TECHNOLOGY OBSERVER

Issue 2014-2015

NJIT
New Jersey's Science & Technology University

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"Nature uses human imagination to lift her work of creation to even higher levels."

-Luigi Pirandello

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New Jersey Institute of Technology (NJIT) is a public research university enrolling just over 10,000 students. The university offers bachelor's, master's and doctoral degrees in 126 programs through its six colleges: Newark College of Engineering, College of Architecture and Design, College of Science and Liberal Arts, School of Management, College of Computing Sciences, and Albert Dorman Honors College.

A top-tier research university, NJIT offers laboratories in 48 key areas of research and 20 state-of-the-art multidisciplinary centers. Research initiatives include life and healthcare science and engineering, nanotechnology, transportation, information everywhere, solar astrophysics, sustainable systems, and design.

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For more information, visit: **honors.njit.edu**

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LETTER FROM THE EDITORS

Dear Reader:

Biomimicry, the practical application of unique mechanisms found in nature to man-made designs, is an expanding field that is more necessary now than ever before. Technological breakthroughs have always solved existing problems in novel, more efficient ways. The multiple designs found in nature have withstood the test of time, lending themselves to scientific advances that would not be possible without imitating them.

We are truly excited to bring you the 2014-15 issue of the *Technology Observer*. There have been many topics tackled over the years, but perhaps none quite as uniform and simultaneously diverse as biomimicry. Taking models from living organisms, biomimicry in this issue is explored in applications ranging from bridge design to water filtration, from energy harvesting to information systems, from building ventilation to medical applications. This investigation not only showcases the imitation of natural processes, but also of social structures surrounding living organisms. Thus, the focus is not only on the microscopic, but also on the macroscopic. We hope that exploring this topic will give you a greater appreciation of advances in technology, while cultivating an interest in a venue of innovation that can be applied in any technological field you enter.

We would like to thank Dr. Dine, Assistant Dean for Student Programs, for his many contributions and hours of work in putting together this issue and every issue over the years. We also extend our sincere gratitude to Dean Passerini, Dr. Collins, Professor Wolf, and the Albert Dorman Honors College. Lastly, this issue of the *Technology Observer* would not have been possible without our team of dedicated editors and writers.

I hope you enjoy reading this issue of the *Technology Observer* as much as we enjoyed creating it.

Sincerely,

Jeremy Jen
Pooja Banginwar
Editors-in-Chief

LETTER FROM THE DEAN

Dear Reader:

If you are familiar with the prior editions of the *Technology Observer*, you will know that this is a publication founded, managed, researched, written, designed and edited by the Albert Dorman Honors College students. Honors volunteers work together in identifying a mainstream topic to explore; they research the topic and present it from many angles of observation; and conclude with interviews of faculty and other stakeholders who are experts in the selected theme.

This 13th edition follows the same format, except that it experiments with a new editorial approach featuring a larger number of brief articles enabling the inclusion of a greater variety of viewpoints within the same space. These articles, written by students at various stages of their undergraduate degree – from freshman to seniors – introduce the reader to a fundamentally important, and I would say "fun," topic: biomimicry. The articles can be read separately and selectively according to the reader's interests. Each writer did a great job at presenting a well-thought and user-friendly explanation of the word "biomimicry" in each short piece, thus creating the necessary context and seamlessly linking each topical investigation to the underpinning theme of the issue.

Let me start with addressing why biomimicry is fun. If you have ever seen a child exploring the world while chasing butterflies and beetles, following little ants in the linear path they so diligently assemble, climbing on trees or playing with the large leaves that capture tiny drops of water on their surface, you will identify with the suggestion that learning from nature is an incredibly fun experience. To a child, these encounters with the wonders of nature aren't necessarily a boring "learning" experience and may indeed be "fun." This issue of the *Technology Observer* reminds us that there is much to learn while having fun with nature. If we pause and observe the beauty and complexity of the environment, even an untrained eye will wonder how everything might work together so efficiently.

Of course, the scientific discoveries described in this issue are not the results of the observations of untrained eyes. They are the results of the work that multidisciplinary teams of scientists around the world have been conducting with sophisticated equipment, a significant amount of preparatory work, tireless dedication, and significant resources. However, these emergent studies and discoveries tell us that with the right infrastructure, as well as the right dose of imagination, the exploration of the elements of nature can hold the key to solving many of today's complex problems.

We have always used nature's wonders and benefits for medical discoveries, aeronautics and other inventions. In this issue, the "techie" reader will also find information on how observing ants' defensive behaviors can provide an approach to solving information security threats. However, the dominant biomimicry focus that the reader will find in this issue is that of sustainability. To live and prosper in an environmentally sustainable world we need to learn from nature. The desert beetle is teaching us how to collect water from fog by manipulating water molecules in the air. Following the patterns of the Namib beetle's specialized skin, we may be able to create materials that will facilitate access to water in arid environments. Leaf veins on trees can show us how to distribute energy efficiently and with enough redundancy to guarantee continuous access to power through dynamic re-routing. Although still in their nascent and high-investment stage of discovery, smart-grid systems that imitate nature can hold the key to better match the demand and supply of electrical power. Moving to solar power efficiency, we learn how the study of the structure of butterfly wings may further enable better capturing and filtering of solar energy.

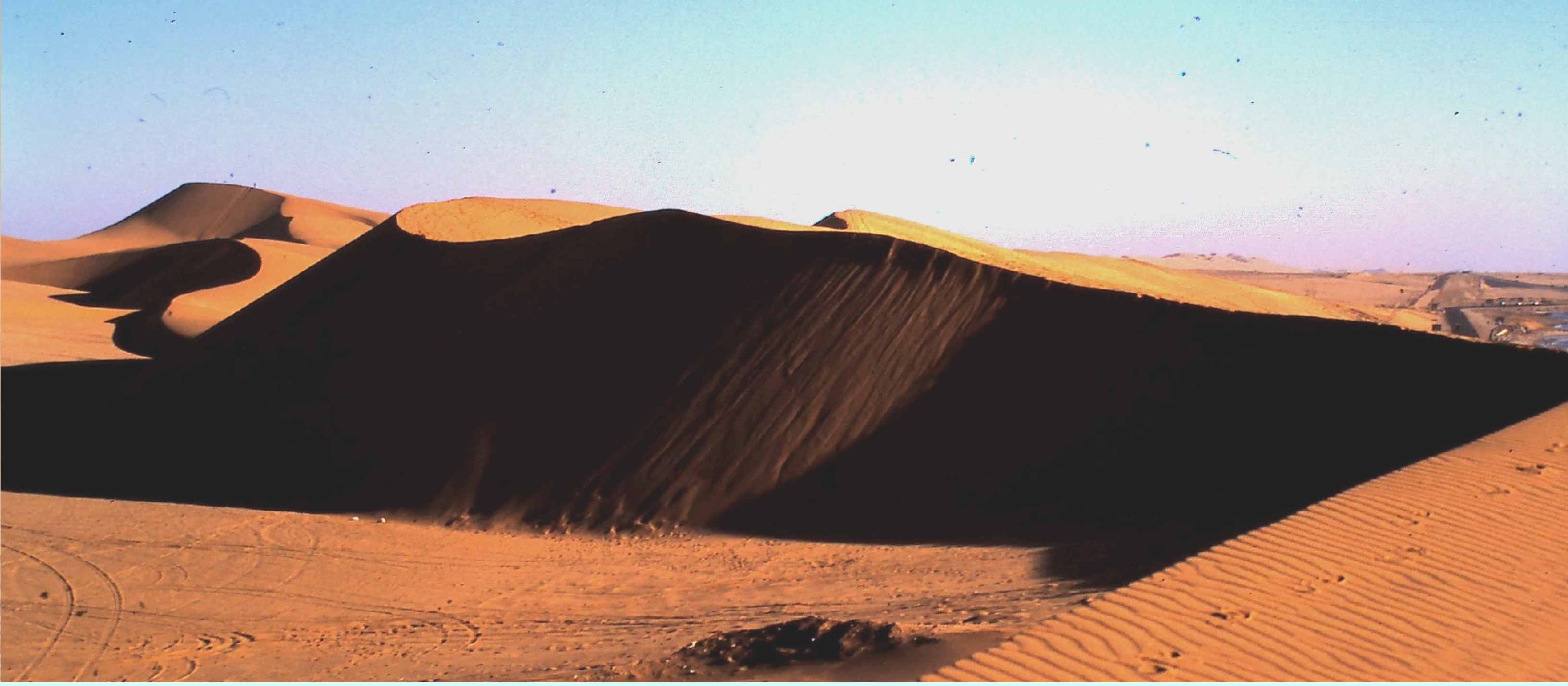
It is interesting to see that nature's self-healing principles can be applied to the "regeneration" of material structures (see "Self-healing polymers in everyday machinery") and findings on weight-bearing structures in the human body can inform principles for resilient physical infrastructures (see "Mimicking the femur bone to improve resiliency of built structures"). The application of natural principles as drivers of construction, ventilation systems and city planning, such as in the example of Lavasa, India's planned city, show the way forward. It is primarily through the alignment with nature's ecosystem that we may anticipate a sustainable allocation of scarce natural resources. After all, it only took a few billion years to perfect these systems.

As current and future Honors students and stakeholders, you now have an opportunity to study this enormous complexity. You can learn from mimicking nature or you can further work together to build new knowledge. It is fascinating to see the variety of approaches that each student in a different major took towards the exploration of a common theme. Every scholar aligned the topic with personal interests and know-how. Continuing these conversations across disciplinary boundaries is exactly what will enable us to progress in the race to a sustainable society.

Resiliency and sustainability are critical elements of our current work and hold the key to a better tomorrow. The Albert Dorman Honors College's new strategic plan (2014-2020) advocates and sets some targets for learning outcomes related to sustainability (environmental and beyond) because this is one of the fundamentally urgent issues that a planet with seven billion people (World Bank data, 2012) must cope with. The type of integrative thinking that is presented in this issue is what we wish the Honors Scholars will continue to engage in to build the future.

Most sincerely,

Katia Passerini, PhD, PMP
Professor and Hurlburt Chair of Management Information Systems
Interim Dean, Albert Dorman Honors College



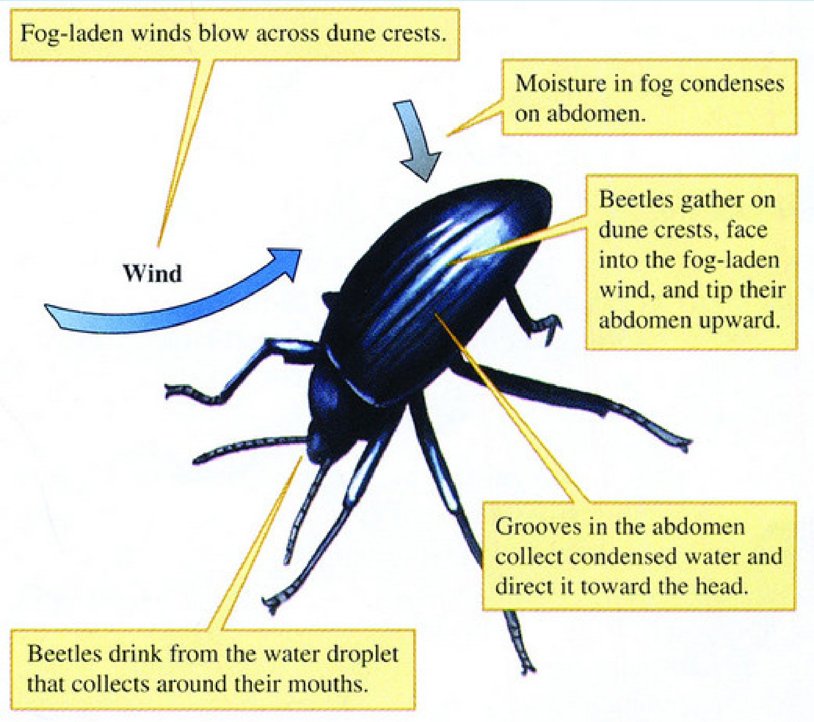
The Namib Desert Beetle: a Living Water Filter

Kevin Barretto

Deserts are known for their dry, waterless environments, which are usually sparce in life diversity. However, many years of evolution have driven one species of desert beetles to overcome even the harshest desert conditions. The Namib Desert Beetle is a native species of the Namib Desert, located on the southwest African coast. The primary source of water for this region comes from the Benguela current, which runs along the coast of the desert. This cold current occasionally provides an ocean mist that penetrates one hundred kilometers inland from the coastline.[1] The Namib Desert Beetle has evolved to take advantage of these early morning fogs caused by the Benguela current. A highly specialized surface on its abdomen is able to manipulate water molecules in the air so that a condensation reaction takes place, which allows the beetle to convert the fog into water.[2] Essentially, this trait allows the beetle to draw moisture from air and sustain itself without requiring water in liquid form.

To drink water, the Namib Beetle climbs to a high point that is usually the top of a sand dune. Using its long spiny hind legs, the beetle is able to tilt its body forward to a 45-degree angle. It then positions itself to face the incoming early morning ocean breeze. The specialized surface on its abdomen condenses the moisture in the air, forming water droplets that roll down the beetle and fall into its mouth.[3] It is common to see multiple beetles gather during the early desert morning fog to tap water from the air. This extraordinary product of evolution shows how intricately beautiful nature can be.

The specialized surface on the abdomen of the Namib Beetle is hard and bumpy. The bumps on its skin are lined with alternating hydrophilic (water-loving) and hydrophobic (water-fearing) regions that are microscopic in nature.[2] The hydrophilic areas of the specialized skin attract minute oncoming water droplets from the ocean breeze and cause them to condense instantly on the hard surface of the beetle. Waxy hydrophobic welds surround these hydrophilic areas, which keep the condensing water droplet in place while preventing it from being blown away by the wind. The hydrophobic welds also concentrate the water molecules in the hydrophilic area, enhancing the condensation process and increasing the mass of the forming water droplet. Once the mass of the water droplet is large enough to overcome the wind force and the resistance from the waxy hydrophilic ends, gravity allows it to slide down in-between the bumps, which guide it to the head of the beetle.[3]



This simple concept that has allowed the Namib Beetle to survive its arid climate has many significant features that make it highly efficient. For example, the entire process can occur without the use of pumps to collect or move water. The process is also passive, meaning it can happen without the input of energy. Another key factor is the applicability and diversity of environments where this process can occur. Any environment with wind and moisture can be a potential site to apply this specialized skin to collect water from the air.[4] Essentially, this type of environment can be found in most parts of the world, excluding regions with a climate colder then the freezing point of water.

