Machine learning

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Artificial intelligence for weather forecasting

Medium-range weather prediction – forecasts up to 15 days – is crucial for science and society. However, traditional methods that rely on the weather-governing physics equations translated into algorithms are time consuming, laborious and costly, resulting in speed-accuracy trade-offs.

Now writing in *Science*, Remi Lam et al. present an alternative weather forecast system, GraphCast, that harnesses machine learning and graph neural networks (GNNs) to process spatially structured historical data. "GraphCast learns from four decades (1979–2017) of curated atmospheric data provided by the European Centre for Medium-Range Weather Forecast (ECMWF), finding patterns in the weather that it can then exploit to make forecasts," says Alvaro Sanchez-Gonzalez, one of the authors of the paper. GraphCast models the Earth using a GNN over a uniform mesh around the Earth surface. The inputs are the current weather state and the state six hours earlier; the output is the weather six hours ahead.

Until recently, medium-range forecasting had been facilitated by WeatherBench 1, which provided training and verification data at low resolution. The primary goal of the researchers was to demonstrate the potential impact of this model. It turned out that it was possible to extend the resolution of WeatherBench 1, leading to the development of GraphCast. Substantial verification efforts to evaluate GraphCast against operational models across various metrics and applications followed. The release of an improved WeatherBench 2 benchmark is expected to further enhance progress in evaluating this type of model.

Operating at a high resolution of 0.25° longitude/latitude grid (roughly 28 × 28 km resolution at the equator) and thus covering over 1 million grid points, GraphCast predicts several Earth-surface and atmospheric variables – temperature, wind speed and direction, mean sea-level pressure, specific humidity, and more – with high accuracy. Despite the computationally intensive training (about 4 weeks on 32 Google TPU v4 machines), the method is highly efficient, producing 10-day forecasts in less than one minute on a single TPU. In comparison, gold-standard deterministic methods such as ECMFW's high resolution forecast (HRES) can take hours on a supercomputer with hundreds of machines. Moreover, GraphCast outperforms HRES on over 90% of test variables and forecast lead times, reaching 99.7% accuracy in the troposphere – a crucial atmospheric layer because it is the closest to the Earth's surface and the one that affects our lives the most.

"Our goal was to show real-world impact, and early results hinted that we could potentially scale-up our approach to work at the resolutions required for GraphCast to become a competitive operational model," continues Sanchez-Gonzalez. GraphCast is now recognized as the world's most accurate 10-day global deterministic weather forecasting system, extending the prediction horizon for extreme weather events, including extreme temperatures, cyclones and floods, aiding in and planning emergency responses.

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To enhance accessibility, the code for GraphCast has been open-sourced, with ECMWF already experimenting with the 10-day forecasts. Pioneering artificial intelligence (AI) in weather forecasting aims to benefit billions of people in their daily lives by empowering the global community to address environmental challenges. "One of the greatest advantages of AI systems is that they learn from data. GraphCast was trained using atmospheric data, so it learned to predict the evolution of the atmosphere. You could imagine training GraphCast with other data – for example, agricultural data to predict harvests; ecology data to predict deforestation and biodiversity; and also renewable energies, or even road traffic," concludes Sanchez-Gonzalez.

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