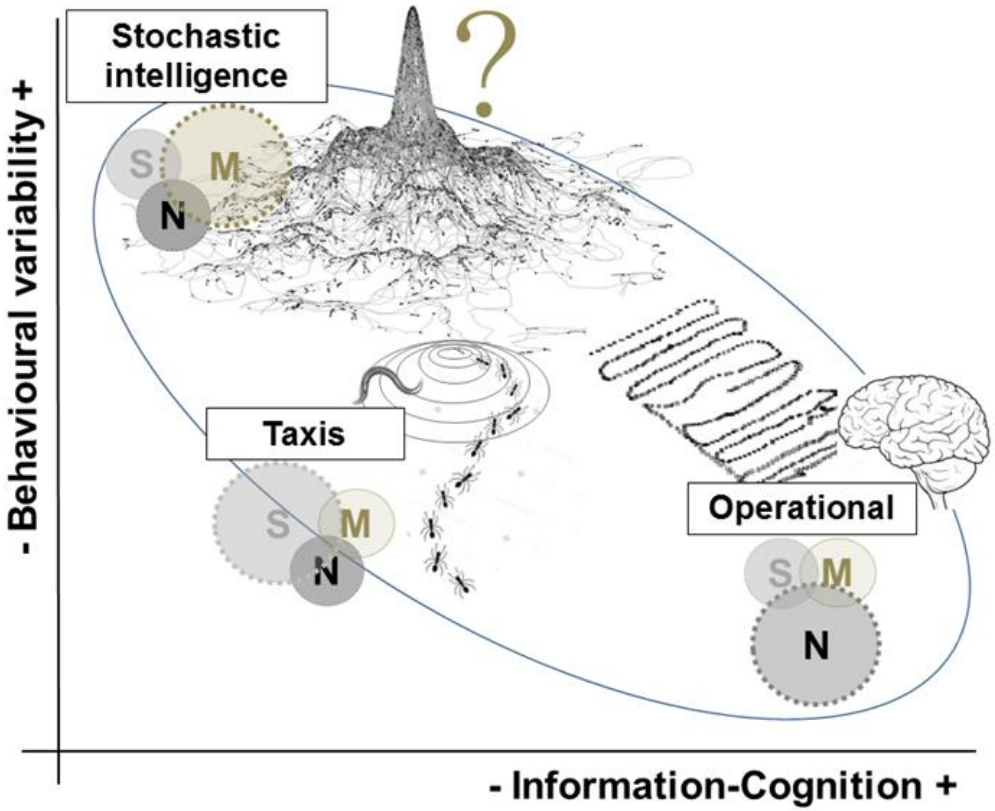
$$F = T \nabla S_T.$$



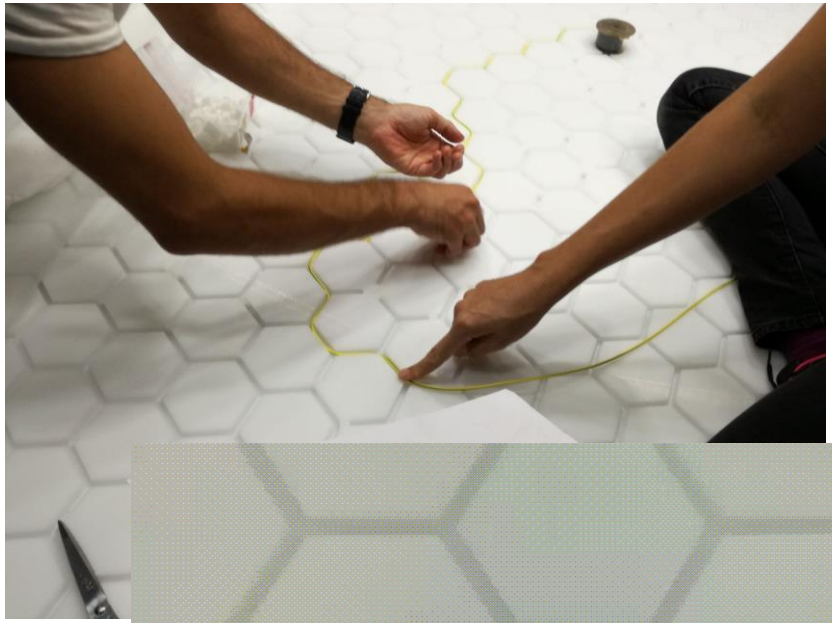
"Intelligence" is about not getting trapped, keeping future options open

