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The K.U. Leuven Competition Data: a Challenge for Advanced Neural Network Techniques

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Abstract. In this paper we shortly discuss the K.U. Leuven time-series prediction competition, which has been held in the framework of the International Workshop on *Advanced Black-Box Techniques for Nonlinear Modeling*, K.U.Leuven Belgium July 8-10 1998. The data are related to a 5-scroll attractor, generated from a generalized Chua's circuit. The time-series consists of a given set of 2000 data points, where the next 200 points are to be predicted. In total, 17 entries have been submitted. The winning contribution by McNames succeeds in making an accurate prediction over a time horizon of about 300 points using a nearest trajectory method, which incorporates local modeling and cross-validation techniques. The competition data can serve as a challenging test-case for advanced nonlinear modelling techniques, including neural networks. The data are able to reveal shortcomings of many methods.

Keywords. Time-series prediction, generalized Chua's circuit, chaos.

1. Introduction

The prediction of time-series is a challenging area for nonlinear modeling techniques. This has been demonstrated earlier by the Santa Fe time series prediction competition [17], where several data sets such as laser data, currency exchange rates and astrophysical data were to be predicted. Despite the fact that chaotic systems have a limited predictability, related to the first Lyapunov exponent of the system, it has been shown that accurate short term forecasts are feasible. In this context the choice of the model structure and embedding,

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the parametrization of the model, the parameter estimation procedure and cross-validation are important issues in order to obtain successful results.

Within the framework of the International Workshop on *Advanced Black-Box Techniques for Nonlinear Modeling*, held at the K.U.Leuven Belgium July 8-10 1998, a new time-series competition has been organized. The competition data were made available from Nov. 1997 till April 1998. [1] The data are generated from a computer simulated 5-scroll attractor, resulting from a generalized Chua's circuit. This fact was unknown to the participants in the competition. A real-life implementation of this electronic circuit has been given in [18]. Chua's circuit is well-known to be a paradigm for chaos [3, 5], being a simple nonlinear electrical circuit that reveals a rich variety of phenomena. It can be represented in Lur'e form [16, 14] as the interconnection of a linear dynamical system with a static nonlinearity, which is in the present case a piecewise linear characteristic with 2 breakpoints. The generalized Chua's circuit consists of a nonlinearity with multiple breakpoints, leading to a family of n-scroll attractors [10, 11]. The n-scroll attractors have been used for secure communications applications exploiting chaos, such as the method of nonlinear H_∞ synchronization of chaotic Lur'e systems in [12]. Steps towards unmasking chaotic communications schemes have been taken which are related to identifying the nonlinear system [9]. The latter is a motivation for understanding the limits of performance of time-series prediction strategies.

The winning entry by McNames [6, 7] and the second best result by Bersini [2] were significantly better than the remaining submissions (17 entries in total) [13]. They both make use of a local modelling technique in combination with a leave-one-out cross validation procedure. Although a number of neural network approaches have been tried, results from other advanced techniques such as support vector machines [8, 15] and Bayesian learning neural networks [1,4] have not been submitted and should be further tested on this data set.

This paper is organized as follows. In Section 2 we explain the K.U. Leuven competition data. In Section 3 we present the two best results.

2. K.U. Leuven Time-Series Competition Data

The competition data were generated from the following computer simulated generalized Chua's circuit [11]:

$$\left\{ \begin{array}{lcl} \dot{x}_1 & = & \alpha\,[x_2 - h(x_1)] \\ \dot{x}_2 & = & x_1 - x_2 + x_3 \\ \dot{x}_3 & = & -\beta x_2 \end{array} \right. \tag{1}$$

with piecewise linear characteristic

$$h(x_1) = m_5 x_1 + \frac{1}{2} \sum_{i=1}^{5} (m_{i-1} - m_i)\,(|x_1 + c_i| - |x_1 - c_i|) \tag{2}$$

[1] Competition data available at http://www.esat.kuleuven.ac.be/sista/workshop/.

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with parameters $\alpha = 9$, $\beta = 14.286$ and for the vectors $m = [m_0; m_1; ...; m_{2q-1}]$, $c = [c_1; c_2; ...; c_{2q-1}]$ one takes

$$\begin{array}{rcl} m & = & [\,0.9/7\,;\,-3/7\,;\,3.5/7\,;\,-2.7/7\,;\,4/7\,;\,-2.4/7\,] \\ c & = & [\,1\,;\,2.15\,;\,3.6\,;\,6.2\,;\,9\,]. \end{array} \tag{3}$$

The generalized Chua's circuit has been simulated for initial state $[0.1; -0.2; 0.3]$ with a Runge-Kutta integration rule (ode23 in Matlab). The competition data have been obtained then by taking a nonlinear combination of the 3 state variables:

$$y = W \tanh(Vx), \tag{4}$$

where $x = [x_1; x_2; x_3]$ is the 3-dimensional state vector and the nonlinearity is a multilayer perceptron with 3 hidden units, interconnection matrices

$$W = \left[\begin{array}{ccc} -0.0124 & 0.3267 & 1.2288 \end{array}\right], V = \left[\begin{array}{rrr} -0.1004 & -0.1102 & -0.2784 \\ 0.0009 & 0.5792 & 0.6892 \\ 0.1063 & -0.0042 & 0.0943 \end{array}\right]$$

and a zero bias vector. This multilayer perceptron is hiding the underlying structure of the attractor. A picture from the scope of a 5-scroll attractor, generated by a real-life electronic circuit implementation [18], is shown in Fig.2.