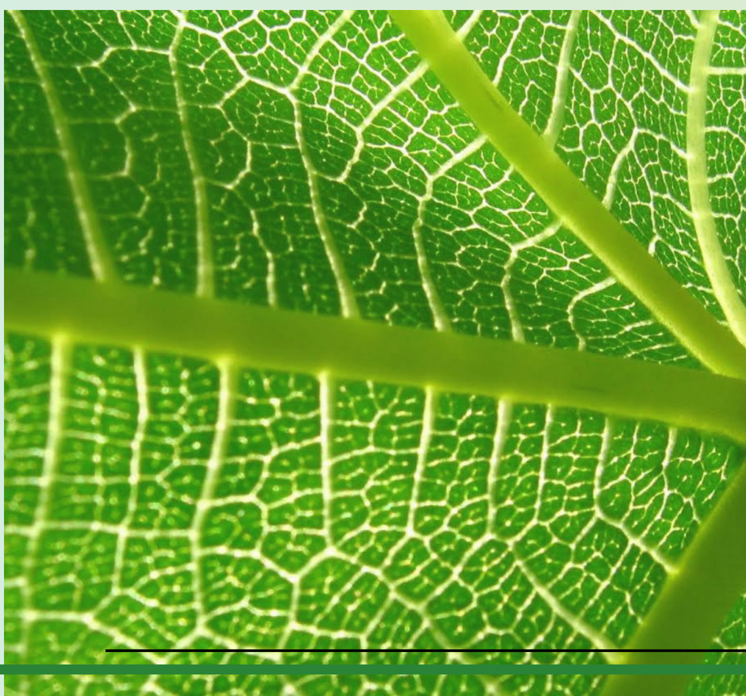
For this reason, many universities and research institutions are interested in the material that constitutes the back of the Namib Beetle. Utilizing emerging nanotechnology, researchers at MIT have created a similar material from synthesized plastic that has alternating areas of hydrophilic and hydrophobic regions. The material has several concept designs that have already been proposed. Some envisaged products that would utilize the beetle-inspired material include a self-filling water bottle, fog-free windows and mirrors, and a passive water purification and collection system that involves minimal energy input.[5] All of these ideas harness the ingenuity of the beetle's skin in a similar way. The goal is always to capture, store, and redistribute water. For example, the fog-free windows and mirrors would collect the condensed water in the hydrophilic regions, increasing the mass of the water droplet until it rolls down the window. The self-filling water bottle works in the same way, except it is itself able to collect the water for storage. An important factor and added benefit of note is the purity of the water, since it would not require filtration to be drinkable.[3]

Future developments over the next few years aim to industrialize this material in order to make it more accessible and practical for everyday use. For example, NBD Nanotechnologies is a company that intends to commercialize the material created by their research departments in order to make the products outlined above.[5] The fog-free windows and mirrors can be sold on cars, and the bottles can be mass-produced to use for humanitarian causes in underdeveloped countries where people have limited access to water due to an arid environment.[3] Even the United States military has plans for using this emerging technology, since evidence shows that it can be employed to clean up radioactive spills. With all these potential advancements in technology, it is remarkable to consider that the inspiration came from the humble yet beautifully complex adaptations of the Namib Desert Beetle.

Kevin Barretto *is a sophomore majoring in biology.*

Leaf Veins and Intelligent Distribution

Srihari Rao



The current paradigm implemented for electricity distribution networks resembles that of a tree, beginning with one trunk and branching off into separate nodes. The electrical engineers who designed the original frameworks by which we still power our world to this day decided that this linear model was, mathematically, the optimal model in terms of resource allocation and therefore cost efficiency. "[They] proved that the optimal branched networks are always mathematical trees, which contain no loops." [1] In this method of power distribution, the root or trunk of the tree is the source of electricity, and "branches" carry electricity to the nodes. These nodes can be houses, commercial buildings and the like. The underlying problem with this method is that when a specific branch gets "cut" (i.e. incurs a power outage), subsequent branches lose their ability to receive any electricity as well. As it turns out, however, the solution to this problem can be found by studying the distribution of nutrients in a tree. Looking at the leaves of a tree over time, instead of focusing only on the trunk and branch model, can provide a better understanding of the best way to deliver electricity to consumers.

Primitive trees from the past typically possessed vein structures that were very straight and had a more direct means of delivering nutrients. The veins on the leaves of these trees were arranged in a finger-like structure, in which the veins did not overlap but met at a common point at the base of each leaf. Modern trees tend to have leaves with a different vein structure that appears to be "loopy" in its construction. The veins of these leaves have a structure that resembles a web rather than extended fingers. Scientists, including Dr. Eleni Katifori from the Rockefeller University, have found that this leaf vein architecture is optimally constructed to handle nutrient absorption and delivery "on demand". Furthermore, the redundancy of pathways in the loops allows nutrients to be delivered to other parts of the leaf even if a specific part undergoes damage. "They found the loops are structured in such a way that no matter which piece of a leaf's supply mechanism is disrupted, there is usually enough capacity in the rest to distribute water and nutrients."[2]

Often inherent complexity in nature can be overlooked or underestimated

The "Smart Grid System" has grown in popularity over the last decade or so as a new way to use computer programs and machine-learning algorithms to analyze consumer demand and cater to it effectively. Thereby, this process theoretically uses no excess power. Smart grids computerize the electricity distribution process, allowing for finer monitoring and control over large power distribution networks. A key component of the Smart Grid System is called "distribution intelligence." This ability makes the use of sensors that can identify when certain parts of the distribution system have lost power, just like a damaged part of a leaf. The system then intelligently re-routes power through redundant connecting routes that have not lost power, so as to restore power to areas affected by the blackout. This redundancy in connections is directly analogous to the "loopy-ness" in leaf vein structure.

Currently the technology for smart grids is much more theoretical than practical. Boulder, Colorado embarked on a plan to become the first city to make use of Smart Grid technology with the SmartGridCity plan, but the company in charge of building this network, Xcel, faced many setbacks. Xcel grossly overestimated the benefits and underestimated the costs. Smart grid technology is definitely something we should work toward achieving, but it is hard to determine when current technology will be cost-effective enough to upgrade pre-existing infrastructure at an affordable rate.[3]

Often inherent complexity in nature is overlooked or underestimated as engineers use the same model for years believing that it is the best possible solution. Looking at the past means of providing electricity to the masses, engineers have realized that the math for analysis was merely numerical, but did not take the big picture into account. After seeing how the vein structure of a leaf contributes to the tree as a whole, they were able to abstract the idea to electricity distribution for society. By mimicking the elegance of this natural design, we can push power systems to better cater to demand while maintaining efficiency and reducing overall costs.

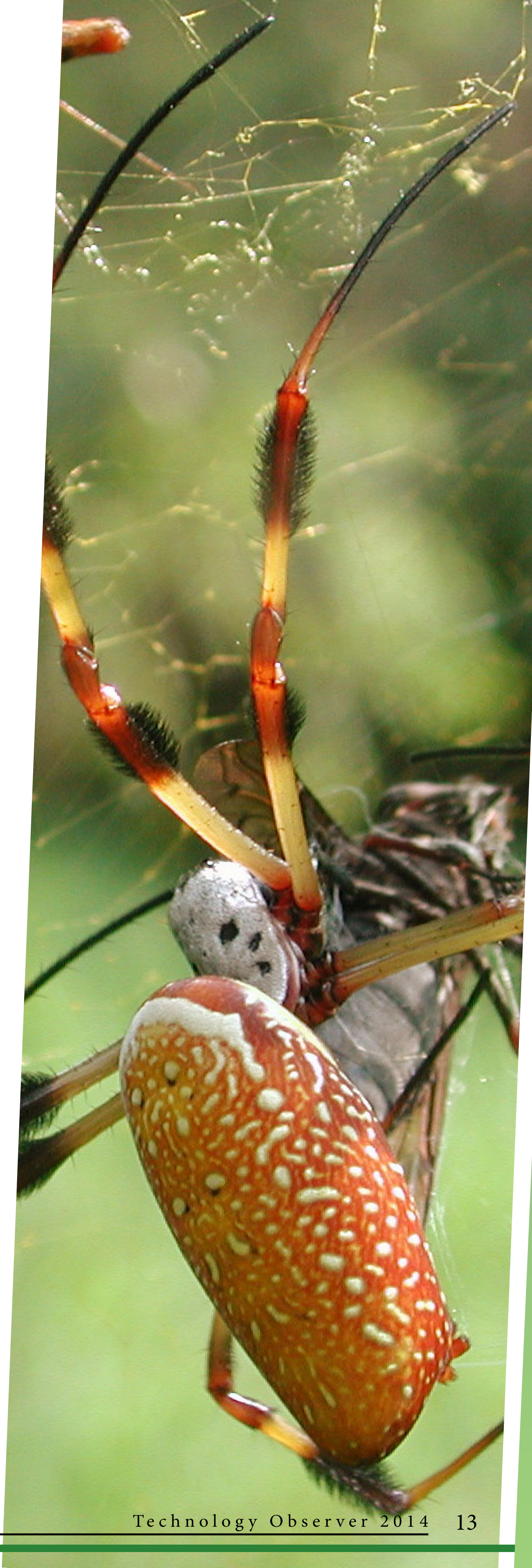
Srihari Rao *is a senior majoring in web and information systems.*

Spider Silk: More than just an annoying mess

Dharni Patel

Mimicry is a phenomenon generally associated with brightly colored snakes, newts, and lizards. Not only is this process used by many organisms for survival, but it is also used by humans for innovation. From a biological perspective, mimicry is the copying of another species to increase chances of survival or reproductive success. Whereas from a modern technological view, biomimicry is drawing upon models found in nature to solve human problems. Mimicry is an evolutionary process, however, that generally takes years in the natural world. So speeding up this process for human use requires the integration of complex processes, one of which is the creation of recombinant DNA. DNA is a genetic building block that contains instructions for building proteins. Any alterations in DNA will alter the product that is produced when the DNA is translated. The ability to alter DNA advantageously presents extensive possibilities. Creating recombinant DNA is the process of combining two or more sequences of DNA, generally from different species that would normally not occur together in nature.[3] Recombinant DNA can be used as a method of biomimicry to produce substances that either mimic that of another species or even combine DNA sequences to form products not found in nature.

Recombinant DNA involves the fusing of two different DNA sequences, a task easier said than done. Through complex engineering systems, numerous methods have been designed to produce recombinant collagen, fibronectin, and silk, among other products.[3] Recombinant DNA is useful because it can produce a naturally occurring substance more cheaply than if it was harvested from a living organism. It can also produce an entirely new substance not found in nature by using the properties of two different materials. Taking two inexpensive and easily harvestable sources of material and combining them to form the desired product is more cost-effective than producing the same product from an expensive source. In addition, recombinant DNA is particularly useful for producing large repetitive protein sequences such as in silk. The methods of cloning, gene mutation, and gene infusion



have already been established through processes such as the polymerase chain reaction, electrophoresis, and restriction enzymes. Recombinant DNA can be created by combining these previously explored processes.

A material created by recombinant DNA that easily proves the advantages of this method is spider silk. Spider silk is among the strongest natural materials found on earth and could have widespread biomedical applications if harvested in large enough quantities. Spider silk has a tensile fiber strength – the amount of stress from stretching or pulling a material can endure before breaking – comparable to that of steel, and an elasticity nearly equal to that of rubber. Additionally, spider silk is biodegradable and biocompatible, meaning that once within the body, it will be broken down into non-toxic products without inducing inflammation or acute allergic responses.[1]

