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A Recurrence Flow based Approach to Attractor Reconstruction

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In the study of nonlinear observational time series, reconstructing the system's state space represents the basis for many widely-used analyses. From the perspective of dynamical system's theory, Taken's theorem states that under benign conditions, the reconstructed state space preserves the most fundamental properties of the real, unknown system's attractor. Through many applications, time delay embedding (TDE) has established itself as the most popular approach for state space reconstruction[1]. However, standard TDE cannot account for multiscale properties of the system and many of the more sophisticated approaches either require heuristic choice for a high number of parameters, fail when the signals are corrupted by noise or obstruct analysis due to their very high complexity.

We present a novel semi-automated, recurrence based method for the problem of attractor reconstruction. The proposed method is based on recurrence plots (RPs), a computationally simple yet effective 2D-representation of a univariate time series. In a recent study, the quantification of RPs has been extended by transferring the well-known box-counting algorithm to recurrence analysis[2]. We build on this novel formalism by introducing another box-counting measure that was originally put forward by B. Mandelbrot, namely *succolarity*[3]. Succolarity quantifies how well a fluid can permeate a binary texture[4]. We employ this measure by flooding a RP with a (fictional) fluid along its diagonals and computing succolarity as a measure of diagonal flow through the RP. Since a non-optimal choice of embedding parameters impedes the formation of diagonal lines in the RP and generally results in spurious patterns that block the fluid, the attractor reconstruction problem can be formulated as a maximization of diagonal recurrence flow.

The proposed state space reconstruction algorithm allows for non-uniform embedding delays to account for multiscale dynamics. It is conceptually and computationally simple and (nearly) parameter-free. Even in presence of moderate to high noise intensity, reliable results are obtained. We compare the method's performance to existing techniques and showcase its effectiveness in applications to paradigmatic examples and nonlinear geoscientific time series.

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