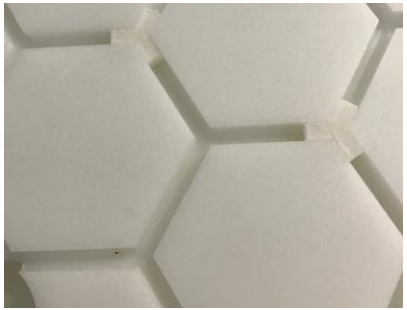
> "...a force that acts to maximize future freedom of action (or keep options open) with some strength *T*, with the diversity of possible options *S* up to some future horizon *t*."

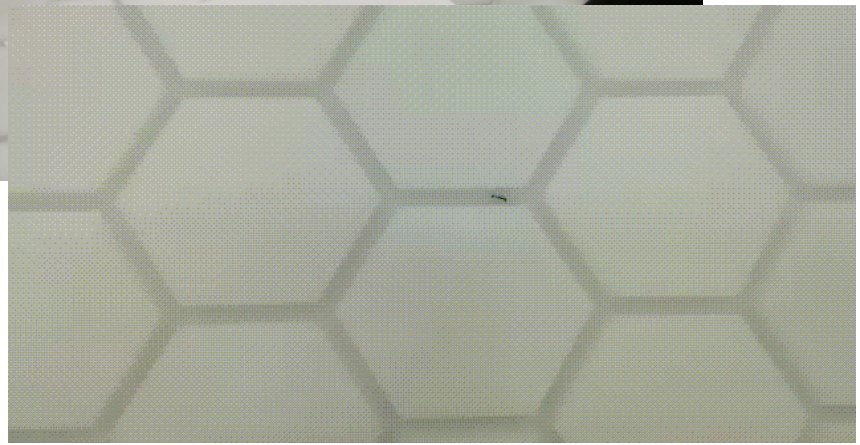
Search Behavioural Strategies

