Learning from biology to accelerate discovery

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Dew on a spider's web in the morning. Credit: Wikipedia/Luc Viatour/Lucnix.be

A spider's web is one of the most intricate constructions in nature, but its precious silk has more than one use. Silk threads can be used as draglines, guidelines, anchors, pheromonal trails, nest lining, or even food. And each use requires a slightly different type of silk, optimized for its function.

"Each type of silk has similar proteins, but they are synthesized differently," said Sinan Keten, assistant professor of mechanical and civil engineering at Northwestern University's McCormick School of Engineering. "Then the spider knows how fast to reel the silk to get different properties. Nature is smart. It can tailor a structure to get different mechanical properties."

Spider silk is one biological material that Keten discusses in his new paper "The role of mechanics in biological and bio-inspired systems," published in the July 6 issue of *Nature Communications*. Surveying everything from sea cucumbers and Venus flytraps to human muscles and trees, the review paper broadly explores the strategies that biology employs to create different functions and the mechanics at play within those functions. Discovering how and why biological systems attain desirable static and dynamic mechanical functionalities often reveals principles that inform new synthetic designs based on biological systems.

Coauthored by Philip LeDuc of Carnegie Mellon University, Keten's paper covers three themes: bottom-up assembly, multiscale and multiphasic organization, and the passive and active features found in different materials.

"We wanted to point out some of the overarching principles that many systems share," Keten said. "By understanding these and learning from biology, we can speed up discovery."

Much of the paper focuses on nanoconfinement, a major part of Keten's research. The term describes the ability to control the building blocks of a material at the smallest level in order to ensure specific properties. When a spider creates its dragline, for example, it spins silk faster than when its constructing a web. The crystals comprising the silk are smaller when it's spun faster, resulting in stronger material. When the crystals are larger, the silk is less structured and contains more defects.

Although Keten spent the early part of his career studying spider silk, he has more recently shifted his focus to cellulose in tree branches. "We see the same things in silk as we do wood," Keten said. "Small crystals are preferred to larger crystals. It call comes back to nanoconfinement, which is to make the material's building blocks small enough that you don't have defects and therefore get stronger features. Additionally, nanoscale building blocks give rise to more interfaces in materials where intriguing physical phenomena may emerge from the large surface of nanoparticles."

Funded by the Army Research Office, Keten's team discovered that, on the nanolevel, cellulose crystals are transparent and as tough as Kevlar. He suggests that these properties could be mimicked to develop bulletproof glass and goggles and uses computation to explore the best ways to arrange the crystals to achieve different properties.

"You never mimic the biological system one-to-one," Keten said. "Like flight, for example. We can learn about aerodynamics from birds, but we don't design an airplane like a bird. That also applies to spider silk, which is a very tough and strong material. We don't use the exact same building blocks to develop a tough, man-made material. We use other building blocks but arrange them using the same methods we learn from biology."

Provided by Northwestern University