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Neural Network Based Representation of Time-Delay System Models

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Abstract:

Time delay models have proved useful in many application areas, from distributed parameter systems and systems with transportation delays to supply chain management, population dynamics, and networked and multi-agent systems. A mathematical description of time-delay systems (TDS) has been introduced via a functional generalization of ordinary differential equations. Conventional modeling and identification approaches usually assume a priori knowledge of a model structure (order, number of time delays, nonlinear parts, etc.). However, in many cases, no a priori information is provided, and making blind assumptions might be a dull way. Therefore, more complex models are often used. Neural networks (NNs) can be used to learn dynamic systems and efficiently simulate their dynamics. For instance, neural ordinary differential equations (NODEs) express the right-hand side of the differential equation, while the evolution of the network over a given period provides the map from the initial condition to the terminal state. Time delays can also be incorporated into NNs. Delays can either be fixed or considered within the trained parameter set. A suitable approximation can transform a delay differential equation to an ordinary differential equation, enabling the direct use of a NODE.

A doctoral student in their dissertation thesis should use NODEs and/or NDDEs to represent continuous-time or discretized TDS. Weights, biases, and delays within the NN can be estimated using several parameter-optimization methods, which can be benchmarked. Besides, the student may consider various discretization techniques for continuous-time-delay models (e.g., semi-discretization, full-discretization, and partial spectral discretization). In addition, as the NN representation of the so-called universal differential equations has proven efficient for large-scale systems, the student may attempt to extend this approach to systems with delays.

Literature:

[1] HALE, Jack K. and VERDUYN LUNEL, Sjoerd M. Introduction to Functional Differential Equations. Springer, 2013.

[2] JI, Xunbi A. and OROSZ, Gábor. Learning time delay systems with neural ordinary differential equations. IFAC-PapersOnLine. 2022, vol. 55, no. 36, pp. 79-84. ISSN 2405-8963. DOI: 10.1016/j.ifacol.2022.11.337.

[3] KOCH, James; CHEN, Zhao; TUOR, Aaron; DRGOŇA, Ján and VRABIE, Draguna. Structural inference of networked dynamical systems with universal differential equations. Chaos An Interdisciplinary Journal of Nonlinear Science. 2023, vol. 33, no. 2, art. no. 023103. ISSN 1054-1500. DOI: 10.1063/5.0109093.

[4] LEGAARD, Christian; SCHRANZ, Thomas; SCHWEIGER, Gerald; DRGOŇA, Ján; FALAY, Basak et al. Constructing neural network based models for simulating dynamical systems. ACM Computing Surveys. 2023, vol. 55, no. 11, pp. 1-34. ISSN 0360-0300. DOI: 10.1145/3567591.

[5] MOU, Qianying; YE, Hua and LIU, Yutian. Enabling highly efficient eigen-analysis of large delayed cyber-physical power systems by partial spectral discretization. IEEE Transactions on Power Systems. 2019, vol. 35, no. 2, pp. 1499-1508. ISSN 0885-8950. DOI: 10.1109/tpwrs.2019.2936488.

[6] STELZER, Florian; RÖHM, André; VICENTE, Raul; FISCHER, Ingo and YANCHUK, Serhiy. Deep neural networks using a single neuron: folded-in-time architecture using feedback-modulated delay loops. Nature Communications. 2021, vol. 12, no. 1, art. no. 5164. ISSN 2041-1723. DOI: 10.1038/s41467-021-25427-4.

[7] ZHANG, Xiaobo; XU, Xiangguo and ZHU, Yuxian. An improved time delay neural network model for predicting dynamic heat and mass transfer characteristics of a packed liquid desiccant dehumidifier. International Journal of Thermal Sciences. 2022, vol. 177, art. no. 107548. ISSN 1290-0729. DOI: 10.1016/j.ijthermalsci.2022.107548.

[8] ZHU, Qunxi; SHEN, Yifei; LI, Dongsheng and LIN, Wei. Neural piecewise-constant delay differential equations. Proceedings of the AAAI Conference on Artificial Intelligence. 2022, vol. 36, no. 8, pp. 9242-9250. ISSN 2159-5399. DOI: 10.1609/aaai.v36i8.20911.