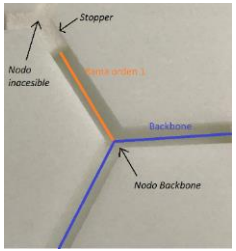


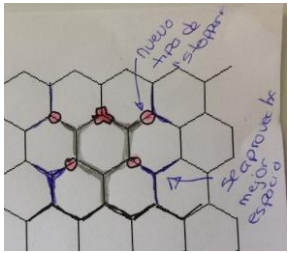
Theory...but also Experiments



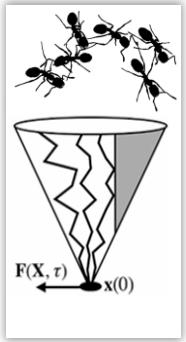


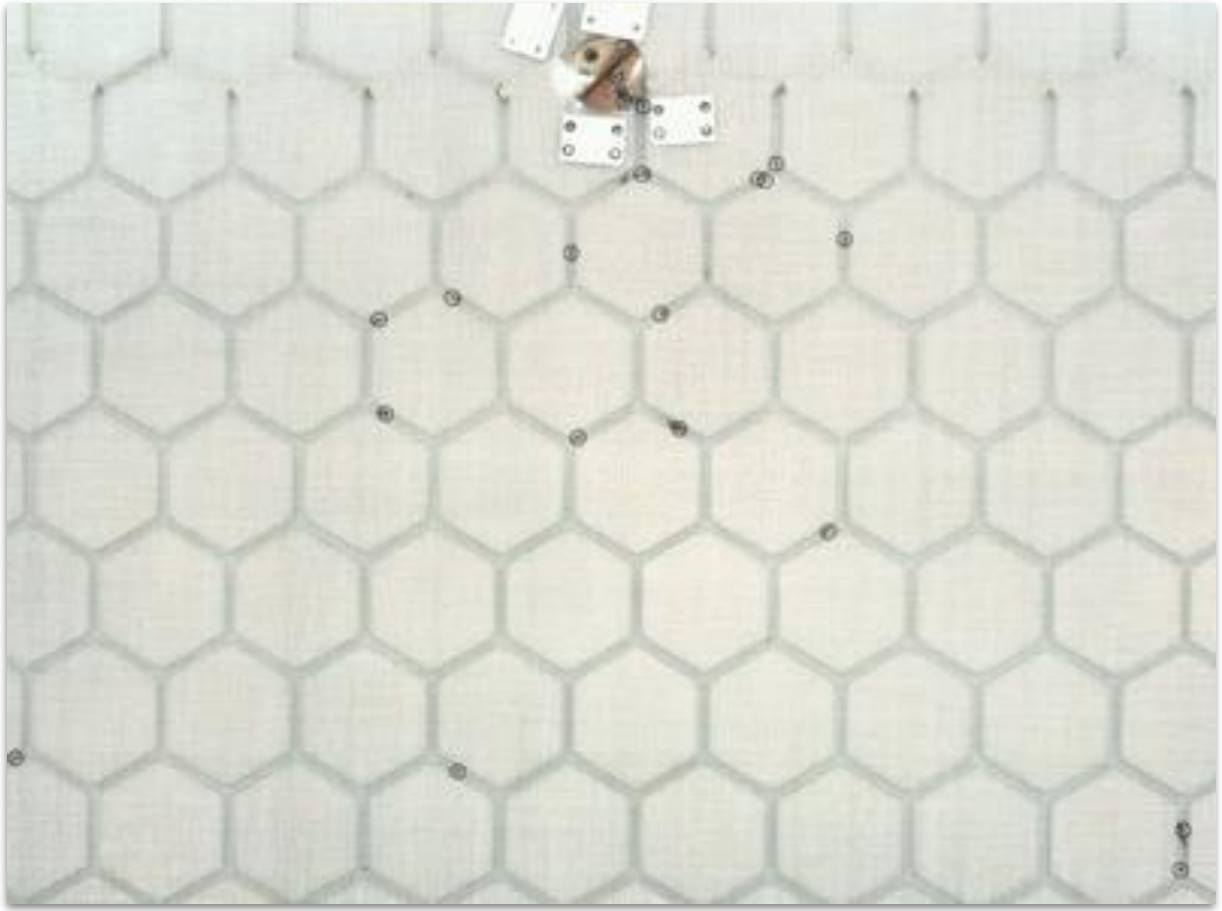




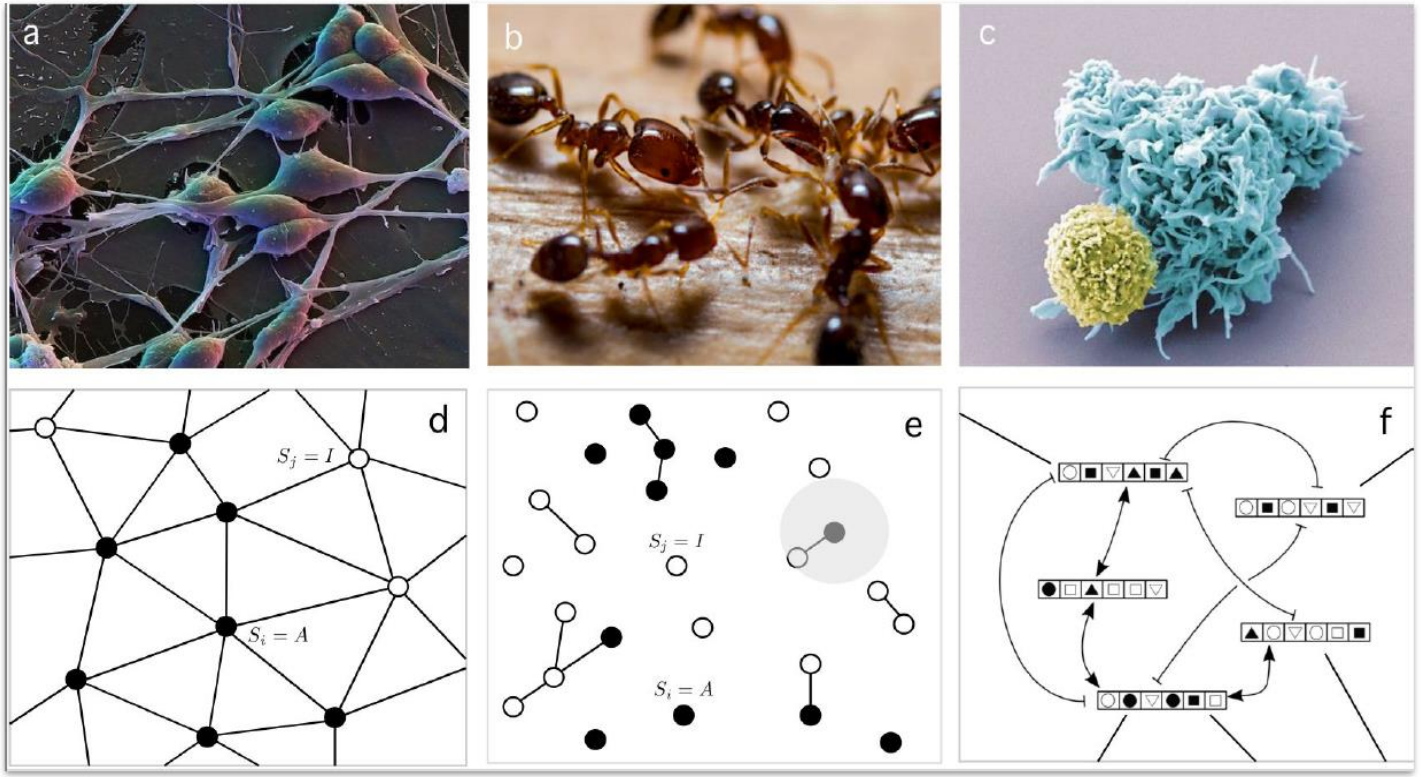


Ants in the Entropic Table



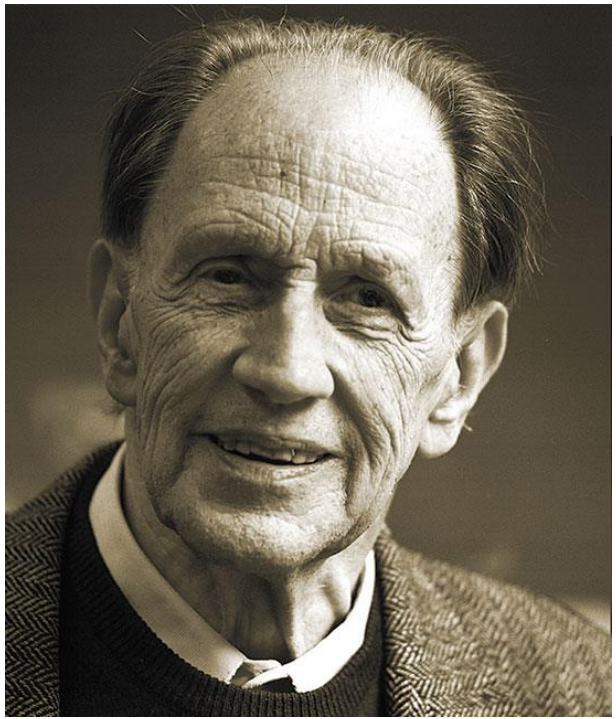


Statistical physics of “liquid brains”



Piñeiro J, Solé RV (2019) bioRXiv

Complex Adaptive Systems



"Dissipative/Self-Organizing Systems"

Ecosystems and the biosphere as complex adaptive systems

SA Levin (1998). Ecosystems 1:431-436
R Margalef (1997), Our Biosphere
SA Levin (1999), Fragile Dominion