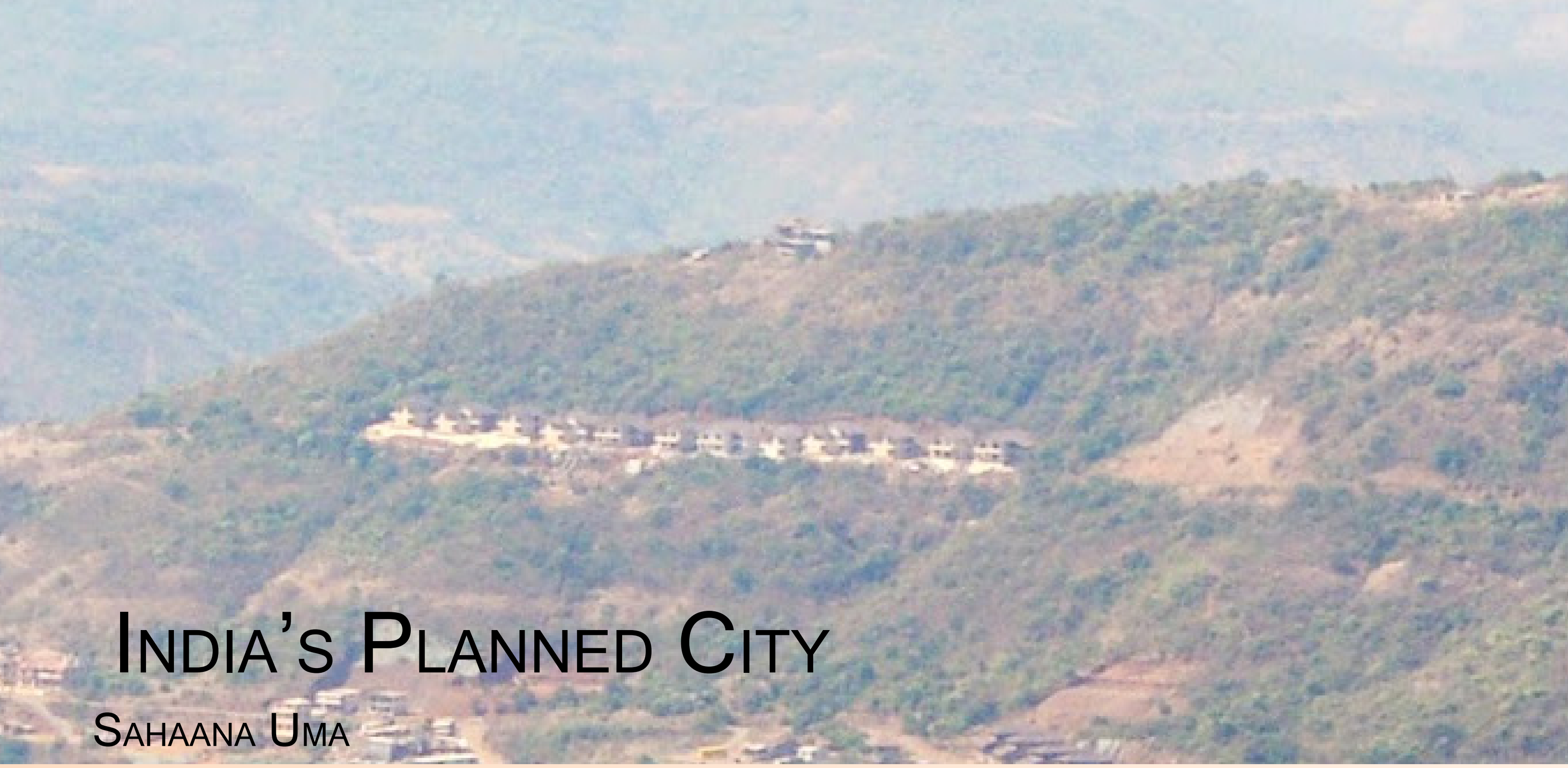
Research in tissue engineering is geared towards producing temporary biodegradable implants that help the human body fully reconstruct itself after injury and then degrade after use without necessitating surgical removal of the implant. One of the biggest challenges is finding materials for this use. However, spider silk is a feasible option due to its mechanical stability and biocompatibility with the human body.[1] Because any wound or implant site is prone to infection, taking a preemptive strike against infection can be accomplished through the creation of antimicrobial spider silk, which is not found naturally in nature. The bactericidal properties of more than 600 peptides have been studied as they function naturally in the human body.[2] By using recombinant DNA, it is possible to produce antimicrobial spider silk, which mimics the behavior of human antimicrobial peptides. In the first known study of its kind, researchers at the University of Minho and Tufts University explored this application by fusing spider silk and human antimicrobial peptides (human neutrophil defensin 2 (HNP-2)), human neutrophil defensins 4 (HNP-4) and hepcidin). This was done by inserting both spider silk copolymer DNA sequences and the antimicrobial peptide cDNA sequence into a vector – a molecule that acts as a vehicle for the transport of foreign material into a cell. The spider silk copolymer and peptide each had restriction sites which were cut off using restriction enzymes. The two sequences were joined using human DNA ligase. *E. coli* cells were then targeted with the ligation product to create cells that produced antimicrobial spider silk. The newly created silk proteins were then separated from the *E. coli* cells by lysing the cell and using centrifugation and a denaturing buffer. The resulting antimicrobial spider silk showed antimicrobial activity against *Staphylococcus aureus* and *E. coli*, two common types of bacteria that are known to cause infection at wound sites, if not regulated. In vitro studies with human osteosarcoma cells showed compatibility with mammal cells and, by extension, the human body.[2]

> "By using recombinant DNA, it is possible to produce antimicrobial spider silk, which mimics the behavior of human antimicrobial peptides."

Due to the success in creating antimicrobial spider silk, its possible applications now include use in sutures for wound litigation, ocular and cardiovascular surgery, and scaffolding for tissue engineering and tissue repair. This is particularly helpful for burn victims through the application of skin grafts. One of the most promising uses for antimicrobial spider silk is as a drug delivery system for growth factors, such as bone morphogenetic proteins (BMPs), and antibiotics. While other antibiotic delivery systems have been explored, numerous problems have been encountered with them. These problems included early release of the antibiotic, demonstrating a lack of control in sustained drug delivery over time.[2] This problem has not yet been encountered in studies using spider silk. In addition, the antimicrobial peptides used in the study by Gomes and colleagues are more susceptible to proteolytic digestion, increasing their effectiveness over time. Nonetheless, antimicrobial spider silk is not without its disadvantages. Spider silk is in itself difficult to produce in large quantities due to the highly cannibalistic and territorial nature of spiders. However, this area has been explored employing recombinant DNA by using species of bacteria to produce large quantities of silk.[3]

While antimicrobial spider silk has been explored and researched only recently, it shows promising results that indicate possible use in human applications. Recombinant DNA is currently the only method that produces silk resistant to *S. aureus* and *E. coli* by combining the spider DNA sequence that produces silk with that of human antimicrobial peptides. Areas for future study include investigating DNA sequences from different spider species, particularly the black widow, which has silk as strong as Kevlar (a high strength synthetic fiber used in body armor among other things) but lighter and of a lower density.[1] Furthermore, combining spider silk with different antimicrobial proteins results in new properties in the material; determining which peptide will yield the greatest antimicrobial properties is a question yet to be answered. While these areas require further exploration, it is obvious that the use of spider silk for biomedical engineering applications is a promising and exciting venture.

***Dharni Patel** is a junior majoring in biomedical engineering.*



India's Planned City

Sahaana Uma

Humans have been making significant advances in technology and many of these advances have been inspired by nature. Biomimicry is an emerging discipline that has led to many innovations based on functions and mechanisms found in biological processes. It is the application of nature's ideas to solve human problems. Recently, biomimicry experts have been attempting to construct cities with features inspired by the natural processes of plants and animals. This strategy would result in a city that is attuned with nature and optimizes natural resources.

In India, developers are working on constructing their first planned hill city called Lavasa. Developed by an Indian infrastructure firm, Hindustan Construction Company (HCC), the city is spread out over approximately 12,500 acres. The Lavasa development consists of three towns: Dasve, Gadle, and Dhamanohol. Biologists from Biomimicry 3.8, a Montana-based consultancy firm, are working in conjunction with HCC in order to achieve this goal of successfully constructing these picturesque urban villages located near southeast Mumbai. Ideally, the city will be complete by 2020.[1]

The landscape master plan includes future landscaping, the protection of natural open spaces, reforestation, green roofs, rainwater harvesting, and environmentally friendly construction. Another goal is constructing bioswales: landscape elements designed to remove silt and pollution from runoff water.[2] Designers aspire to include these amenities while maintaining what is called the "hill station appeal" of bright green hills, scenic waterfronts, and open land. The construction plan, inspired by both Indian traditional town patterns and vernacular forms of building, emulates culturally based principles that have proven sustainable over the years.[3] The population is targeted to be around 30,000 to 50,000 inhabitants.[1] Additionally, designers anticipate this technological city to attract many tourists.

According to the plans, many biomimicry principles are going to be applied in the construction of the city for the purpose of minimizing waste, preserving the environment, and creating a city that is more attuned to nature. For example, landscape architects suggest planting many trees to form a canopy. This would allow rainfall in the monsoon season to settle on the leaves and trickle down, making it more difficult for the water to overflow and cause damage. This strategy would help prevent flooding and drought because the expanse of trees would catch rainwater and retain it for longer periods.[2]

Another biomimicry strategy that is being implemented is the design of roof shingles inspired by banyan leaves. Banyan trees are large trees that spread by aerial roots, which eventually become trunks. These trees have large leaves that are approximately 25 x 17 centimeters in size, with a surface texture that is leathery smooth, but an underside that is hairy. The texture and shape of the

leaves make them hydrodynamically efficient because they begin at a wide, rounded base but conclude with a narrow tip at the apex.[4] It is this structure that allows water to be collected and expelled efficiently. In Lavasa, the banyan leaves influenced the design of water-dispatching roof shingles which will be used in buildings and homes.

In addition to monsoon engines and banyan leaf-inspired roof shingles, the Lavasa towns will also feature water diversion systems based on the nests of harvester ants. In order to avoid up to eleven meters of rain during the monsoon season, harvester ants in India construct their nest in a way that diverts the water and prevents it from damaging the nest. The ants build their nests on a slat and construct spiraling channels that guide water away.[5] Water diversion systems using this concept, typically consist of an underground system connected to drainage and irrigation structures to prevent flooding, erosion, and runoff, since they transport excess water elsewhere. The diversion system can catch water, preventing it from causing pollution, flooding, and contamination to the household water supply. By emulating the harvester ants' method of diverting water away, an efficient and environmentally attuned water diversion system is designed.

The Lavasa project has faced its fair share of problems so far. The company faced charges of illegal land acquisition and violation of environmental norms.[6] After fighting with the government and denying the acquisitions, the state government finally approved the continuation of the construction in 2004. In late 2010, however, the central government issued a "show-cause and stop-work" notice. As a result, HCC faced losses of about 12 million dollars.[7] All this put HCC and its Lavasa project under a negative spotlight and gave rise to bad publicity. The company has gradually redeemed itself over the past three years and delivered a promising city that has attracted many admirers.

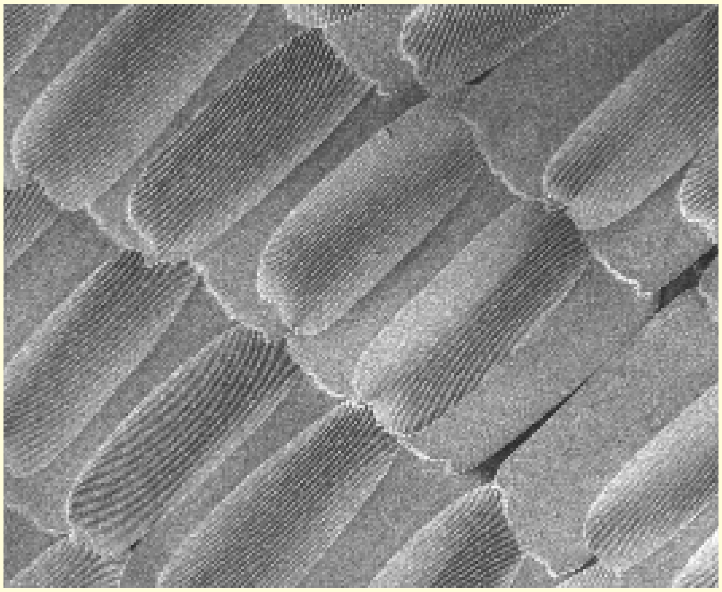
Using biomimicry as their guiding principle for the design of India's first planned city, developers are hoping to see successful results. These designers carefully studied the creatures and plants of the moist local ecosystem before developing models for the construction plan, and the biomimicry examples discussed here are only a few of the techniques that are being used in this ambitious project. Lavasa is one of a few places that will break conventional barriers and set new ecological standards for cities. When cities perform like ecosystems, they are more attuned to nature and will last longer on the planet. Due to the emergence of new environmentally attuned locations like Lavasa in India, Songdo IDB in South Korea, and Masdar City in Abu Dhabi, the idea of transforming major cities in the world into a new kind of model city is becoming a real possibility.

Sahaana Uma *is a sophomore majoring in chemical engineering.*

Plants and Animals Inspire Efficiency in Solar Energy Production

Jeremy Buhain

Nature knows what nature does. Through biomimicry, humans utilize processes and designs found in nature to improve technology. Scientists essentially mimic these natural processes and apply them to various fields, such as solar energy production. Although solar energy being harnessed by humans is nothing new, the application of biomimicry to existing solar energy technology is altering the science behind capturing this abundant energy. Researchers now turn to both animals and plants—the masters of solar energy themselves—for ideas on how to tackle limitations in solar energy technology, including inefficiencies in solar energy collection, hardware production, and maintenance.



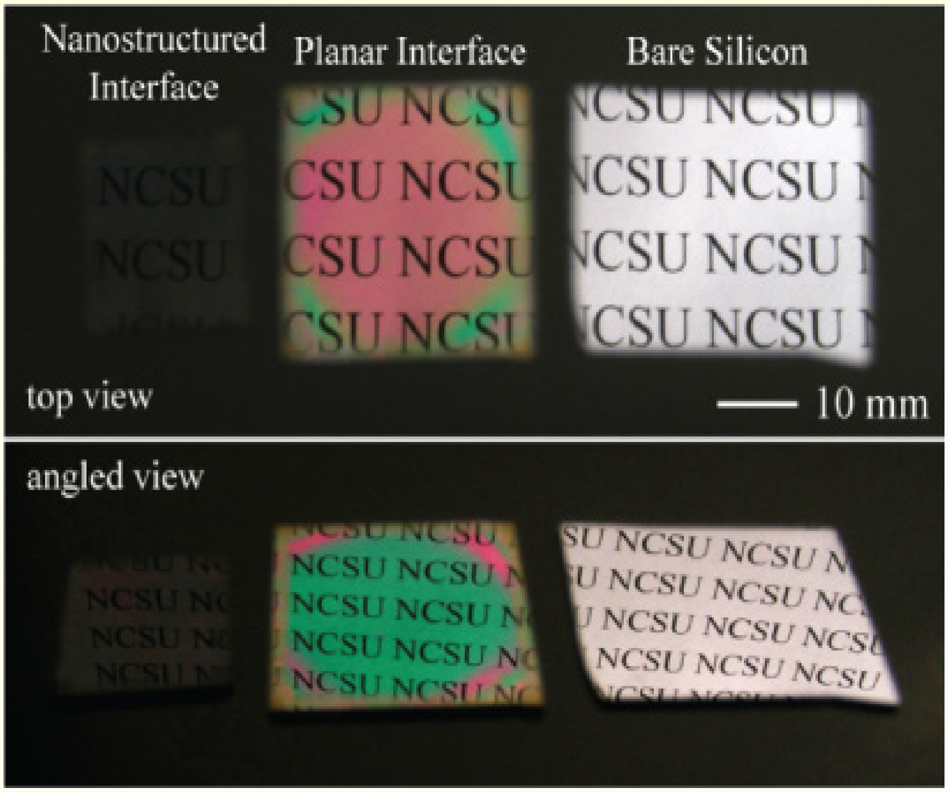
ANIMALS

The wings of a butterfly do more than grant this insect flight and beauty; they help butterflies retain heat through their efficiency in capturing solar energy. This discovery has brought researchers led by Prof. Tongxian Fan of the Research Institute of Composite Materials at Shanghai University to study the structure of butterfly wings with the purpose of applying their findings to solar energy technology. Researchers have attributed this efficiency to the clever arrangement of the scales on the butterflies' wings. Laid out like shingles on a roof, these overlapping rectangular scales are present in the wings of different butterfly species. Additionally, each individual scale is marked by steep ridges on its surface (see above), with small holes on the walls that lead to an underlying layer. These ridges allow the capturing of the longer wavelengths of sunlight, while the holes function as filtering systems that allow only the shorter wavelengths to pass through to the lower layer. The layout and topography of these scales ensure the butterfly retains the maximum amount of heat from sunlight. Using this remarkable discovery, Professor Fan hopes to apply it to the design of future, more efficient thin-film solar cells.[1]

