Information Physics: Closing Gaps, Opening Perspectives

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COMMENTARY
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Key Points:

- Information Physics reconciles and generalizes statistical, geometric, and mechanistic views on information and Entropy
- Statistical uncertainty stems from dynamic diversity and in turn from Entropy production, with information metrics having a physical meaning
- Information metrics can be developed to enable the study of far-from-equilibrium structural-functional coevolution in hydrology and Earth system dynamics

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Debates: Does Information Theory Provide a New Paradigm for Earth Science? Emerging Concepts and Pathways of Information Physics

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Abstract Entropy and Information are key concepts not only in Information Theory but also in Physics: historically in the fields of Thermodynamics, Statistical and Analytical Mechanics, and, more recently, in the field of Information Physics. In this paper we argue that Information Physics reconciles and generalizes statistical, geometric, and mechanistic views on information. We start by demonstrating how the use and interpretation of Entropy and Information coincide in Information Theory, Statistical Thermodynamics, and Analytical Mechanics, and how this can be taken advantage of when addressing Earth Science problems in general and hydrological problems in particular. In the second part we discuss how Information Physics provides ways to quantify Information and Entropy from fundamental physical principles. This extends their use to cases where the preconditions to calculate Entropy in the classical manner as an aggregate statistical measure are not met. Indeed, these preconditions are rarely met in the Earth Sciences due either to limited observations or the far-from-equilibrium nature of evolving systems. Information Physics therefore offers new opportunities for improving the treatment of Earth Science problems.

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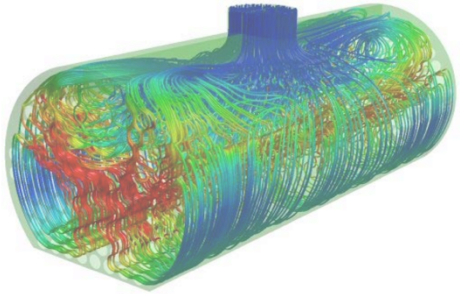
What is Information Physics?

- Current: Information-based Physics: Physics made of Information
- Our take: Physically-based Information: Information made of Physics

Scientific quest for the fundamental nature of information





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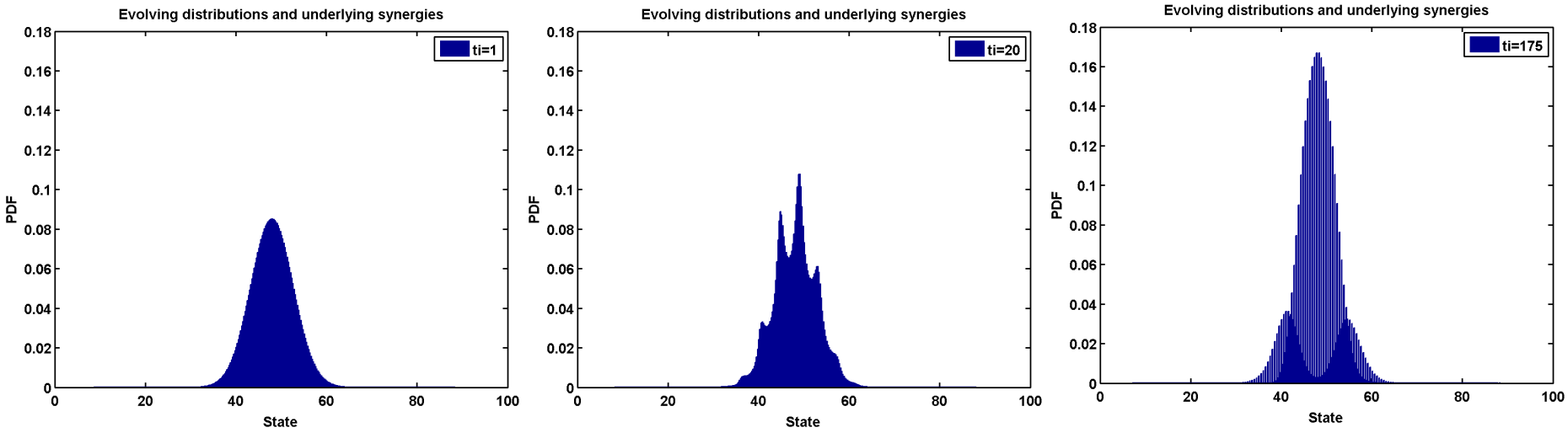