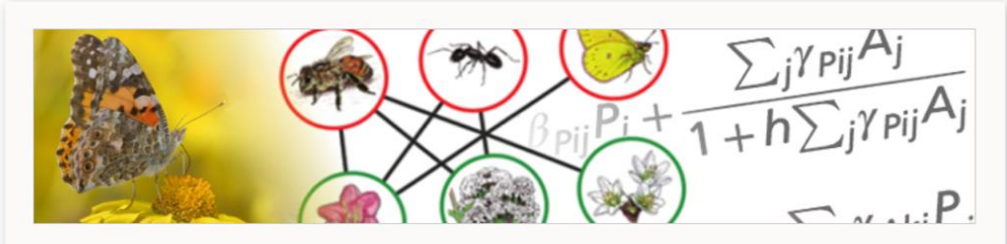
- Multi-dimensional, multi-scale
- Non-linearity, regime shifts, chaos
- Direct and Indirect interactions
- Inherent stochasticity and environmental forcing
- Self-organized dissipative structures
- Individual variability, phenotypic plasticity and evolutive adaptation

Frameworks for Ecological Theory

- Dynamical Systems
- Statistical Physics
- Stochastic Processes
- Networks
- Individual Based Modelling
- Statistical Inference (Bayes)

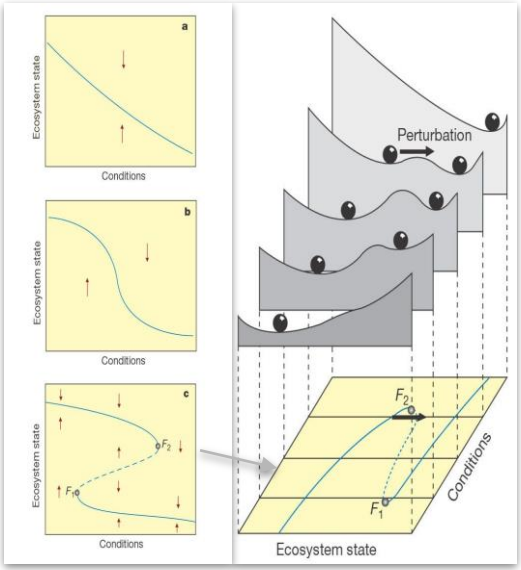
...to combine with empirical data!