The efficiency in collecting solar energy is also influenced by the composition of solar cells. The silicon in the cells has the major drawback of reflecting sunlight, rendering these cells quite inefficient. Though anti-reflecting coatings have been applied to the surface, they work only on a narrow range of wavelengths, particularly between 400 nm and 1400 nm; beyond that range, the coating becomes increasingly inefficient.[2] This inefficiency is attributed to "thin-film interference," a phenomenon that occurs between the thin film of coating and the silicon surface. This optical occurrence can be observed with the iridescence seen in gasoline. Though gasoline is transparent, light still reflects off its surface. At the same time, light that passes is reflected by the surface underneath, and when this light passes through the gasoline once again, it takes on a different path than the one that was reflected off the gasoline surface. This phenomenon produces the rainbow sheen that many associate with gasoline.[3]

Because light is reflected off two surfaces in thin-film interference, much energy is lost. To address this challenge, scientists have studied the surface structure of a moth's eye, which has evolved to not reflect light. What enables moth eyes to reflect little light is the arrangement of ordered bumps on their corneas.[2] Scientists have imitated this arrangement on the interface under the coating by constructing nanocones, which would be made of the same material as the underlying surface – silicon. With the use of these nanocones, reflection from the films occurs only at the top surface, reducing the energy lost. The visual effects of the nanostructures can be seen in photographs of text printed on silicon exposed to white light (see below). If nanostructures are applied to silicon fuel cells, thin-film interference can be eliminated when coating is applied, and the efficiency of these fuel cells can be increased immensely.[4]

Aside from insects, researchers have also looked at mollusks, more specifically, the chiton, for ideas on improving solar energy technology. The chiton has the ability to reconstruct the radula, a conveyor belt-like organ in its mouth with 70 to 80 parallel rows of teeth used to access the algae that grow on rocks. Over time, the radula becomes worn from grinding rocks, and the chiton must produce new teeth to replace the worn ones.[5] This ability has inspired David Kisailus, an Assistant Professor of Chemical and Environmental Engineering at the University of California, Riverside, to study the gumboot chiton (Cryptochiton stelleri) and apply this remarkable ability to manufacturing solar technology. Kisailus and his team have observed the crystallization of certain minerals during this biological process, which can remarkably occur "at room temperature and under environmentally benign conditions." Such a finding would allow for minimal control of surrounding conditions for the process to occur. Now, Kisailus is looking into utilizing this process to produce the minerals necessary for the production of more efficient solar cells.



PLANTS

Since photosynthesis is characteristic of plants, much can be learned from how plants have perfected this invaluable biological process. Although mimicking the efficiency of photosynthesis itself is an onerous task for researchers, many scientists are studying parts of different species of plants to help boost the efficiency of solar energy production. The sunflower, for example, has served as a model for the design of concentrated solar power (CSP) systems. CSP systems increase efficiency by using a focused beam of sunlight, obtained through an arrangement of mirrors or large lenses called heliostats that redirect sunlight to a central receiver at the top of a solar tower. The layout of these lenses is inspired by the spiral formation of florets found in a sunflower. Models of this innovation have shown a greater yield of energy and a reduction in the amount of land used. Although it is still theoretical right now, this innovation has much potential in the future of solar energy production.[1]

Researchers have also studied plants at a microscopic level, looking to mimic a plant's ability to regenerate damaged parts of its leaves. In plants, photosystems – organic photoactive complexes active in photosynthesis and found in the core of leaves – may deteriorate due to overexposure to light. When these photosystems are damaged, the plant essentially disassembles the damaged parts in the complexes and replaces them with new biologically synthesized complexes. This is made possible with the plant's venation network, a network of "microfluidic" channels that allows for the transport of water, ions, and photosynthate, permitting the regeneration of these complexes. Imitating this regenerative ability can help scientists create longer-lasting photovoltaic cells, which use photosensitive organic dye molecules that are susceptible to high temperatures, light, and water, to harvest energy.

"Since photosynthesis is characteristic of plants, much can be learned in how plants have been perfecting this invaluable biological process."

Hyung-Joon Koo is now trying to mimic this same transport mechanism in photovoltaic systems in order to facilitate the regeneration of damaged parts. This new technology would include naturally derived agarose hydrogel that would be strewn with embedded microfluidic channels. These channels would transport dyes and electrolytes needed for the regeneration of solar cells. Once these reagents are delivered, the replacement of the dyes is made possible by the pH-dependent desorption and re-adsorption of the dye molecules on the TiO_2 photoanodes in the solar cell. Such technology can help the maintenance of solar energy harvesting hardware.

Because it is still relatively novel, the production of solar energy has had some drawbacks and obstacles, especially in collecting energy and hardware optimization. But nature truly knows best, and nature has provided plenty of inspiration towards the optimization of solar energy technology. An organism as fragile as a butterfly can help the efficiency of solar cells in collecting energy through its delicate wing structure. With the help of heliostats arranged like the florets of a sunflower and hardware embedded with nanocones inspired by moth eyes, today's researchers can maximize the efficiency of solar energy collection. The production and maintenance of solar energy technology hardware can also derive inspiration from both plants and animals. The biological process that allows chitons to regenerate their worn radula and the process that plants utilize to restore their damaged photosystems have provided scientists with ideas to engineer ways to efficiently manufacture and maintain durable hardware. With biomimicry, scientists produce the ideas, but nature provides the instructions.

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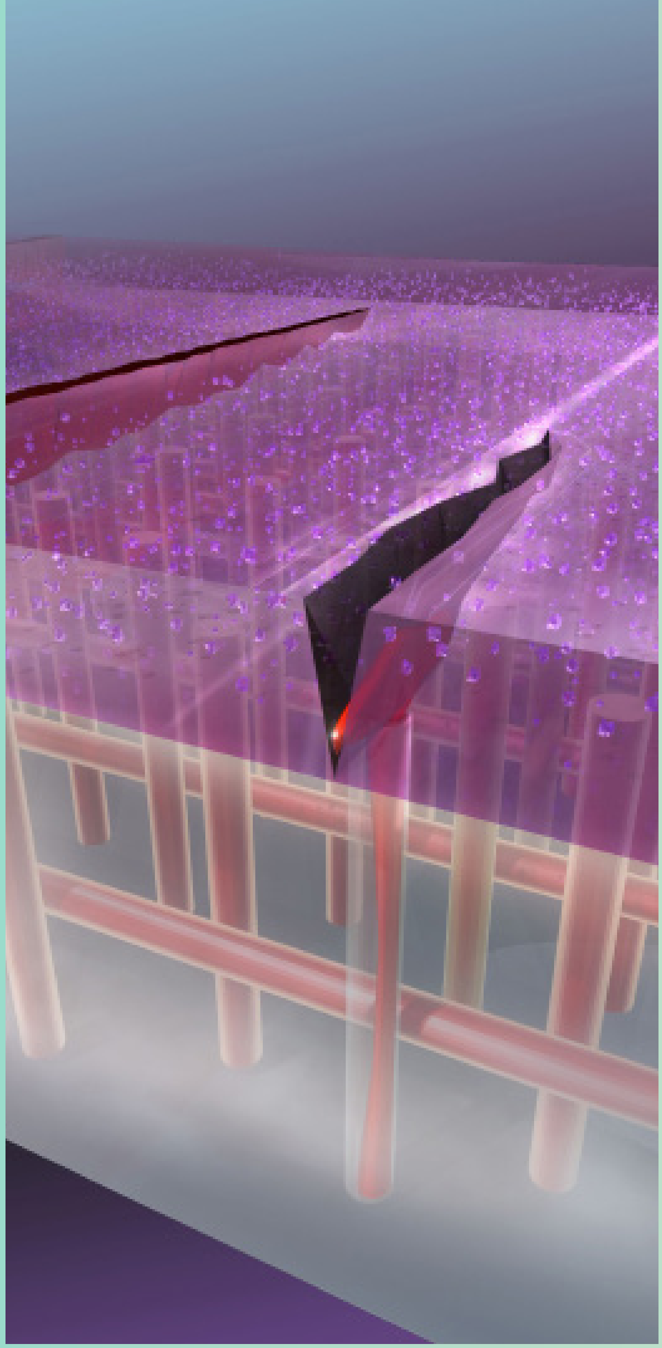
Self-Healing Polymers in Everyday Machinery

Saad Ali

The human body's ability to repair itself after virtually any injury has long been studied and documented, for the purpose of determining a way to replicate the mechanism in products. Inspired by materials in nature that can self-repair – such as the human skin, insect exoskeletons, bones, and starfish arms – Natural Process Design Inc. has developed self-healing matrix materials that allow a structure to repair microcracks.[1] When the skin is cut and begins to bleed, platelets are released to seal the cut and start healing the wound. Dr. Carolyn Dry and Natural Process Design Inc. have mimicked such a process with their self-repairing polymer composite.

The clearest implementation of the self-healing polymer is in vehicles, such as airplanes, boats, and cars, as well as in bridges. The polymer consists of hollow fibers filled with a selectively releasable modifying agent and a composite matrix of inorganic and organic materials with chemical components that either inhibit further corrosion or modify the existing structure.[1] When a microcrack or some other stimulus is detected within the matrix, the hollow fibers release the modifying agent to seal the damaged area, much like platelets do in the human skin.

According to Dr. Ian Bond, a researcher at the Engineering and Physical Sciences Research Council (EPSRC) in the United Kingdom who is also working on a similar material, the self-healing polymer is just the first step in implementing human processes in machines. He hopes to further advance the technology to create a structure more like a "fully integrated vascular network."[2] Currently, the polymer is capable of restoring microcracks in a structure to 80 to 90 percent of its original strength.[2] Furthermore, when released, the polymer is colored, so that maintenance workers investigating the structure can easily spot areas where damage has occurred and replace those parts. This method increases efficiency because it is much easier for maintenance workers to replace parts for a microcrack than it is for them to replace parts for a macro or larger-scale crack.



The self-healing polymer is not meant, however, to replace maintenance workers, but rather to make the process of checking and inspecting easier and more efficient. The implementation of self-healing polymers significantly reduces the need for major, overhauling repairs.[1] Currently, 20 percent of all airplanes undergo major repairs every year just to maintain current conditions.[1] However, self-healing materials would prevent minor cracks from developing into major, catastrophic cracks that require much more time and effort to repair. Otherwise, detecting microcracks before they develop into macrocracks almost always requires invasive maneuvers that damage the material, and cracks are usually undetectable until they are visible to the naked eye.

There are also clear advantages to using self-healing polymers in vehicles. Utilizing materials made of self-healing polymers prolongs the life of the vehicle, and significantly reduces its overall weight while also increasing strength. For example, glass fiber composite is five times stronger than traditionally used aluminum and also lighter by 30 to 40 percent.[1] Polymer composites are three times stronger than steel and five times lighter.[1] The weight reduction as a result of self-repairing polymers allows for more fuel-efficient vehicles, which leads to fewer pollutants released into the atmosphere. Additionally, polymer composites resistant to environmental chemicals and water damage, are also more resilient to vibration damage than steel and concrete.[1] Lastly, in order to simply maintain current bridges, 200,000 bridges will have to undergo major repairs and might even have to be completely replaced in the next two decades.

As one might expect from a relatively new and highly advanced technology, self-healing polymers are quite expensive to manufacture compared to cheaper, traditional products such as aluminum, steel, and concrete. However, as the benefits of self-repairing materials are realized, the popularity and demand for such materials will rise, and more manufacturers will look to cut costs in the long run by switching to self-repairable materials. In fact, polymer bridges already exist as of now and the use of polymer composites in airplanes has increased substantially in recent years.[1] Moreover, the scope of polymer composites has expanded as well; international conglomerate LG Corporation recently announced the LG G Flex, the world's first phone capable of repairing scratches itself.[3] Furthermore, Autonomic Materials Inc. of Champaign, Illinois has raised over 4 million dollars in hopes of producing self-repairing coatings that prevent corrosion.[4] As manufacturing companies and governments look for efficient and effective ways to keep infrastructure intact with minimal repair costs, self-healing polymers will begin to gain traction and may eventually be employed on a large-scale.

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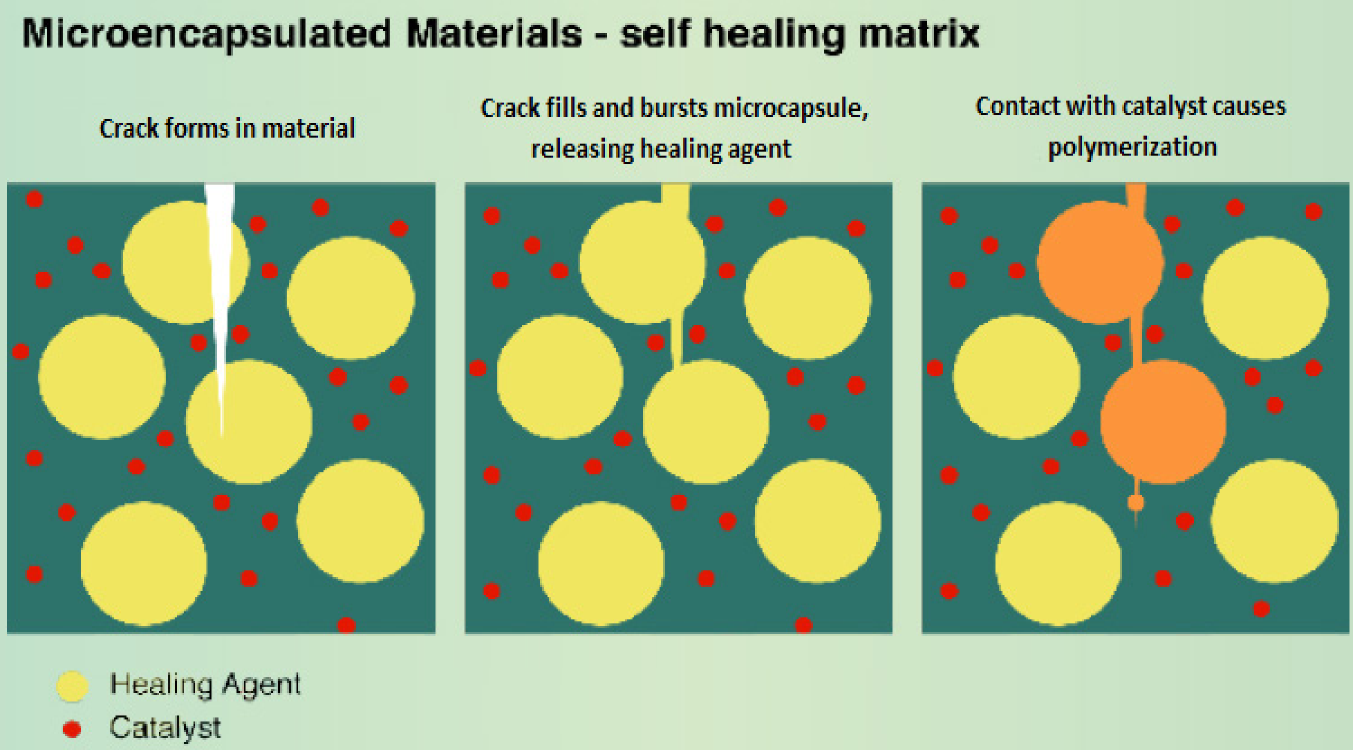

Mimicking the Femur Bone to Improve Resiliency of Built Structures

Rebecca Deek

There is evidence that erratic and extreme weather is becoming more common and predictions are that it will become even more frequent and severe.[1] However, as physicists, environmental scientists, politicians, and others continue to debate the connection between weather events and climate change, other scientists, engineers, and urban planners are exploring how our habitat can become more responsive and resilient to such phenomena.

