Nonlinear Sciences > Adaptation and Self-Organizing Systems

Quantifying Emergence in terms of Persistent Mutual Information

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We define Persistent Mutual Information (PMI) as the Mutual (Shannon) Information between the past history of a system and its evolution significantly later in the future. This quantifies how much past observations enable long term prediction, which we propose as the primary signature of (Strong) Emergent Behaviour. The key feature of our definition of PMI is the omission of an interval of 'present' time, so that the mutual information between close times is excluded: this renders PMI robust to superposed noise or chaotic behaviour or graininess of data, distinguishing it from a range of established Complexity Measures. For the logistic map we compare predicted with measured long-time PMI data. We show that measured PMI data captures not just the period doubling cascade but also the associated cascade of banded chaos, without confusion by the overlayer of chaotic decoration. We find that the standard map has apparently infinite PMI, but with well defined fractal scaling which we can interpret in terms of the relative information codimension. Whilst our main focus is in terms of PMI over time, we can also apply the idea to PMI across space in spatially-extended systems as a generalisation of the notion of ordered phases.

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