Chapter 1
An Application of Deep Neural Network Using GNS for Solving Complex Fluid Dynamics Problems

Pamir Roy
North Eastern Regional Institute of Science and Technology, India

S. K. Tamang
http://orcid.org/0000-0001-6000-8088
North Eastern Regional Institute of Science and Technology, India

Samar Das
Indian Institute of Technology, Guwahati, India

Thanigaivelan Rajasekaran
http://orcid.org/0000-0001-9514-9120
AKT Memorial College of Engineering and Technology, India

ABSTRACT

The present work investigates the possibilities of solving complex fluid dynamics problems using Navier-Stokes equations, through simulation based techniques using deep neural networks in real time and along with provision of a singular architecture that achieves cutting-edge performance while maintaining a very high accuracy and precision at par with ground truth. The study employs Graph Network-based Simulators (GNS) to compute system dynamics. The developed model shows robust behavior in its prediction giving prediction accuracy of around 99%. The model generalizes well from unit-timestep predictions with huge number of particles at

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training phase, to completely differing starting conditions for timesteps ranging into the thousands and with even more particles at test time. Based on GNS, the model is immune to choices of hyper parameters over differing metrics for evaluation. The proposed model shows that deep learning is effective for solving a large set of complex fluid dynamics related problems in both forwards and backwards in time.

INTRODUCTION

In this modern era, the focus for solutions of complex fluid flow problems are encountered frequently in fluid dynamics and has shifted from pure numerical and analytical approach to realistic simulations based solutions. These simulations prove to be precious to many problems of science and engineering concerning various disciplines. But these traditional simulators prove to be highly costly to develop and use. For building a robust simulator, it demands high time in years towards engineering effort and quite hast to make trades-offs in generality for precisions and accuracy in a narrow settings range. Often the resulting simulation requires high computing resources for high quality solution and thus prevents from scaling up efficiently. All these methods also suffer from inaccuracy due to approximation or incomplete capturing of the underlying physics. Moreover, all these are not real-time simulators.

As such, the researchers have been trying to find a way to tackle such situations. A lucrative solution would be an intelligent system that knows completely the underlying physics and can provide high quality simulations in real time. This calls for machine learning by training directly from observed data. But due to huge state spaces and highly complex dynamics standard approaches become infeasible.

Another obstacle for scaling up such a system was the need for highly parallel system that is not only quick but also accurate. The main issue in this way of scaling up was that for fluid being represented as a particle system, each particle is affected by nearby particles which are affected by their nearby particles and likewise, owing to which the interaction detail representation of the system blows up with increase in the number of particles for maintaining same level of quality. For that an efficient way of just passing the necessary information from nearby particles to the particle in focus is needed. This is solved by implementing message passing graph architecture for representing the system using GNS. It enables to deploy a single deep learning model which could accurately learn simulation of a wide set of fluid dynamics systems that can provide for fluid-fluid, fluid-deformable materials-rigid solids to interact with each other while being highly parallelizable. It can generalize well for larger systems with higher time steps than that was used to train it. It is free from inductive biases for spatial invariance and accumulation error over long simulation trajectories.

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