The ability to prepare for, respond to, and recover from environmental hardships requires that our physical infrastructure is designed in a manner that allows it not only to withstand natural disruptions, but also to adapt to changing conditions and ensure functional continuity at the individual and community levels. Nature itself provides a model in resiliency, innovation, and progress reaching back billions of years, and offers rich templates and examples for developing sustainable human technologies. This process is what is known as biomimicry.[2]

IMITATING NATURE

Human imitation of nature is not new, and could explain our status as one of the most resilient creatures on this planet. In fact, biomimicry seems to be increasingly serving as a guiding principle for managing our natural resources, designing our machinery, and planning our built environment. Although we have not yet found a way to produce only clean energy, to exploit all the sunlight that is emitted, or to generate no waste, we are becoming less wasteful and more resilient in our everyday lives. In that regard, we remain novices compared to nature, but our buildings, in particular, are becoming more responsive to disasters by employing design strategies that aim to invest minimal resources for maximum effect,[3] thereby taking a page out of nature's book.

Take the human body as an illustrative point. The skeletal system is composed of bones and joints. There are also ligaments, tendons, muscles and cartilage which, together, facilitate movement. From a structural viewpoint, the femur bone, longest and strongest amongst them all, is shaped like a hollow cylinder – an interesting fact to consider. The femur design takes into consideration its role in supporting the upper body, with all the strain and heavy weight resulting from compression, bending, and torsion. The femur also endures equal strain from standing, walking, running, and jumping. It is specifically designed to provide maximum strength at minimum weight so that it does not weigh down the lower body or hinder its mobility; at the same time, this allows it to sustain the even heavier upper portion of the body. The cylindrical anatomy of the femur is based on multi-layered bone fibers that are aligned and crisscross each other to withstand the forces of the

upper body. It is not hard to conclude that a parallel between the human skeleton and the structure of buildings can be drawn, particularly for construction in geologically active areas where structures have to withstand the unusual forces of nature.

Shaking produced by earthquakes, volcanic eruptions, hurricanes, floods, and tsunamis create stresses on built structures similar to those endured by the human body as a result of its various movements. Unlike the human skeleton and its harmony with the needs of the body it supports, the overwhelming majority of existing built structures are not consistent with Earth's dynamics and its flow of forces. For example, seismic waves, depending on intensity, and the geophysical characteristics of the area, routinely cause damage to buildings, ranging from minor damage to total collapse. Because of this, natural disasters often cause significant material and human loss.

THE FEMUR AS AN ADAPTATION MODEL FOR BUILDING DESIGN AND CONSTRUCTION

Recently, architects and civil engineers have been using the anatomy and mechanics of the human body as a basis for designing and constructing buildings, often referred to as bio-structures. These buildings have an improved ability to withstand and respond to natural and human disturbances.[4] Designing such structures involves mimicking biological forms with their material strength, movement flexibility, and structural sustainability in order to produce architectural schemes and building solutions with similar properties. The characteristics of the human skeleton are used as a basis for constructing structural beams that can mimic the strength and flexibility of the human body and can be used in geologically active areas.

The idea that the human femur can serve as a basis for building structures capable of sustaining load and stress is not new. Constructed in 1887, the Eiffel Tower was intentionally shaped like an upside-down human femur. Borrowing from the anatomy of the internal bone fibers within the femur, it was built with the aim of using the least amount of iron for the most strength.[5] Such a strong foundational base was required given the heavy weight of steel and the height of the tower. Figure 1 on the next page presents a drawing of the upper femur (upside-down) and its lines of stress based on mathematical analysis placed side-by-side with a sectional drawing of the right half of the Eiffel Tower.

Similar to femurs, columns and beams can also be shaped like hollow cylinders and made to precisely fit specific load conditions with force applied where needed. This modification alone allows for roughly thirty percent reduction in concrete use.[6] The intensity of seismic activities on building frames that use hollow-shaft columns and beams is similarly reduced as a result of mimicking the human femur in building structures. Less concrete means less weight and reduced building seismic vulnerability.[4]

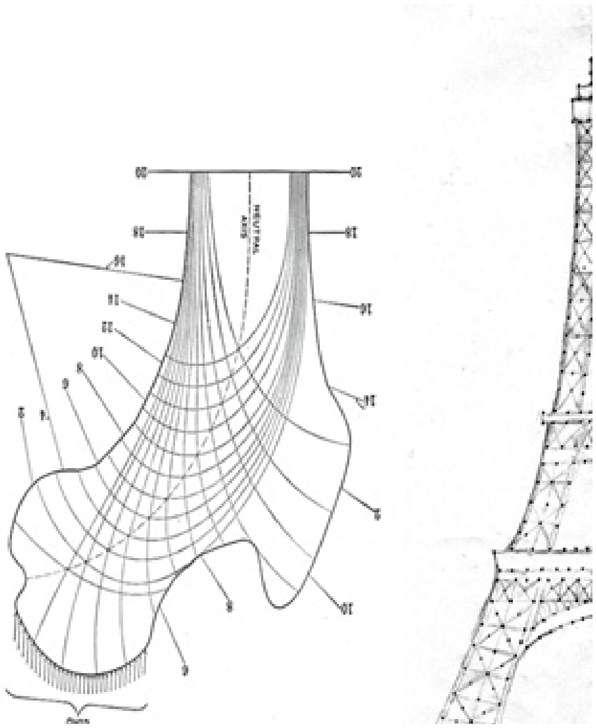

FIGURE 1

Various concrete blends, masonry, and mortar have been used in construction for centuries, and the subsequent invention of reinforced concrete made it the most commonly used building material. Blending steel and concrete allows for a higher force resistance giving it more strength in the face of vibrations caused by earthquakes, heavy wind, and other such forces. But even the most robustly reinforced concrete suffers damage in the face of strong seismic waves from earthquakes, volcanoes, explosions, or even storms. The use of heavy materials, such as concrete, to construct the walls and roofs, increase the likelihood of casualties from destroyed buildings. The vulnerability of buildings and the resulting casualties can be partially mitigated by reducing the weight of the used material without compromising the structural integrity of buildings, which in turn increases adaptation to site geology and reduces potential human casualties.[6]

CONCLUSION

Every year, natural disasters and extreme weather affect the lives of many people in various parts of the world. While the risks and dangers of these occurrences can be anticipated, it is impossible to fully confront all threats. Hence, it is logical to explore ways to lessen the impact of natural disasters and extreme weather on built structures so as to improve their resiliency.

The damage resulting from natural disasters not only has clear environmental consequences, but also has human, social, and economic ones. The human race has been working to better protect itself from foreseen calamities such as floods, droughts, and famine since its early existence. Our response has included a mix of developing tolerance for such conditions, migration to areas less prone to these challenges, and building better dwellings and infrastructures. It is clearly much harder to defend against unforeseen devastations, such as those caused by earthquakes and tsunamis. Over time, however, we have also learned that technology is a key component of our strategy for improving resilience, robustness, and, consequently, the protection of human lives.

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From Samara Seed to Samarai

Melanie Deleon

The maple seed inspired the development of a nano air vehicle, called the Samarai. A single bladed vehicle, the Samarai resembles the single leaf design of the samara maple seed. Development of the vehicle's design has shed light on possible uses for military and surveillance purposes.

A samara is a fruit with a leaf or pod that stores seeds. When the leaves fall, they autorotate and land at a point far away from the original tree. The flight of the samara maple seed is an admirable process that scientists have recently tried to emulate because of the astounding stability of its landing. No matter how randomly it is thrown, the samara maple seed will begin to autorotate and fall in a vertical helical path.[2] Scientists believed that the explanation behind this autorotation lay in the aerodynamics of the single wing-like leaf attached to the seed. However, experiments with torn, cut up leaves reveal that the seed still proceeds to fall in a helical manner despite a broken wing.[1]

Because of this unique ability, the samara maple seed's path of flight was recreated and applied to nano air vehicles for military purposes. In 2005, DARPA'S defense offices began the Nano Air Vehicle (NAV) program to delve deeper into this concept.[5]

Hence, with the autorotation characteristic of the maple seed in mind and the need for a nano air vehicle for military operations, Lockheed Martin began research and development of the "Samarai Flyer," a small nano air vehicle with military purposes such as "surveillance, reconnaissance, and payload delivery." [7]

While approaching the construction of the nano air vehicle, scientists faced a setback. Usually, small functional parts such as the engine are developed first, and then the body is manufactured based on the size of the functional parts. However, for this particular project, the size of the vehicle body was the first thing taken into consideration in order to incorporate a single blade, small enough to achieve the aerodynamics similar to that of the samara seed.[5] Then the functional parts could be designed to fit the model.

Once scientists completed a model of the Samarai, it was approximately 7.5 centimeters in length and about 10 grams in mass. The Samarai "[could] fly for up to 20 minutes with a range of 1 [kilometer]" and could rotate at approximately 12,000 rpm.[5][6] It resembled the single-winged samara maple seed with its lone blade. It was also self-propelling in order to make "hovering and forward flight by a tip jet engine" possible.[6] The Samarai vehicle is fairly simple without many complicated parts. Its more important parts include a fuel tank for the propellant located in the center of the model, with the two gram removable payload placed underneath, and electronics to assist in "communication, sensing, and control."[6]

One of the main uses for the Samarai, developed by Lockheed Martin, is for surveillance and reconnaissance missions.[3] Having the NAV technology will allow soldiers to observe with a bird's eye view locations they cannot get close to.[4] The 360-degree camera attached to the vehicle records while it is in motion to provide the view. There are also potential civil uses of the vehicle such as "police use and inspection of sewer pipes, nuclear plants, and delivery systems."[7]

After much testing and research, Lockheed Martin went public with the Samarai flyer and performed its first public flight at the Association for Unmanned Vehicle Systems international conference in Washington D.C. on August 11, 2011. The final model of the Samarai consisted of a circular disk with electronics that helped run the vehicle, a video camera, and a rotor wing (comparable to the single leaf on the samara maple seed). The vehicle can be launched like a boomerang and then observed as it hovers in a circular path, similar to that a samara follows.[6]

Humans are continually learning from nature by trying to replicate its processes in ways that advance technology. Evidently, the samara exemplifies how biomimicry has sparked innovation in recent years. At first glance, humans may have considered its distinctive helical motion ineffective. However, after much development and design, researchers were able to create the Samarai Flyer. The Samarai Flyer and other similar NAVs have great potential in future applications for military and civil use. As technology advances, these flyers or the like may one day revolutionize surveillance techniques as we know them.