The resulting time-series is shown on Fig.3: 2000 data points were given (data before the vertical line). The aim was to predict the next 200 data points. In Fig.1 we have marked with a star the data points that correspond to the competition data. One can observe that the 2000 data points cover the whole attractor, i.e. the 5 scrolls. Within these 200 data points a transition between scrolls is taking place.

3. Best Results

In total, 17 entries have been submitted for the competition, taking into account the deadline for submission. The winning contribution is made by *James McNames* [6, 7]. The strategy incorporates a weighted Euclidean metric and a novel multistep cross-validation method to assess model accuracy. A nearest trajectory algorithm is proposed as an extension to fast nearest neighbor algorithms. The second best result has been obtained by Hugues Bersini [2], using lazy learning which selects a local model representation by assessing and comparing different alternatives in cross-validation.

4. Conclusions

We discussed the competition data of the K.U. Leuven time-series prediction contest. The data set is a challenging test-case for advanced nonlinear modelling techniques including neural networks. It is able to reveal shortcomings of sub-optimal approaches and is requiring from a given nonlinear modelling technique to reach its limits of performance.

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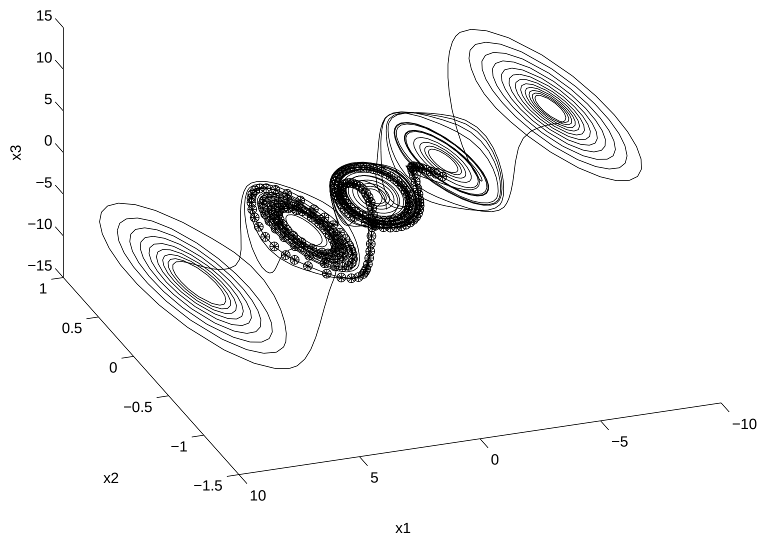

Fig.1: *Computer simulated 5-scroll attractor from which the competition data have been generated. The marked part of the trajectory corresponds to the data that have to be predicted.*

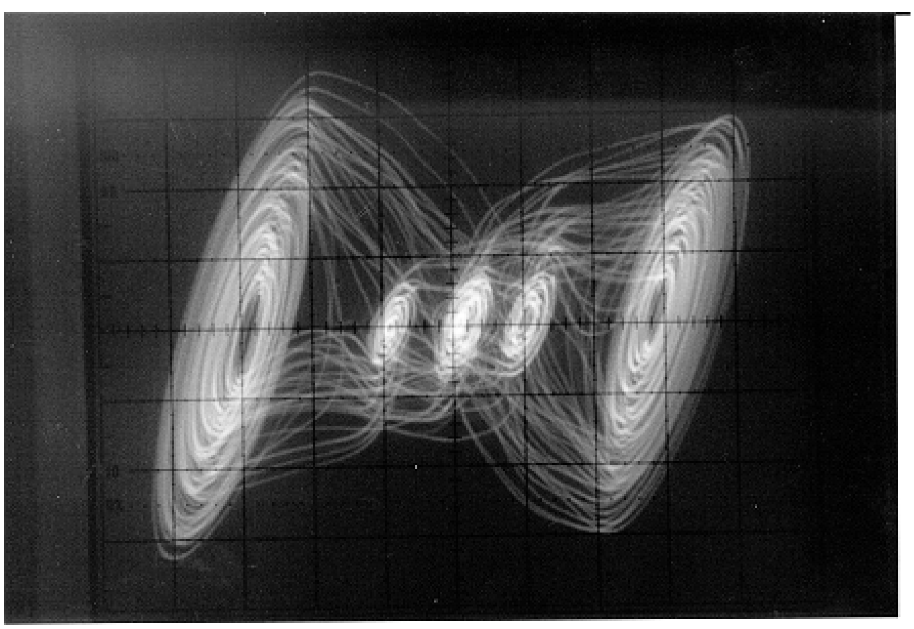

Fig.2: *Picture from the scope of the 5-scroll attractor generated by a real-life electronic circuit implementation.*

