The Dragonfly Wing Project

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Nature has always been the master of design skills to which humans only aspire, but new approaches bring that aspiration closer to our reach than ever before.

Through 4.5 billion years of iterations, nature has shown us its extraordinary craftsmanship, breeding a variety of species whose body structures have gradually evolved to adapt to natural phenomena and make full use of their unique characteristics. The dragonfly wing, among body structures, is an extreme example of efficient use of materials and minimal weight while remaining strong enough to withstand the tremendous forces of flight. It has long been the object of scientific research examining its structural advantages to apply their principles to fabricated designs.[1] We can imitate its form and create duplicates, but thoroughly understanding the dragonfly wing's mechanism, behaviour and design logics is no trivial task.

Deciphering Nature

Among recently developed AI approaches, two that had not previously been used to analyse the geometric formation of this natural structure offered intriguing possibilities: a geometry-based equilibrium method called graphic statics for structural analysis; and machine learning for rule summarisation. To explore these possibilities, the Dragonfly Wing Project at the University of Pennsylvania's Polyhedral Structures Laboratory has used graphic statics to analyse the structural features of the convex-only networks of a dragonfly wing, and created a related dataset for machine learning.

The dataset contains the morphological form and topological force diagrams of dragonfly wings as images, and represents the corresponding edge lengths as vectors. It then trains the machine-learning model, which maps the connections between the morphology of the wing and the structural topology of its convex-only network. From this mapping, the trained machine-learning model can generate similar internal structures for any given morphological boundary.

After successfully learning the features of the dragonfly wing, the same method was applied to analyse structures from other species, including grasshopper wings, damselfly wings and Amazon water lilies. Surprisingly, the project shows that graphic statics provides the necessary features to analyse all of these lightweight structures, and the resulting data can be used to train machine-learning models. Not only does this method generate structural geometries similar to the original species, but it also successfully predicts the thickness of the bodily structures.