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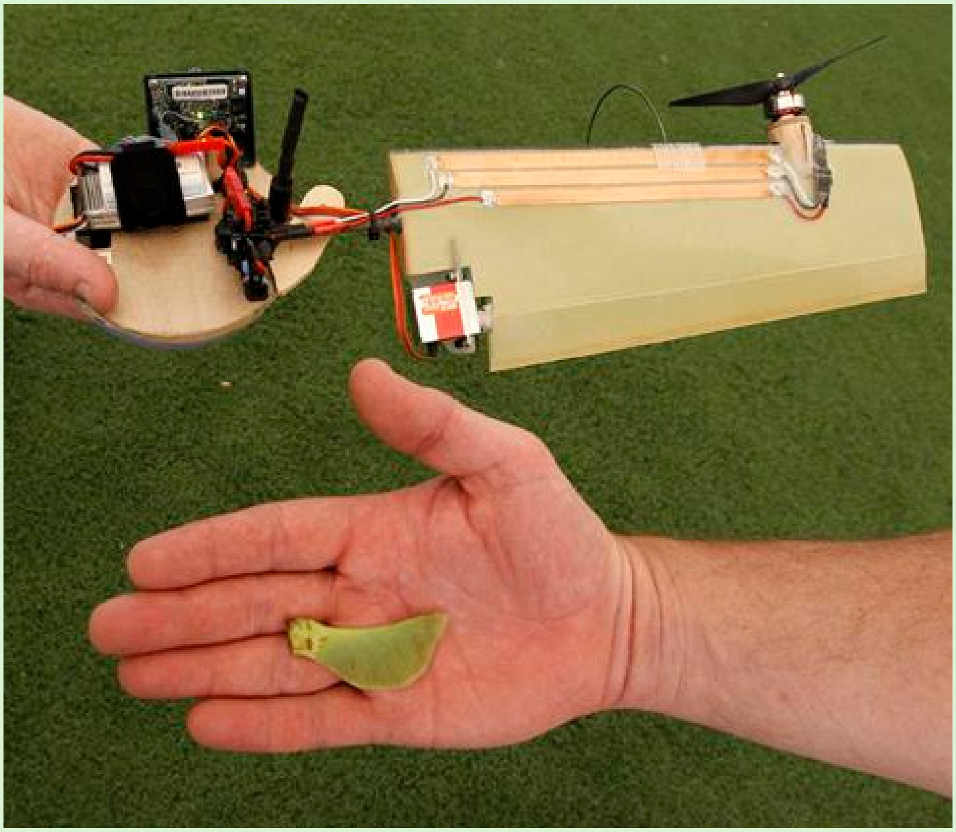
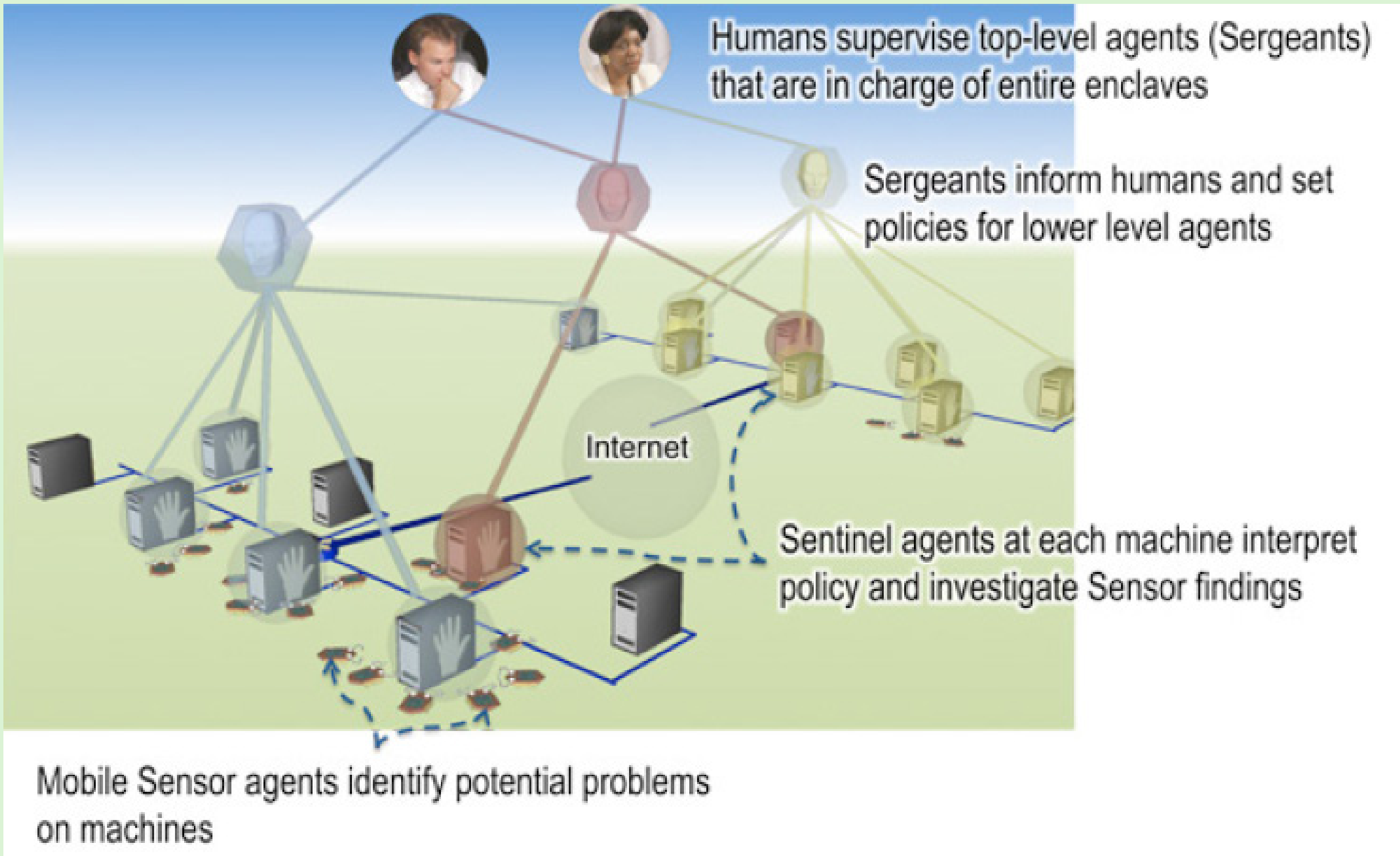


Attention! Digital Ant Army Reporting for Duty

Jasmine Faldu

In modern society, biomimicry has become an integral part of technological advancements made in the world today. Biomimicry is the process of taking naturally occurring biological mechanisms, and using them to find solutions to problems in everyday life. This ability to take an idea that already exists in another form and transform it to work in a completely unrelated model is awe-inspiring. A specific example of biomimicry is developing better computer protection systems based upon the model of how ants swarm for survival. Once an ant detects a threat, it secretes a scent to signal to other ants that there is danger nearby. Cohesively, the ants will attack the threat, grouping together and forming an army to target and conquer the foreigner until the danger dissipates. This form of survival is effective because one ant alone would be unable to combat a threat successfully, but the large magnitude of force generated from numerous attackers makes it possible for the ants to beat threats. Swarming together and working as a team against a foreigner is what makes this system so effective. The application of this mechanism called ant swarm intelligence, is being implemented in computer software programs to help fight against computer viruses in the same manner.

A common problem in the technological



world today is protecting personal accounts and data from getting into the wrong hands. Worms and viruses infect computers so frequently that it is necessary to install antivirus software to avoid being hacked. Jaymi Heimbuch, a well-respected editor for TreeHugger, an online science website, explains: “By looking at the way ants call for backup and overpower invaders through sheer quantity of soldiers, security experts have devised a ‘digital ant’ that will help human operators more quickly spot threats to computer systems.”[3] Computer security has been transformed to mirror the way in which ants swarm together, multiplying in strength as more ants gather to fight against invaders. This same concept has been applied to computer security so that many more protecting agents come to fight against a foreign virus while recruiting backup as needed.

One may believe that software which attacks computer viruses efficiently already exists, but these old software programs are designed to defend all known threats simultaneously. This clearly forces the protection software to spread its army out farther, across the entire computer system at all times, making it harder to fight against threats as they arise. Unfortunately, programmers in recent years with malicious intent continuously add deviations to viruses, making it more difficult for the security system to detect them as threats; swarm intelligence, however, creates a system that is constantly adapting to the environment.[2] Constant changes in the implemented virus causes a glitch in the computer’s defense system, which is why research studies on the application of digital ants has been a main focus for Wake Forest University’s Department of Computer Science (WFU) and the Pacific Northwest National Laboratory (PNNL).[6] Due to the widespread prevalence of cybercrime in the 21st century, PNNL and WFU have teamed up to attack this problem head on, using solutions from the natural defense mechanisms and survival tactics of ants.

This technology revolves around the concept of being dynamic rather than static, which sets it apart from the other available cybersecurity systems.[2] The studies on ant defense mechanisms, specifically known as swarm technology, use the simple idea of how ants attack their invaders. The Pacific Northwest National Laboratory is a pioneer in this area, which focuses on cybersecurity concerns.[4] Glenn Fink is a research scientist at PNNL who originally conceived the concept of mimicking the behavior of ants swarming for survival. Fink explains that PNNL and WFU wish to ultimately implant digital ants that will move throughout the network leaving behind a digital trail. This concept mimics the way ants leave trails to steer other ants towards a food source. When a digital ant recognizes a threat, the "scent" left behind will be intensified and will attract more ants to migrate to that area, creating a swarm of digital ants that will attack the computer infection.[1] This swarm of digital ants will trigger a human operator, who can then intervene and more critically investigate the malware detected within the system. The research team has created a strategy for how the digital ants will report threats they find within the network using a hierarchy of command, closely shadowing an actual ant army.

In 2009, Fink's research became public and the Pacific Northwest National Laboratory was the only one out of ten Department of Energy Laboratories that delved into cutting-edge research on the subject matter of cybersecurity.[2] In conjunction with Wake Forest University Professor of Computer Science, Errin Fulp, they have been able to run many tests on this new "swarm intelligence". Fulp is an expert in computer networks and security, and in reference to ants has stated, "They can ramp up their defense rapidly, and then resume routine behavior quickly after an intruder has been stopped. We were trying to achieve that same framework in a computer system."[6] Fulp also recruited some students from WFU to interact and work with PNNL, and together this team is studying how to train an army of "digital ants" to navigate and discover any potential threats on the power grid that could detrimentally impact a computer system.[5] These preliminary tests on the power grid will eventually allow the technology to be applied to larger databases, such as those that control mass transit systems or even manufacturing.

"The research team has created a strategy for how the digital ants will report threats they find within the network using a hierarchy of command, closely shadowing an actual ant army."

According to Fulp, swarm intelligence technology can be broken down into three components: digital ant, Sentinel, and Sergeant. A digital ant is programmed and has a life span corresponding to how well it works within the system. There is a base population of digital ants, but those which are successful in finding threats are rewarded with more energy to survive. Those ants that are not as skilled will eventually deplete their energy supply and are left to die. The digital ant will essentially "crawl" through the coding of the computer to look for foreign or unfamiliar data and malware. The team of researchers wants to eventually have an infantry of 3,000 various types of digital ants out for battle at all times while the device is running.[4] All of these ants will be on the hunt for a threat and once an ant detects an invader, it will call for backup, which will trigger a reinforcement of more ants to attack the intruder.[1]

The Sentinel servers are the immediate managers of the digital ant army that exists on a single computer. This manager makes the decision of whether further steps are necessary once information received from the digital ants is processed. The condition of the local host is analyzed by the Sentinel before signaling the Sergeant. This is done because the Sentinel is programmed to understand what "normal" conditions are. It will digitally sign the code being passed onto the Sergeant to ensure that the code is not infected by any malware or transformed in the exchange process. The Sergeant is responsible for managing several Sentinels. The number of Sentinels and Sergeants is dependent upon the magnitude of the network and computer system in use. Sergeants are then controlled by human supervisors, who will oversee the entire system and analyze the reports provided by the Sergeants, the highest level of technological command in the system.[4] This three component system was created with multiple feedback systems in order to ensure accuracy in identifying a threat. When the Sentinel compares the information received to its normal database, it is able to identify what is a threat and what is not. The ant swarm intelligence system has been methodically thought out by the PNNL and its researchers. This vigorously tested system is part of a bright future and is expected to be implemented in larger computer networks, but may eventually find its way into household computers as well.

Two more team members who were crucial for their knowledge and understanding of mathematical modeling were Kenneth Berenhaut, an Associate

Professor of Mathematics, and Z. Smith Reynolds, a Faculty Fellow. Their keen awareness of mathematical modeling and simulation allowed their studies of the ant swarm technology to take a more visual approach since the digital ants could be tracked along a smart grid. A smart grid is a technology that allows the researchers to use computer-based automation and control in order to achieve two-way communication. This way, the patterns of the digital ants within the computer system could be more easily observed. [5]

Wake Forest University and PNNL are working together towards a safer cyberworld and creating an improved cyber attack mechanism. Their first plan is to program the digital ants to attack on a larger computer network, but after testing and regulations are assessed, their next goal is to be able to implement this system within homes. These researchers have raised the concern that, as society becomes more interconnected through social media sites, online money transfers, and entertainment streams from disreputable websites, the World Wide Web poses a potential threat to everyone – not only the government or international corporations. Interconnectedness increases potential threats because people are interacting and sharing personal information with others they believe are trustworthy. An ever-present Internet security concern is the fact that online users can easily create fake identities since the other party cannot directly see them. Computers need antivirus spyware in order to avoid falling victim to online worms that will steal personal information once inside the system. The tool that most helps the community connect with one another has some of the greatest potential to be hacked and fall apart. This is why cybersecurity is so important in the 21st century.

> "Since computer hackers have been able to create viruses that adapt to spyware, the ant swarm technology is growing due to its unique attacking strategy."

In the summer of 2009, the digital ants were tested on sixty-four computer networks to analyze the efficiency and effectiveness of this new swarm intelligence process. Fulp was able to infect a computer system with a worm and the digital ants were able to successfully find the worm and attack it. He further explains that this type of swarm technology is most fitting for large networks, which are commonly found in corporations, universities, and even governments, where identical machines are being used simultaneously. Individual computer users are not likely to come across digital ants soon since the team wants to work on the special software that contains the three components necessary – the digital ant, the Sentinel, and the Sergeant – for functionality before introducing the technology for public use.[2]

Since computer hackers have been able to create viruses that adapt to antivirus software, the ant swarm technology is growing due to its unique attacking strategy. The possibilities for ant swarm intelligence implementation are growing since society is so dependent on the cyberworld to communicate; eventually, this innovative technology may find its way into individual households. Without a top-of-the-line protection system, online users become vulnerable to threats in the cyber community. Thus far, studies have shown optimistic results regarding the digital ant spyware. There is a promising future for swarm intelligence as a dynamic approach to virus control on a personal computer level, even though currently it is only implemented in larger computer networks. Using this biomimicry application to improve technological devices and shelter computer systems from danger is the forefront of contemporary computer science research. Scientists and researchers are learning from nature to improve the current defense practices, which are expected to guard the complex computer systems the government uses to protect the nation. Technological networks will be at an advantage by implementing ant swarm intelligence because the digital ants have the unique ability to find and conquer threats directly.

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Termite Mounds to Modern Ventilation

Gabrielle Rejouis

Solomon writes, "Go to the ant, O sluggard; consider her ways, and be wise."[1] Mick Pearce, an architect who looked to this insect for inspiration, shows that there is much to be learned from ants. Pearce modeled the ventilation system of the Eastgate Centre, located in Harare, Zimbabwe, after termite mounds. After studying how termites maintain a consistent temperature in their mounds, he was able to use this to model the ventilation system of the Zimbabwe building which hosts offices and retail space. The Centre implements the design in order to be eco-conscious in its use of energy, to heat and cool the building, and to save money.

Pearce changed the face of architecture by his use of biomimicry. He earned his architecture degree in London, and now uses sustainable development in his design as a part of his desire to be conscious of the environment and build structures that coexist with nature.[2] Pearce uses biomimicry to pursue his passion for learning from and imitating nature's use of renewable and reusable energy to improve structures. He designs his buildings to benefit both the environment and those who live in it.[3] For the Eastgate Centre, Pearce drew inspiration from a termite mound.