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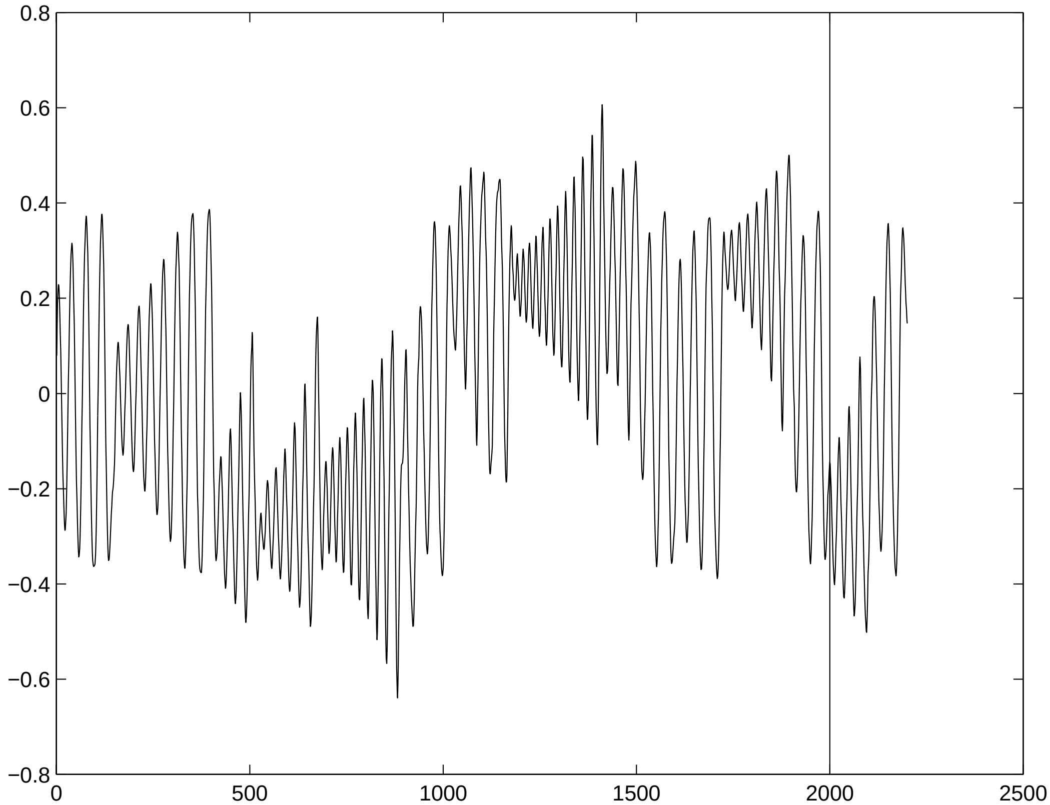

Fig.3: *Competition data: shown are the 2000 given data points (before vertical line) together with the 200 points to be predicted.*

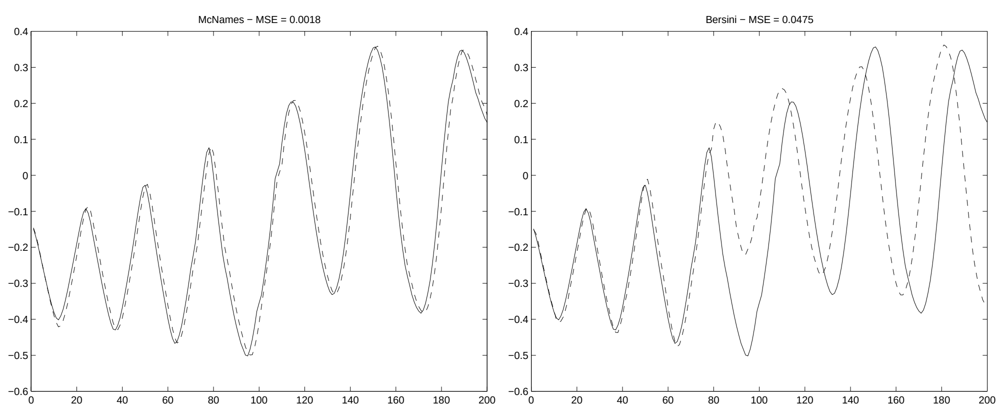

Fig.4: *200 Points to be predicted (full line): (Left) Winning entry by McNames; (Right) Second best result by Bersini.*