Nonlinearly excited quantum evolution and its associated entropy production, bringing out information emergence. In: Perdigão R.A.P. (2017): Fluid Dynamical Systems: From Quantum Gravitation to Thermodynamic Cosmology. https://doi.org/10.46337/mdsc.5091

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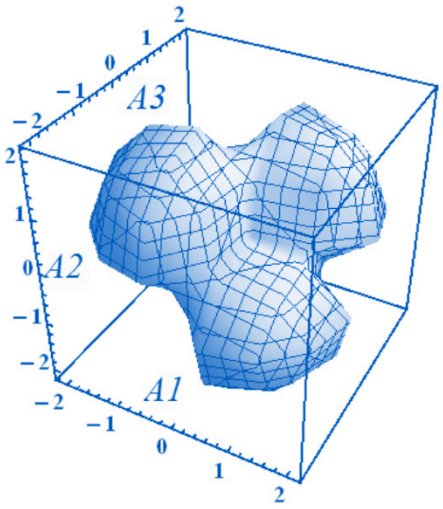
Beyond IT: connecting the dots in coevolutionary systems

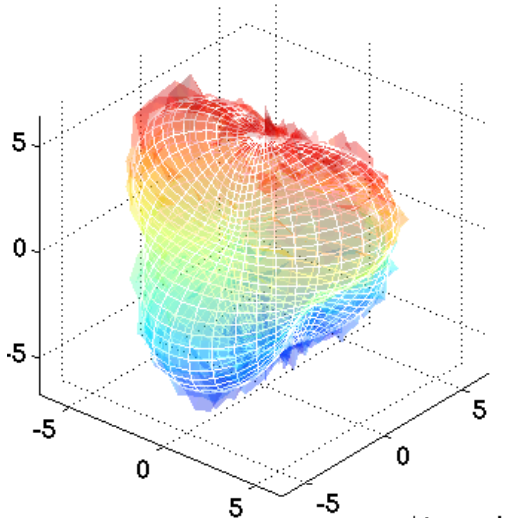
IT with Boltzmann-Gibbs-Shannon/Von-Neumann Entropies:

- Multivariate and inferential links among aggregates;
- Thermodynamic Principles with microstate independence;
- Valid only in local equilibrium (granular like a perfect gas).



Beyond IT with Polyadic Info Physics (Perdigão 2017, 2018a,b)**:**

- Coevolution and causation among underlying microstates;
- Thermodynamic and IT laws reshaped by microstate links;
- Valid also in far-from-equilibrium coevolutionary systems.



IT captures aggregate statistical links. We connect the underlying dots.