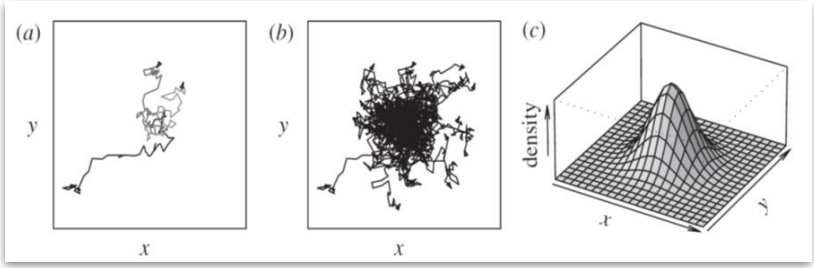
Networks



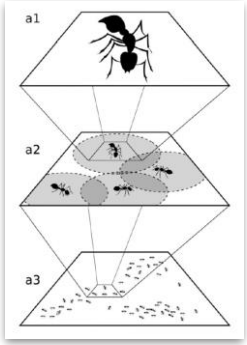
Stochastic processes

Dynamical systems

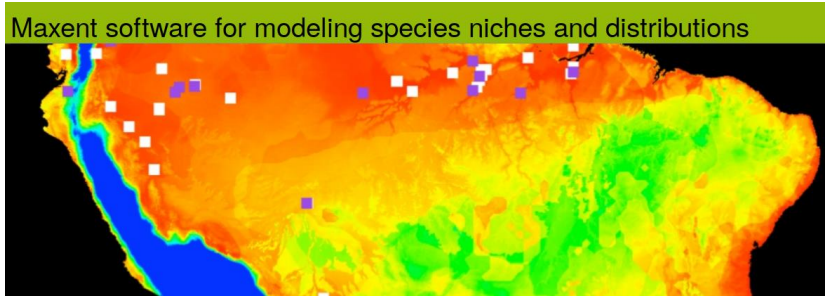




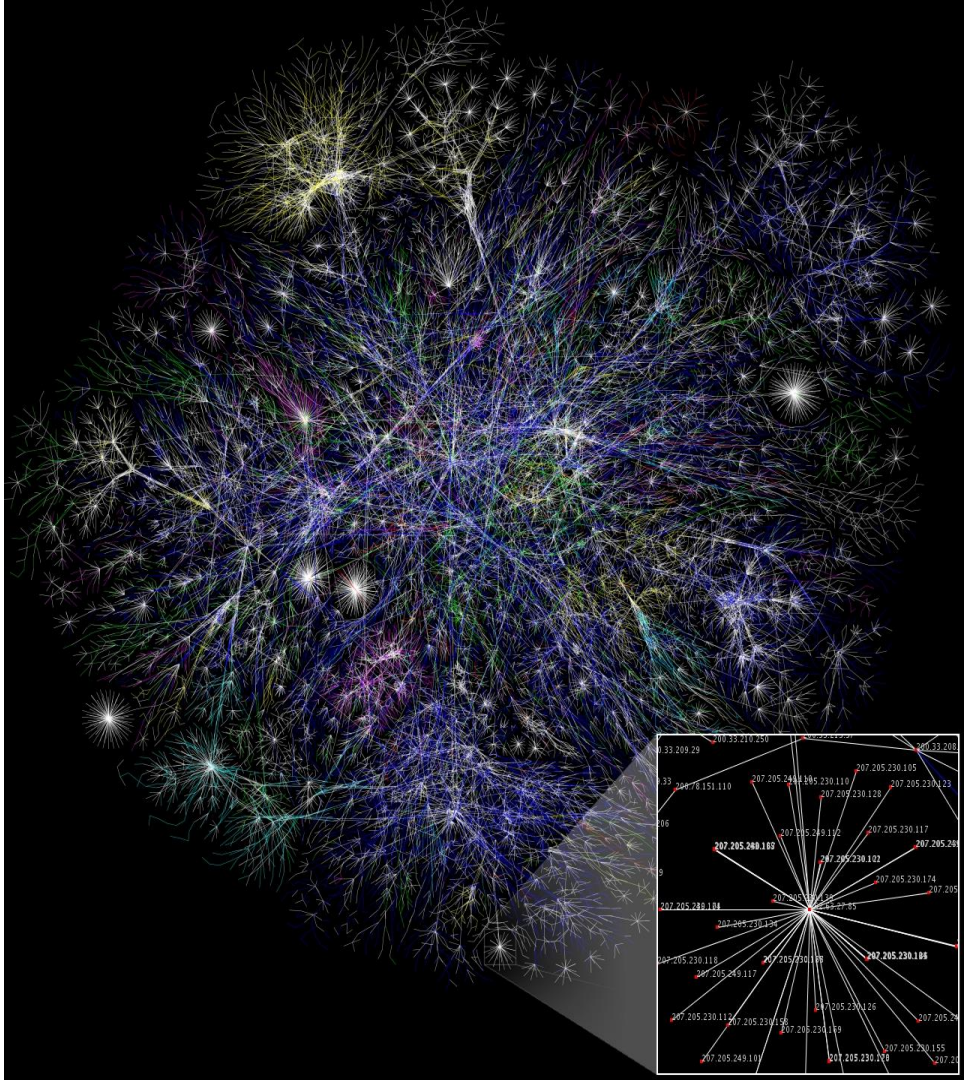
Individual-based Modelling

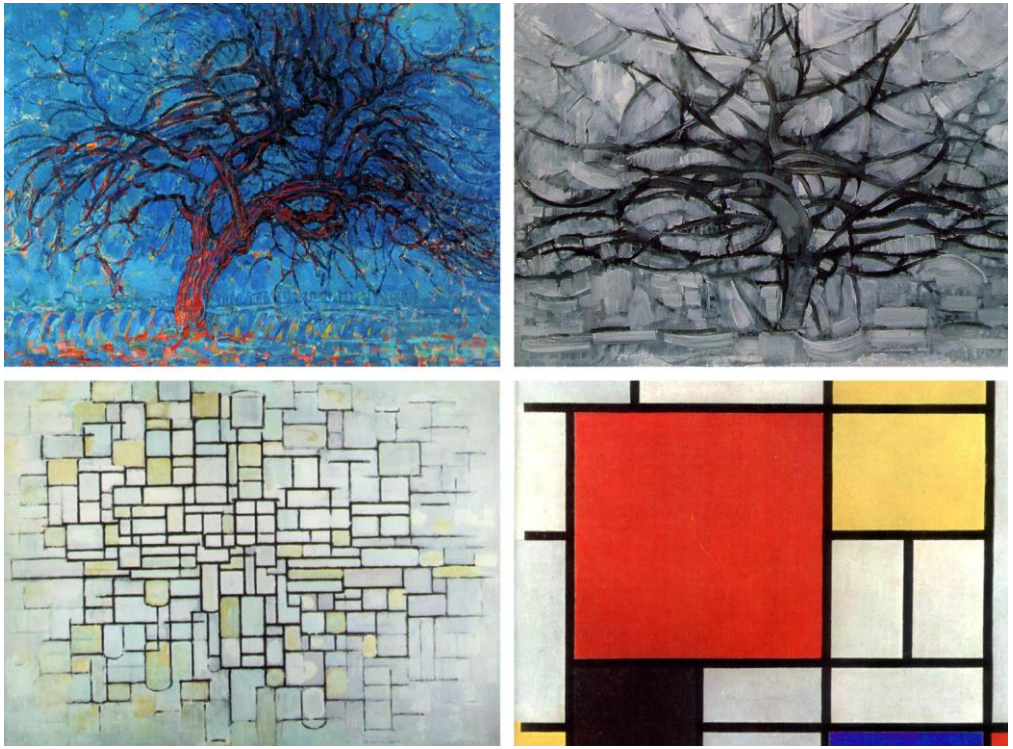


MaxEnt



New Sensor and Big Data ERA



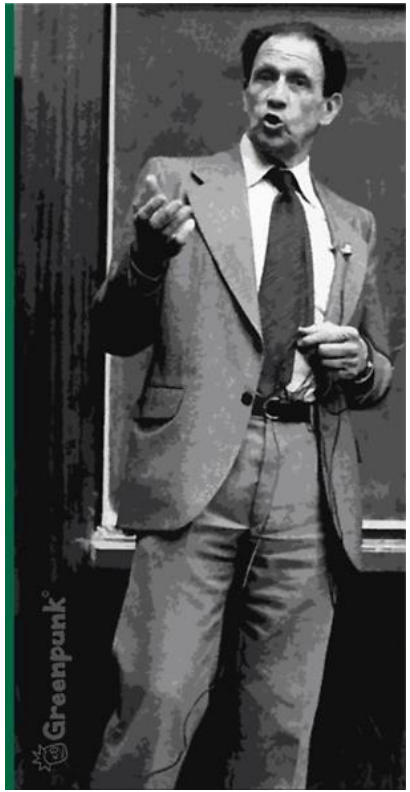


Art from Piet Mondrian (1872-1944)

“Margalefian perspective” for Ecological Theory

T.Bjordan
Lichens, photography, Tone Bjordam, 2008

E.Ballesteros
Parc Nacional de Cabrera (Mallorca)
Red Coral Community



Enabling Dual Thinking

How scientists and scientific institutions might make best use of dual thinking? (Margalef inheritage)

- Emptying time
- Diversifying inputs
- The arts as partners
- Small interdisciplinary institutes

Dual thinking for scientists, Scheffer et al. (2015)

Influencers
(Acknowledgements)

- **R Margalef**
- J LL Pretus
- J Flos
- J Catalan
- RV Solé
- J Bascompte
- S Pueyo
- D Alonso
- D Oro
- S Levin
- W Bialek