Turbulence state modelling using Machine Learning for fusion plasmas, De Vinci Research Center, Paris

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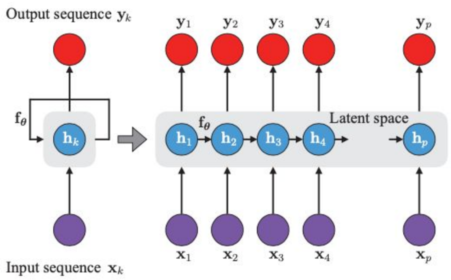
- Like in a predator-prey ecosystem, a system of ODEs can model turbulence and zonal flows occurring in tokamak plasmas [1]
- The system of ODEs is nonlinear and exhibits chaotic behavior
- Neural networks excel at predicting nonlinear patterns from data
- We can use neural networks for **future state predictions** of dynamical systems [2]

$$\frac{dx}{dt} = f(x, \lambda)$$

$$x_{k+1} = x_k + \Delta t\, f(x_k, \lambda)$$

$$x_{k+1} = x_k + \Delta t\, g_\theta(x_k, \lambda; \theta)$$

- Recurrent Neural Network diagram [2]



[1] *Chen, L., Lin, Z., & White, R. (2000). Excitation of zonal flow by drift waves in toroidal plasmas. Physics of Plasmas, 7(8)*
[2] *Brunton, S. L., Kutz, J. N. (2022). Data-Driven Science and Engineering : Machine Learning, Dynamical Systems, and Control (2nd ed.). Cambridge : Cambridge University Press*

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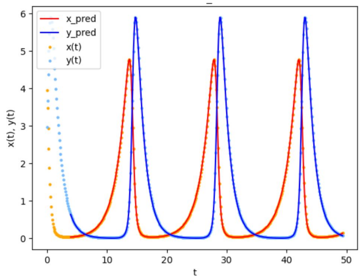
Proof of concept

Lotka Volterra system

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = -\gamma y + \delta xy$$

Example state prediction by Recurrent Neural Network



Recurrent Neural Network and Sliding Window

$$g_\theta : R^{7\times T} \to R^2$$

$$\hat{y}_t = g_\theta(X_t)$$

$$X_{t+1} = concat(x_{t-T+2}, x_{t-T+3}, \ldots, x_{t+1})$$

$$\hat{y}_{t+1} = g_\theta(X_{t+1}), \quad where \quad X_{t+1} = [x_{t-T+2}, \ldots, x_{t+1}]$$

Data Formatting

RNN input: $\mathbf{X} \in R^{7\times T}$: $[x(t),\, y(t),\, \alpha,\, \beta,\, \gamma,\, \delta,\, t]$

RNN output: $[x(t+1),\, y(t+1)] \in R^2$