Fast Machine Learning for Science
Imperial College London
Real-time and accelerated ML for fundamental sciences
25-28 September 2023

Contribution ID: **57** Type: **Standard Talk**

Deep Spectral Networks: Enhancing Orbit Propagation and Determination in Astrodynamics

Tuesday 26 September 2023 13:30 (15 minutes)

The field of Astrodynamics faces a significant challenge due to the increasing number of space objects orbiting Earth, especially from recent satellite constellation deployments. This surge underscores the need for quicker and more efficient algorithms for orbit propagation and determination to mitigate collision risks in both Earth-bound and interplanetary missions on large scales. Often, serial finite-difference-based schemes are the method of choice for solving such initial and boundary value problems. However, as the complexity of the physical model increases, these methods rapidly lose efficiency due to their high number of function calls. While iterative solvers, such as the Modified-Chebyshev-Picard Iteration (MCPI), have shown increased performance for simple propagation problems, this drops for highly nonlinear problems over large time spans, in which large numbers of iterations are required for convergence. This work introduces a mathematical framework for quantifying non-linearity in first-order ODE systems using their Jacobian matrix and presents a new time-parallel iterative method based on the spectral-element approach for solving them. The novelty of this method lies in its mitigation of the nonlinear effects of ODEs through the regularization of the dependent variable with the Frobenius norm of the Jacobian matrix, which results in an optimal time coordinate transformation that minimises the spectral error. To compactly represent this coordinate transformation, a layered, Neural-Network-like architecture is employed using Chebyshev polynomials as activation functions, coined as a "Deep Spectral Network"(DSN). Unlike classical Neural Networks that use an iterative forward and back-propagation process for training, this DSN leverages the orthogonality of Chebyshev polynomials to sequentially construct new layers based on previous coefficient values. The performance of the Deep Spectral Network method is assessed for the Cartesian and modified-equinoctial element formulations of the perturbed two-body problem, against the Runge-Kutta 4(5) and Dormand-Prince 8(7) integrators for orbits of various eccentricities. The DSN achieves a 70x/40x function call speed-up compared to the state-of-the-art serial finite-difference methods. Furthermore, parallel CPU time speed-ups of up to 8 are achieved with multi-threading, for an implementation in the Julia 1.9.1 language.

Authors: Dr AMATO, Davide (Imperial College London, Department of Aeronautics, Lecturer); ANTON, Sabin (Imperial College London, Department of Aeronautics, Postgraduate Student)

Presenter: ANTON, Sabin (Imperial College London, Department of Aeronautics, Postgraduate Student)

Session Classification: Contributed Talks

Track Classification: Contributed Talks