The design of termite mounds combat the drastic temperature changes of Zimbabwe, which can range from 35° F to 104° F.[4] Termites need to maintain the temperature in their mounds at 87° F to grow their food. By using vents inside the walls of the mound, they are able to maintain this temperature despite a drop or rise in temperature outside. To cool the mound, air is drawn inside through tunnels with wet walls. As it enters the tunnels, the temperature of the air drops and the warmth of the air moves into the cooler muddy walls. The difference in air temperature then creates a vacuum, pulling warm air to the top and out of the mound while air from the outside of the mound is drawn in. Termites are able to create new vents or destroy preexisting ones to either lower or increase the mound's internal temperature.[5]

The ventilation system in Eastgate Centre was modeled to mimic the system in termite mounds. The Centre has no boiler to heat the building or air conditioning to cool it, but yet it remains between 70° F and 77° F because it is cooled using passive cooling ventilation. Like the tunnels created in the termite mounds, concrete elements facilitate the heat transfer which the building employs for cooling. These elements function as the muddy walls, absorbing the warmth in the air and minimizing the need for air-conditioning. During the day, air is drawn in at the street level through a chamber. Next, the incoming warm air is cooled as it comes into contact with concrete slabs. The cooler air is then dispersed through large "vertical ducts," cooling the Centre just as the tunnels disperse cool air through the mounds. Using the same principles as in the mounds, warmer

air is forced out of the building through chimneys where a vacuum is created, drawing in new warm air which starts the process all over again. At night, large fans are used to reduce the building's temperature for the next day.[4] This method to reduce temperature is similar to how termites apply more mud or build new tunnels to keep the air in the mound cool. Through this method, the Centre saved 3.5 million dollars during its first five years and used only one tenth of the air-conditioning other buildings use, annually saving thirty-five percent on energy costs.[6] Therefore, the eco-friendly design also provides monetary incentives that may attract architects and engineers to apply this model of ventilation.

Other architects are also simulating nature in their designs for environmental and financial purposes. For instance, creating walls that behave like skin or leaves provides an eco-friendly alternative. These walls can adjust to changes in lighting to reduce electricity use and purify rainwater, thus reducing the use of natural resources and the utility costs of water and electricity.[7] Furthermore, buildings with designs drawing from kapok trees have the ability to absorb the force from hurricanes and conserve water in times of shortages. Another way designers minimize damage caused by storms is by encircling a building with shrubs and trees. These structures utilize nature's methods to counteract water damage and help sustain communities in areas that suffer from flooding or drought, thereby minimizing the costs of rebuilding after disasters and decreasing the rise in water rates during droughts.[8]

Looking to nature for inspiration can save money and lessen the carbon footprint left by mankind. The use of biomimicry in architecture, as in the Eastgate Centre, only simplifies the maintenance and upkeep of buildings with almost no major drawbacks. In the Eastgate Centre, the ventilation system does not use much electricity and as a result reduces costs in addition to creating a smaller carbon footprint. Models like the Eastgate Centre demonstrate how humans can adapt to nature's forces by using methods employed by nature itself. Architecture is advancing by adapting the systems nature employs to become more conscious of the environmental impact buildings make and to address environmental problems.

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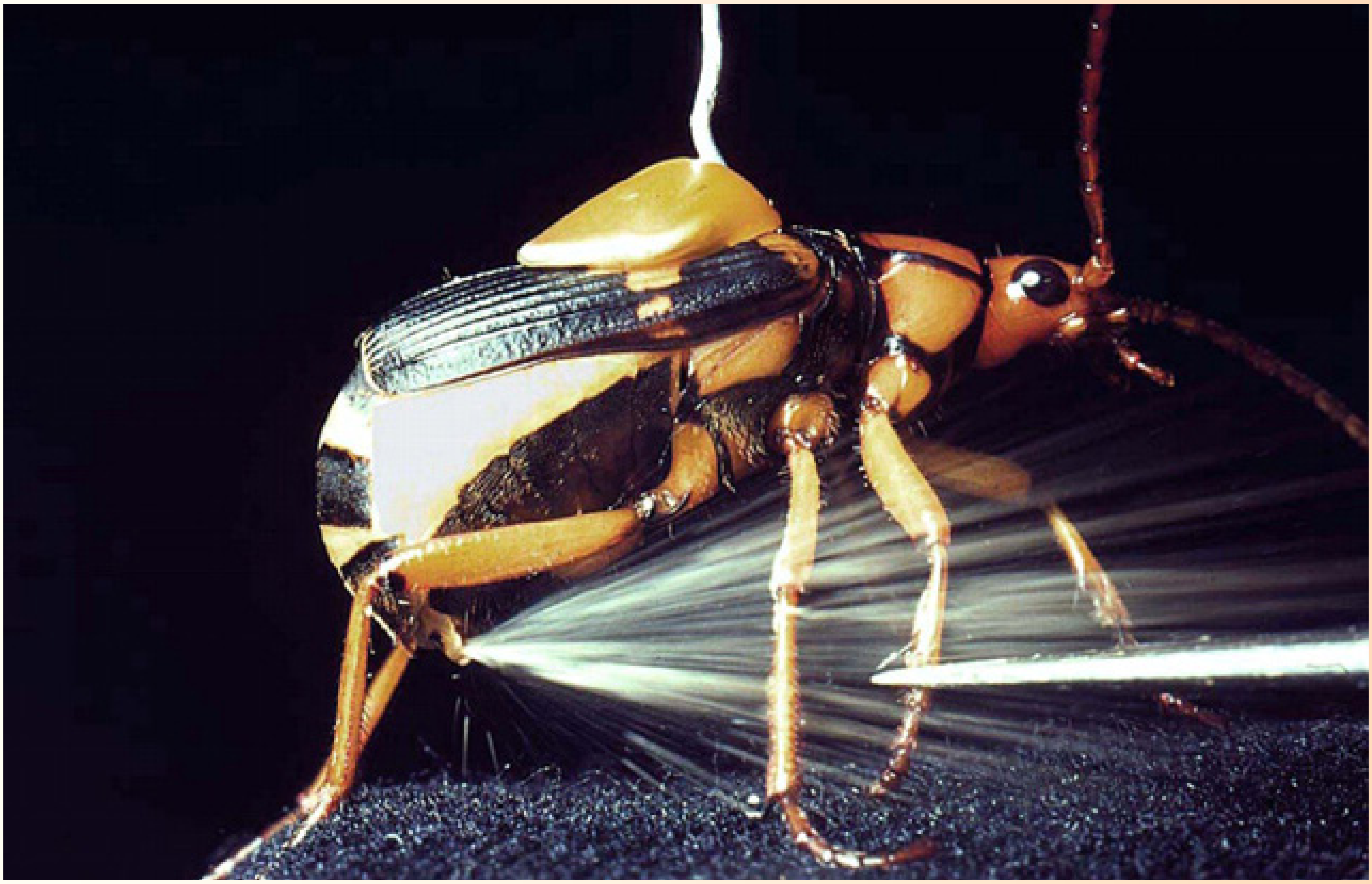

Bombardier Beetle's Toxic Spray Leads to Mist Innovation

Jennifer Ligo

The small bombardier beetle is making a huge impact on the future of various commercial products. This beetle's defense mechanism has been an inspiration for "future fuel injectors, medical inhalers, and even personal care aerosols."[1] Other applications range from airbag inflation to needle-free injection. Industries ranging from manufacturing, pharmaceutical, energy, perfume, and agrochemical can benefit from the technology based on the bombardier beetle. Its unique and powerful spray mechanism holds a lot of potential for helping model more efficient technology in mist systems. Applying the mechanics of this beetle's defense system can bring about significant improvements in the efficiency and environmental effects of sprays and mists. The research needed for industry to implement this new technology is being done at several universities, at times with corporate sponsorship.

The bombardier beetle is a member of the family *Carabidae*, better known as the ground beetle. These beetles can be found in the temperate woodlands or grasslands of Africa and Asia. They are about two centimeters long with vestigial wings, which cannot be used for flying. Since the Bombardier beetle cannot escape predators such as ants, birds, and frogs by flight, it compensates by using a hot, toxic spray released at 100° C for defense. The spray travels a distance of approximately twenty centimeters at a speed of 500 pulses per second from the tip of the beetle's abdomen.[7] As an added defense, bombardier beetles can also rotate the tip of their abdomens up to 270 degrees, which allows them to spray a predator in nearly any direction of attack with impressive accuracy.[2] There are two glands in the beetle's abdomen that play a role in making the toxic spray: one that produces hydrogen peroxide, and another that produces hydroquione. These two chemicals from the glands are mixed with enzymes – namely catalase and peroxidase – in a unique, thick-walled "explosion chamber" in the beetle.[2] The enzymes accelerate the reaction until the beetle, using oxygen as a propellant, ejects the boiling water and chemical stream in the direction of its attacker. This action creates an audible sound, a "pop," which also helps to scare off predators.[3]

Extensive research on how to mimic the techniques of the bombardier beetle has been conducted at the University of Leeds in the UK by Professor Andy McIntosh, who specializes in thermodynamics and combustion theory. In 2001, he began studying the beetle with MSc students, drawing inspiration from a paper by Dr. Thomas Eisner, a chemical ecology professor at Cornell University. For Dr. Eisner, high-speed pictures of the beetle spraying the chemical deterrent led to an interest in researching the design of this beetle's abdomen in 1999. McIntosh was intrigued when he saw that "[the] beetle seemed to have its own combustion mechanism" unlike any other.[1] The work by McIntosh and his students at the University of Leeds School of Process, Environmental and Materials Engineering gained funding for three years from the Engineering and Physical Sciences Research Council (EPSRC) in 2004 to work on the computer modeling of the beetle's mechanics.

The focus of the research was to determine how the beetle formulated and controlled the chemical spray it used against predators. Using computational fluid dynamics, McIntosh discovered that high pressure inside the beetle was key to how the beetle forced out fluid at such a high speed. This worked in a way similar to a pressure cooker. After examining the beetle carefully, it was found that there was an inlet and exhaust valve. Chemicals would enter through the inlet valve where they would meet and begin to boil. Once enough gas was present, heat would generate. When muscles forced both valves to close, the fluid would be under increased pressure for "a split second" until the pressure reached a critical point and the "exhaust was suddenly released," all through the process of flash evaporation.[1] At this point, the beetle would be able to target its attacker and have "the ability to change the rapidity of what [came] out, its direction and its consistency."[4] All of these properties, if studied and replicated, could mean significant innovations in multiple industries. McIntosh reported that "nobody had studied the beetle from a physics and engineering perspective as we did - and we didn't appreciate how much we would learn from it."[4]

"Nobody had studied the beetle from a physics and engineering perspective as we did - and we didn't appreciate how much we would learn from it."

The initial research began with curiosity about the way the beetle's defense mechanism worked and this has now led to a commercial innovation. McIntosh met the founder of Swedish Biomimetics 3000 Ltd. at a biomimetics conference in 2004. The company's purpose is to develop and market biomimetic technologies. Swedish Biomimetics 3000 Ltd. sponsored McIntosh's project for five years so the prototype could be developed from the initial concept, and is now licensing the technique for industrial applications. With the company's help, Professor McIntosh along with other researchers, including Novid Beheshi from Swedish Biomimetics 3000 Ltd., were able to create µMist®, an innovative spray system. The researchers developed an experimental rig to model what they had learned from the bombardier beetle. They were able to essentially replicate the mechanisms of the bombardier beetle by creating a similar cylindrical explosion chamber of approximately a half inch long with water in place of the toxic venom. One important thing they learned was that "the beetle could generate a high frequency spray at very low injection pressures," and this was a huge driving factor for the rig design using CFD (Computational Fluid Dynamics) models.[1] Additions were made to each new model of the rig to improve its performance and better emulate the properties of the beetle. Using heat and flash evaporation techniques, the experimental rig could propel fluids up to 4 meters at a speed of 25-30 pulses per second.[5][8] It could also produce a mist with droplets as small as two microns.[4] This research is continuing at Leeds and at a development laboratory focusing on improving the results of the research and furthering commercial improvements. Such development is of great significance because this technology allows for advancements in several applications where "properties of mist are critical."[4]

Research on the bombardier beetle has been creating many new technologies. There is now the potential for optimizing spray, controlling droplet size, temperature, distribution, throw distance and velocity.[5] If these properties can be closely controlled, there is potential for much advancement in spray technology. The μMist® focuses on areas involving drug delivery systems, fire extinguishers, and fuel injection. A major plus for this system is that it can be more reliable than traditional "mechanically-driven spring technology in, for example, inhalers."[6] In fire extinguishers, the mist size could be controlled and changed depending on the type of mist best suited for putting out a specific fire. This means that extinguishers would become more effective. McIntosh noted this would be particularly useful for extinguishing fires on spacecraft, for which micro mist and a small amount of water are needed.[8] In airplane engines, this beetle-inspired technology may be the key to re-igniting a gas-turbine engine during flight.[7] Combustion engineers could also develop this technology to accurately squirt plasma into the aircraft's combustion chamber mid-flight if required.

Furthermore, there is a great desire to reduce negative environmental effects in the automotive industry, and this technology could lead to a more energy efficient mechanism for fuel injection. Swedish Biomimetics 3000 Ltd. is working with its partners to create a market-ready system for vehicles. In fuel injection, the burning fuel can be optimized by having a smaller droplet size, and an injector that operates at lower pressures with less energy input. At this lower pressure, the cost of manufacturing new injectors falls, which then encourages users to install the new technology. In the future, the company hopes to extend this technology to rail systems, where there is also a demand for lower fuel consumption and green technology. The proposed system is water-based and would also allow for reduced carbon and other emissions, including UBHC and particulates, which all cause severe environmental issues.

The research and work done by the University of Leeds and Swedish Biomimetics 3000 Ltd. "received the outstanding contribution to innovation and technology title at the Times Higher Education awards in London" back in 2010.[5] As McIntosh commented, "copying such natural mechanisms is a part of the growing field of biomimetics where scientists learn much from intricate design features already in nature."[7] Many other people have followed in researching the workings of the bombardier beetle; for example, some have used mathematical models to show the discharge pattern and more. The mechanisms of the bombardier beetle have certainly caused a great deal of innovation already and will likely continue to serve as inspiration for future commercial enhancements in different areas of technology, as more is learned about the beetle.

