Project Proposal: A Comparative Analysis of Machine Learning Models for Predicting the Lorenz System

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1 Project Topic

This project focuses on a comparative analysis of various machine learning models for predicting the behavior of the Lorenz system, a chaotic dynamical system. The Lorenz system, described by a set of three nonlinear differential equations, exhibits sensitive dependence on initial conditions and is widely used to model atmospheric convection. The goal is to evaluate how well different ML models can forecast its trajectories, particularly in capturing chaotic dynamics over short and long prediction horizons.

2 Key Research Questions

- How do different machine learning models, such as regression, recurrent neural networks (e.g., LSTM), and physics-informed neural networks (PINNs), perform in predicting the short-term and long-term states of the Lorenz system?
- What are the strengths and limitations of each model in handling the chaotic nature of the system, as measured by metrics like mean squared error (MSE) and root mean squared error (RMSE)?
- what are the theoretical explanations for the observed metrics?

3 Planned Methodology

The methodology will involve the following steps:

1. Simulate the Lorenz system using Python's SciPy library to generate a dataset of trajectories with standard parameters values
2. Divide the data into training, validation, and test sets. Ensure adequate data is allocated for training.

3. Implement and train selected ML models using standard python libraries such as TensorFlow, Keras, or JAX.
4. Evaluate model performance using quantitative metrics (MSE, RMSE) and qualitative visualizations (phase space plots).
5. Persist and compare the results using jupyter notebooks for ease of presentation.

A search on Google Scholar revealed relevant works, including data-driven predictions using neural networks [Dubois et al.(2020)Dubois, Gomez, Planckaert, and Perret] and physics-informed approaches [Kashyap et al.(2024)Kashyap, Dandekar, Dandekar, and Panat], which will guide the implementation and help explain the variances in results.

4 Github Repository

The project will be tracked using a GitHub repository: `https://github.com/RC1092/MATH_2130_project2`.

References

[Dubois et al.(2020)Dubois, Gomez, Planckaert, and Perret] Pierre Dubois, Thomas Gomez, Laurent Planckaert, and Laurent Perret. Data-driven predictions of the lorenz system. *Physica D: Nonlinear Phenomena*, 408:132495, 2020. ISSN 0167-2789. doi: https://doi.org/10.1016/j.physd.2020.132495. URL `https://www.sciencedirect.com/science/article/pii/S0167278919307080`.

[Kashyap et al.(2024)Kashyap, Dandekar, Dandekar, and Panat] Sameera S Kashyap, Raj Abhijit Dandekar, Rajat Dandekar, and Sreedath Panat. Modeling chaotic lorenz ode system using scientific machine learning, 2024. URL `https://arxiv.org/abs/2410.06452`.