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Giving AI geometric awareness allows it to better understand the world

Artificial intelligence is becoming increasingly vital to everyday activities across diverse sectors of society, from AI assistants to autonomous vehicles to healthcare. But the way these systems are trained doesn't provide them with a conceptual framework like humans use to make sense of the world. This disconnect poses serious risks of failure and raises many concerns about AI use.

Professor Paul Atzberger's group at UC Santa Barbara is tackling these challenges by developing new ways to incorporate common-sense knowledge about the world into AI systems. His recent work with graduate student Blaine Quackenbush has been focused on geometric understanding.

“We're leveraging concepts from mathematics and differential geometry so these AI algorithms see the data as more than just a collection of floating points,” explained Atzberger, a professor of mathematics and mechanical engineering. “This provides awareness of the cohesive whole, with interconnected parts made up of edges, curved surfaces and other forms.”

The result is a more robust AI with applications across research and industry. They just released version 2.0 of an easy-to-use, open-source Python package. This can be found, along with a collection of technical papers, on the group's GitHub page.

The conceptual challenge

Current AI training encourages models to look for patterns in large datasets so they can obtain answers that look good when they are quizzed. As a result, these systems can be quite adept at recognizing things similar to what they've seen in their training. However, anything significantly different can give them trouble, limiting how useful they are in novel applications.

AI models generally don't have an innate sense of geometry — things like the arc-length of a curve or the curvature of a surface — Atzberger explained. Instead, they often rely on general patterns in the overall shape or even the arrangements of specific points in the data. This creates all kinds of problems.

Atzberger's group remedied this by developing new types of neural networks and training approaches that allow AI to learn fundamental geometric properties from its training data. Their architecture further tackles the problem by taking a more continuous approach than current neural networks. Whereas traditional systems take in a sample of distinct data points, their model treats this data as samples from some underlying function. Operating on these continuous functions makes the AI agnostic to how shapes are represented using discrete points.

AI foundations for geometric intelligence

The result is an AI that sees the world more like a geometer and less like a calculator. “It's basically what's referred to as a Geometric Neural Operator, or GNP for short,” Atzberger said. Since points are mapped to functions, the algorithm will return similar results no matter how you sample or organize the data. This makes it robust against noise and other methodological variations. And by using geometric properties instead of general patterns, it can handle shapes that are very different from what it saw during its training.