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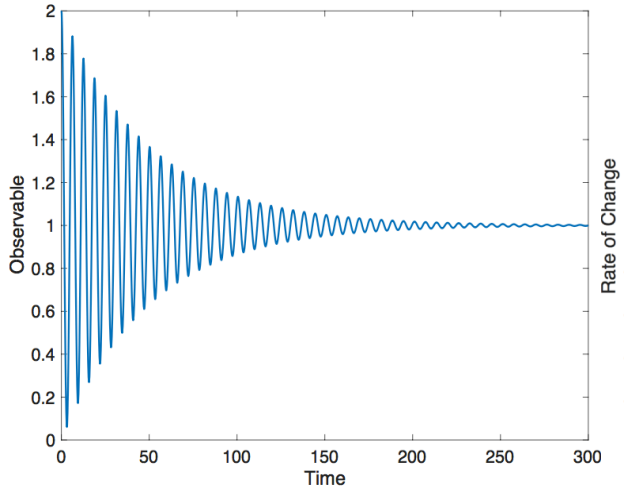
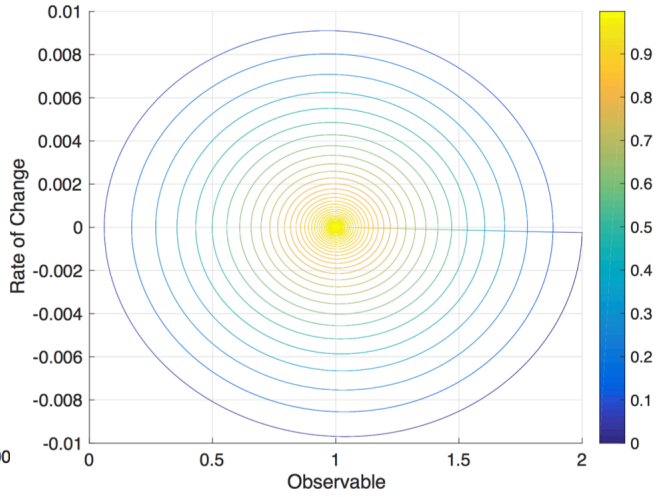
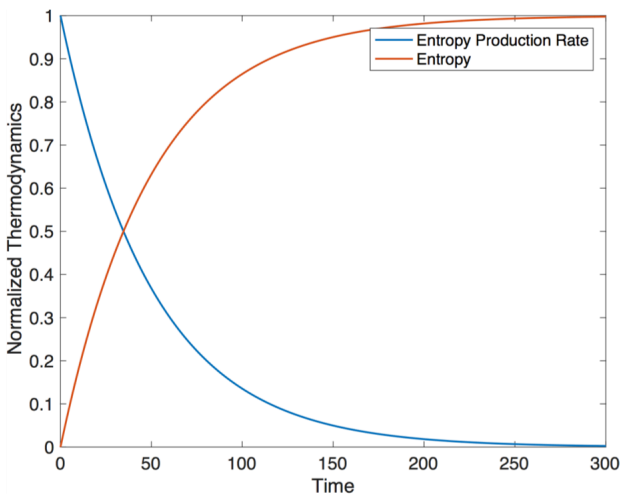
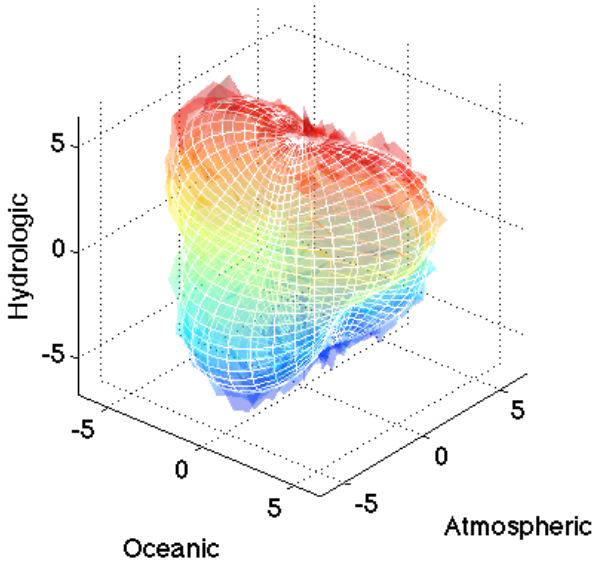
Unveiling System Dynamics with Information Geometry

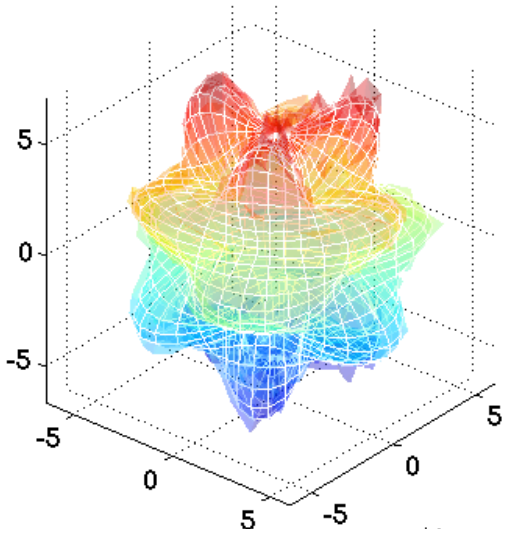
- Information geometry captures entropy production – even in deterministic flows











Entropy evaluated from the energy density of the system dynamics in phase space (Perdigão 2017).

Upper row: 1D state space, 2D phase space and entropy production for an ergodic damped oscillator;

Lower row: 3D state space, 6D phase space (embedded into 3D) for non-ergodic earth system dynamics.

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Thank you for your attention!

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