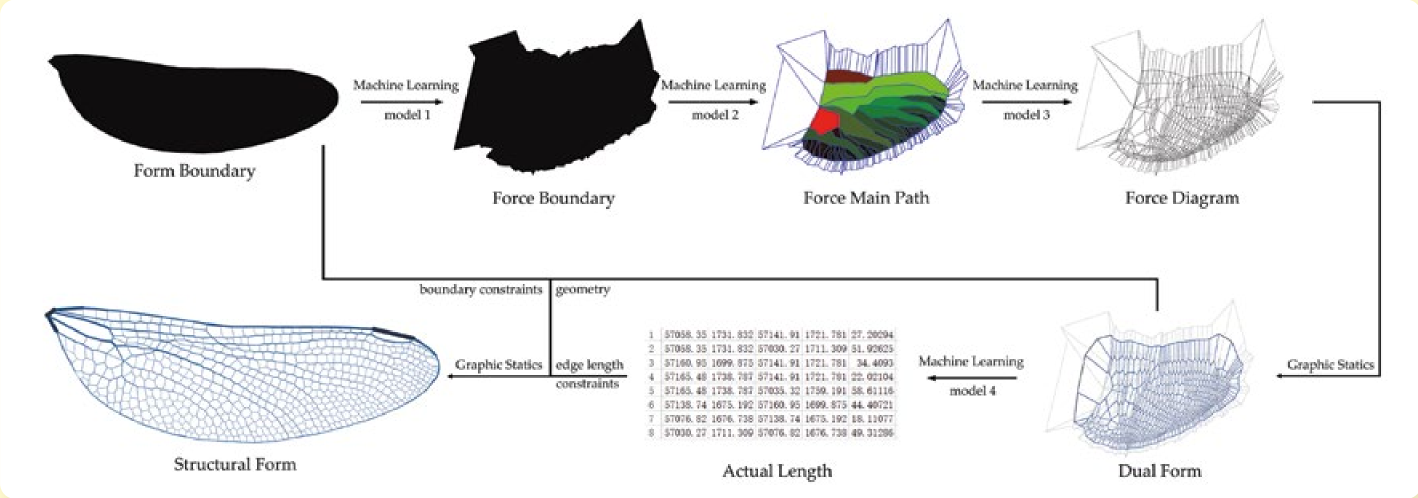
Trained by Nature

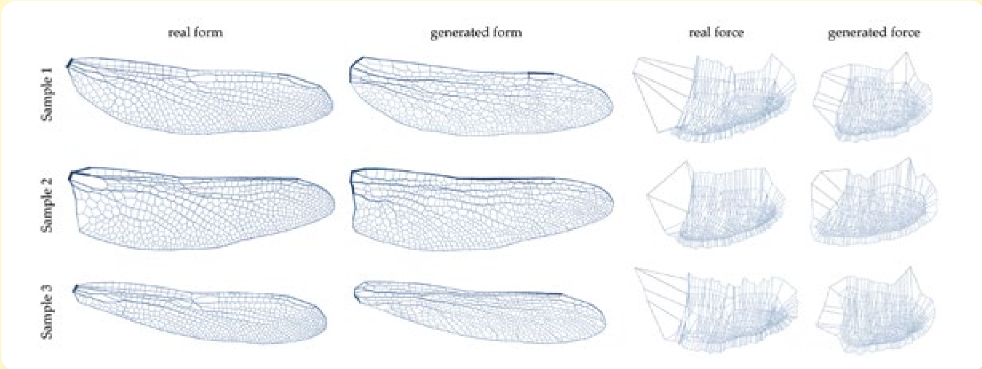
The results enable application of the design logic of a dragonfly wing to an efficient design method for other manufactured structures with similar performance needs; for example, the internal structure of an aeroplane wing. Using the boundary of a conventional aeroplane wing, the new approach can generate an internal structure based on the machine-learning training model of the dragonfly wing. The generated structure can then serve as an internal lightweight structure for an aeroplane wing, bringing the design logic of a highly efficient dragonfly wing to human-designed aircraft. Although the mechanical behaviour of this kind of generated structure calls for further research, multiple other varieties of architectural structures can be generated using this method.

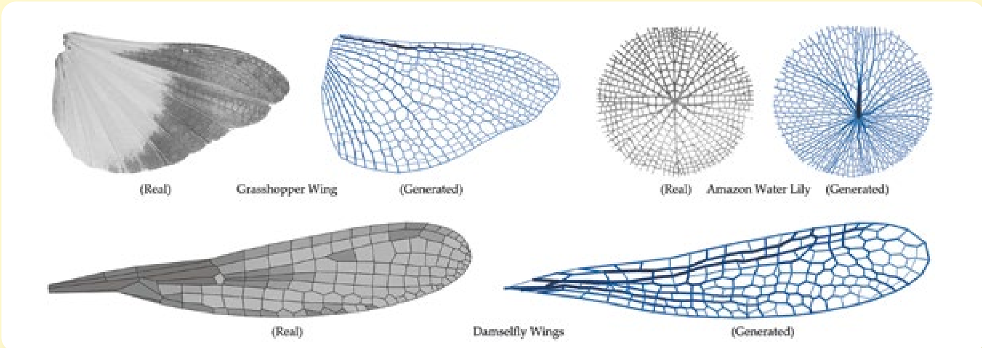
The Dragonfly Wing Project opens a door to other related investigations, where training machine-learning models based on datasets derived from natural species can transfer design knowledge from nature to similar human structures. This approach may improve our understanding of various design parameters needed to craft human-made systems dealing with similar boundary conditions and enhance the performance of human designs.[2]

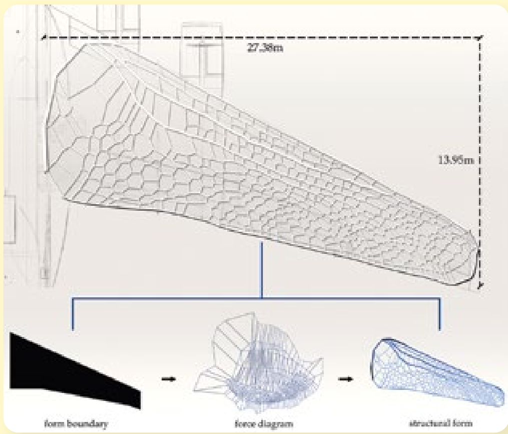
Notes

1. See Praveena Nair Sivasankaran *et al*, 'Static Strength Analysis of Dragonfly Inspired Wings for Biomimetic Micro Aerial Vehicles', *Chinese Journal of Aeronautics* 29 (2), 2016, pp 411–23, and Yunluo Yu *et al*, 'A Dragonfly Wing Inspired Biomimetic Aerodynamic Thrust Bearing for Increased Load Capacity', *International Journal of Mechanical Sciences* 176, 15 June 2020, 105550.
2. See Hao Zheng, Vahid Moosavi and Masoud Akbarzadeh, 'Machine Learning Assisted Evaluations in Structural Design and Construction', *Automation in Construction* 119, November 2020, 103346, and Hao Zheng and Philip F Yuan, 'A Generative Architectural and Urban Design Method Through Artificial Neural Networks', *Building and Environment* 205, November 2021,108178.









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first: The workflow generates the structural form from its boundary using machine-learning models trained with design data from nature – for example, dragonfly wings – and the graphic statics method for the transformation between the geometry and the topology of the structure.

second: The generated structures are highly similar to real dragonfly wing structures.

third: Using the same workflow, the project trained three different machine-learning models with datasets of grasshopper wings, Amazon water lilies and damselfly wings. The image compares the real and generated structures.

fourth: By inputting the boundary of an aeroplane wing, the new method can generate the interior structure through the machine-learning models trained on dragonfly wing datasets. The image shows a prospective design scenario for this AI-assisted workflow.