Image

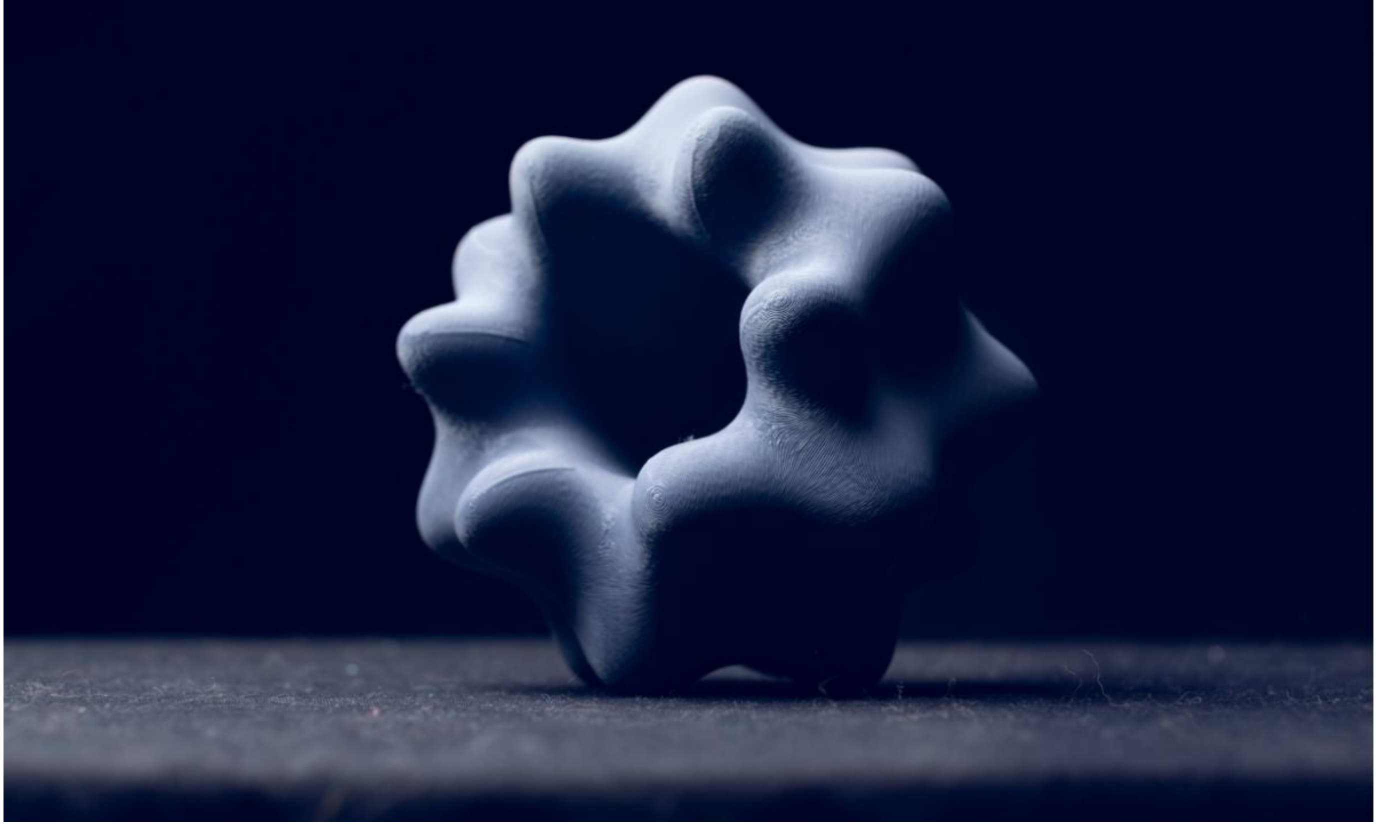

Photo Credit
Matt Perko
Atzberger's AI will be able to understand the curved surface of an object as more than merely a collection of points.

This opens up exciting possibilities for tackling problems where geometry poses an obstacle. "In some cases, we've found you can even use GNPs to avoid the tedium of handcrafting complicated codes," Atzberger said. In one paper, they showed how a GNP can solve heat transport problems on intricately shaped surfaces, avoiding weeks of tedious programming.

Users can feed it any point cloud representation of a surface and it will return curvature, metrics or other geometric properties in a way that's robust to noise, like the shagginess of a lawn or the roughness of a hillside. "No data is ever pristine," Atzberger said. The system can also operate in reverse, identifying an object's shape based on measurements. It can even be extended to tackle problems beyond surfaces to 3D or higher dimensional spaces.

To save others from having to train models from scratch, Atzberger's group has released the weights for using their pre-trained AI. These can be used as foundation models for geometry in new or existing data processing pipelines. Those wanting a quick introduction can see the JupyterNotebooks on their GitHub website. Even people without a strong background in computer programming can leverage the architecture with the help of an AI assistant.

Atzberger envisions a wide array of possible applications for their geometric neural operators. The architecture can help in designing engineered parts that have lots of constraints, such as optimizing heat propagation in thin materials like cooling fins. The methods also could help in modeling and speeding up complex physical simulations, such as transport in biological systems like cell membranes or in fluid flows around complicated shapes. There are many possible applications ranging from physics to biology to engineering.

The group is currently working to extend their methods for use in computer aided design (CAD), processing LIDAR data, and applications in computational physics simulations. "We want people to be able to easily make use of the techniques and the codes," Atzberger said. "It's great seeing this work have an impact out there on interesting real-world applications."

Toward safer and more trustworthy AI

"Current AI techniques are primarily a 'black box'," Atzberger said. "When they work, that's great. But when they fail, it's often hard to find the cause." By providing these systems with conceptual frameworks the group aims to help make AI systems more transparent and safe.

This becomes increasingly crucial as AI algorithms manage more tasks in the modern world — permeating into new sectors of society, matters of health and equity, and in areas with legal liabilities. Sharing a semantic model of the world with these AI tools is an important step in mitigating potential negative impacts and enabling us to audit their decision-making processes.

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