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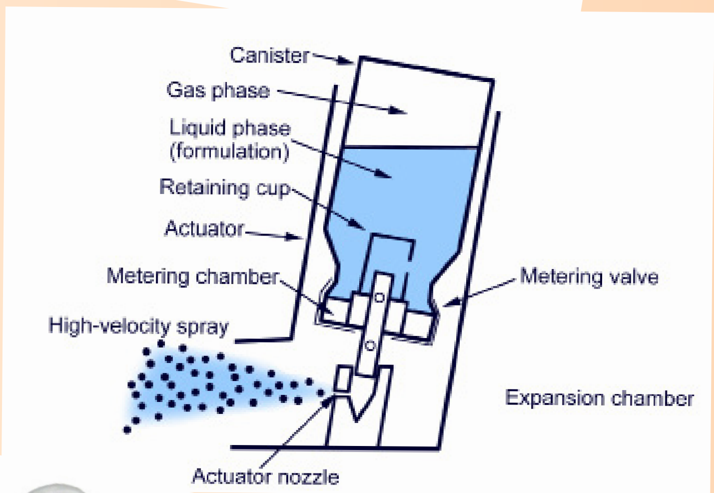
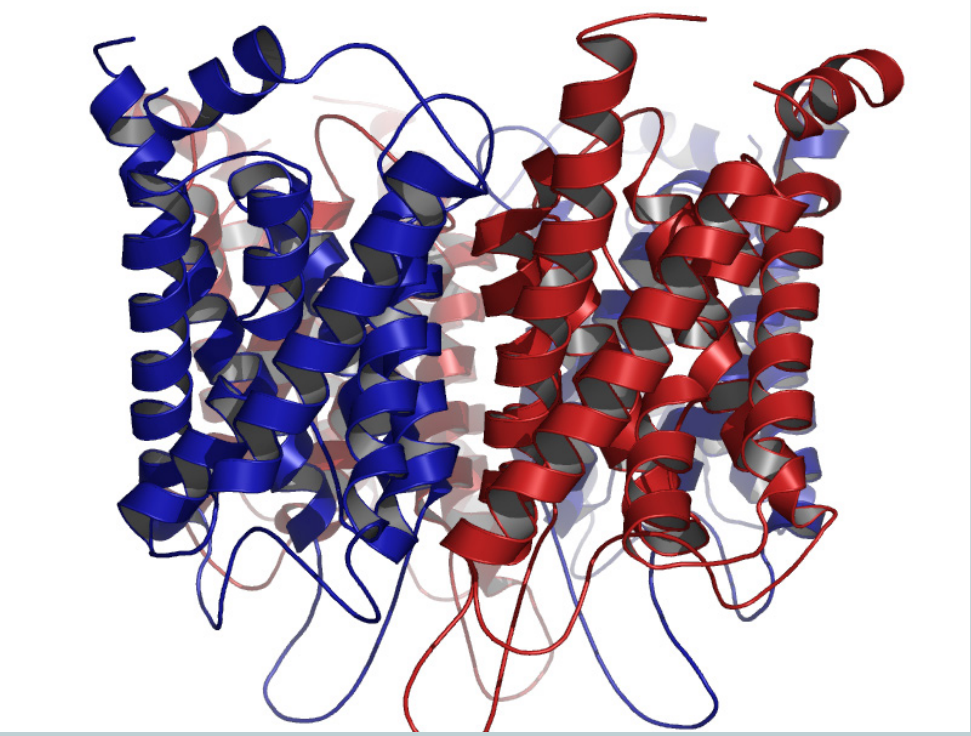


Aquaporin-Inspired Desalination Techniques

Jeffrey Samuel



With the population growing exponentially, is there enough freshwater to support everyone? Desalination, a process that removes salt and other minerals from saline water, has become an important process to meet the increasing demand for freshwater.[1] The availability of freshwater in many regions around the world is limited. There are not nearly enough freshwater sources to quench the thirst of every individual, and so desalination methods provide a way for people who have access to impure water sources to attain drinkable water. Consumption of large amounts of salt water is deadly, and for thousands of years different methods have been used to remove salt and minerals from water. Low-temperature thermal desalination (LTTD) has been a desalination technique that has been used for hundreds of years. Since water evaporates at lower temperatures and lower pressures, environments have been created that foster these conditions to produce purified water. However, although this technique produces freshwater, it requires a copious amount of energy to create a temperature gradient. Due to the energy consumption required, scientists have looked into how biological membranes in the body function, in order to create new technologies that will desalinate water in more ecologically friendly ways.

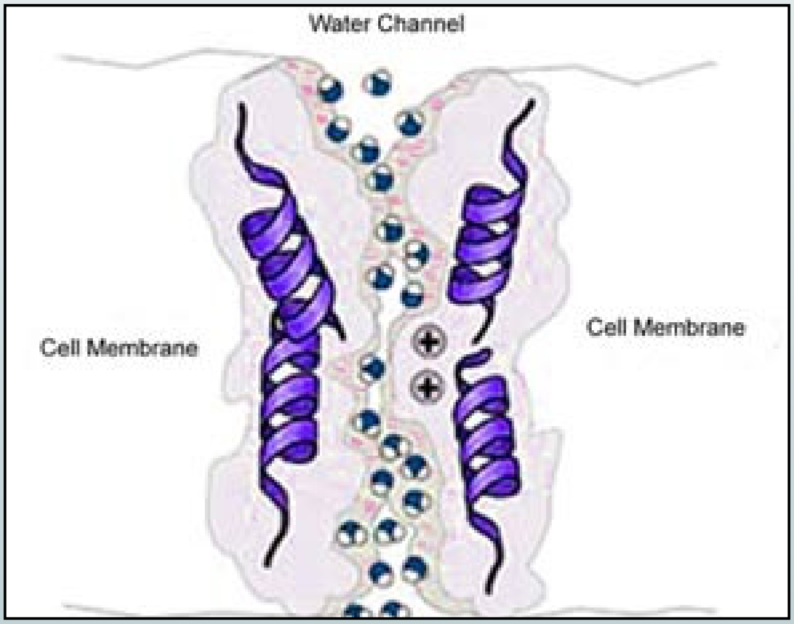
> "Consumption of large amounts of salt water is deadly and for thousands of years different methods have been used to remove salt and minerals from water."

By learning from biological membranes in the body, it is possible to produce membrane-like filters with higher selectivity and permeability for new desalination techniques.[2] Biological membranes contain integral membrane pore proteins called aquaporins that are responsible for the plumbing system of the cell. These water channels allow the flow of water in and out of the cell membrane while also preventing the passage of ions and other solutes.[3] The aquaporin's unique combination of high water permeability and high solute rejection, make it an ideal candidate for analysis by scientists who want to apply these same principles to desalination methods.

Current methods for desalinationare driven by the idea of a membrane that selectively purifies water with reverse osmosis, a type of desalination method that is used to produce the greatest amount of desalinated water. In this process, pressure is used to push water through a membrane, which is similar to a cell membrane, and allows the flow of water but prevents the flow of particles such as salt. This desalination technique is an effective method;

however, the membrane tends to clog up with solutes or bacteria. The clog then hinders the flow of water, and eventually water flow stops completely.

The application of aquaporins has not yet been realized commercially. This new technology will require some time to catch on because companies are still sticking to high-priced factory machines for desalination. Once this membrane concept takes full effect, desalination can become a technology that propels the economy forward. This idea revolutionizes the field of desalination and allows both big business owners and environmentally friendly consumers to shake hands.



As mentioned earlier, present desalination methods use the biological membrane concept and apply it in conjunction with the process of reverse osmosis to create purified water in an energy efficient manner. Due to the problem of membranes becoming clogged, new membranes have been developed since then that have improved water flow; however, clogs are still an unavoidable problem. Improvement in this membrane technology is on its way, but reverse osmosis has not produced high quality water. In one example, reverse osmosis was only able to generate quality water after it was treated with chlorine. In this situation, the chlorine that was used to treat the bacteria ended up causing the membrane to deteriorate.

Although these problems exist, research is being conducted to create new membranes that will purify water in a faster and more efficient manner. New membrane preparation strategy applies both aquaporin and vesicle concepts to create a new thin-film membrane.[2] In comparison to previous methods, this technology is more affordable and easier to repair. Vesicles are small membrane-enclosed sacs within eukaryotic cells that help with the transport of materials the cell requires. These vesicles can enclose certain substances the cell wants and send it from one region of the cell to another region. Applying this vesicle concept to membranes will allow the transport of water molecules across the membrane in a quicker and more efficient manner. The incorporation of these vesicles has produced significantly higher membrane permeability, which can fix the problems that limited the initial production of aquaporin-based membranes.

With the field of desalination beginning to embrace these new aquaporin-based concept membranes, it is not unlikely to see people around the world using this technology to provide freshwater to individuals who do not have access to this vital resource. Aquaporin-based membranes have reduced the high energy costs of desalination methods and produced an environmentally friendly method that will benefit many individuals. With further research, this technology will revolutionize the current market and produce water that is both fresh and free of harmful solutes.

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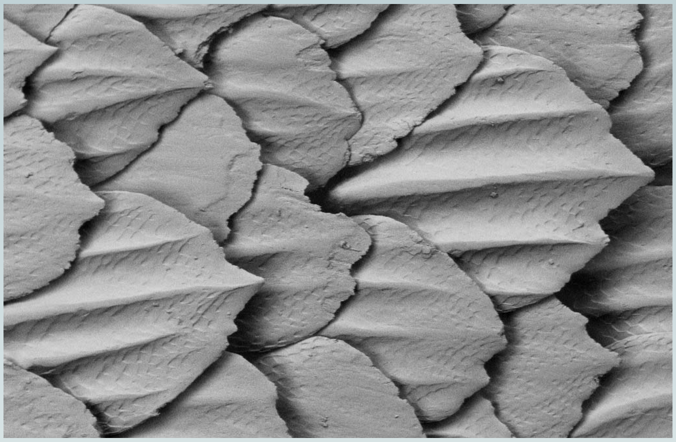
How a Killer Shark can Save Your Life

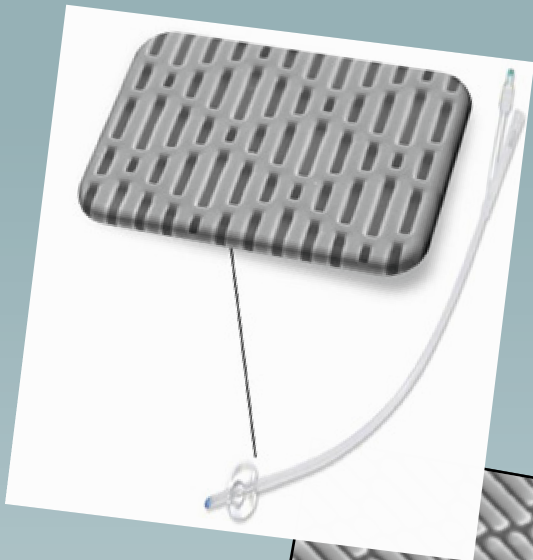
Mohammad Nawaz

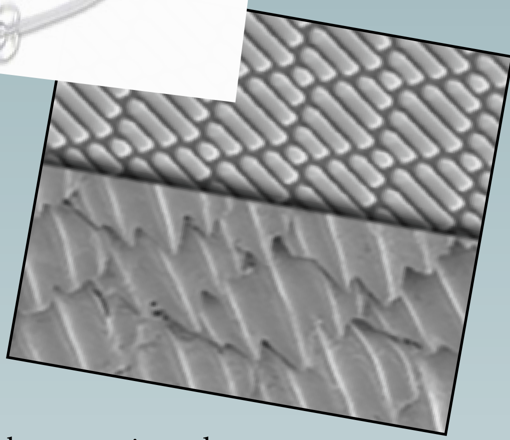
Hospitals are not entirely clean; far from it actually. Due to the overuse of antibiotics, which has given rise to super-resistant bacteria and an increase in nosocomial infections, hospitals are not as sanitary as they once were using the standard protocol for cleanliness. Alexander Fleming, inventor of the penicillin antibiotic, began studying a type of resistant bacteria, *Staphylococcus aureus*, in 1929.[1] He saw that among the bacterial strains he treated with penicillin, *S. aureus* continued to grow. What Fleming observed was that the few bacterial colonies that survived the treatment reproduced and gave rise to a generation more antibiotic-resistant than the previous one. Abandoning the conventional approach of treating bacteria, the solution to this growing problem may lie in something out of the ordinary: sharkskin.[2]

Today, *S. aureus* is one of the toughest bacteria to kill due to its high level of resistance to numerous antibiotics such as methicillin and amoxicillin. Methicillin-resistant *S. aureus* (MRSA) can cause various diseases, including meningitis, endocarditis, and osteomyelitis.[3] Doctors often prescribe increasingly potent antibiotics to combat the spread of drug-resistant bacteria such as *S. aureus*. Simply a palliative, this “solution” is counterproductive, since it can produce more resilient strains in the future.



The main technique of survival used by MRSA colonies is attachment to abiotic surfaces by a few bacterial cells and then rapid reproduction to eventually form bacterial communities. These agglomerations, called biofilms, increase the resistance of the bacteria by allowing it to anchor itself and encourage self-growth in clusters.[4] With this method, strains of MRSA have high drug-resistance and are able to grow in highly sterile environments, including medical instruments such as catheters in hospitals. Catheters are flexible tubes that are inserted into the body during surgical procedures to either administer medication or drain fluids. Use of





a contaminated catheter can introduce a bacterial infection inside the patient, which has led to 1.7 million nosocomial – or hospital acquired – MRSA infections every year.[5]

Dr. Anthony Brennan was one of the first scientists to seek a proactive solution to this problem, and he found his answer in sharks. Instead of using antibiotics on bacteria that have already attached to a surface via biofilm, his innovative approach can prevent the bacteria from attaching in the first place. Brennan was first enthused by shark skin when he and his team at the University of Florida studied the interactions between microorganisms and the surfaces to which they attach, in order to figure out how to prevent the accretion of bacteria to the underwater hulls of ships.[6] Dr. Brennan noticed how the shark is one of the few marine fauna that does not gather bacteria on its skin. He used this discovery to inspire a model that closely mimics the pattern of sharkskin and ultimately founded Sharklet Technologies, a company that manufactures synthetic surfaces, in 2007.[6]

Sharks have what are called dermal denticles, which are tiny, hard, tooth-like projections on their skin. These denticles are pointed backwards in a unified direction and in a diamond-shape pattern. They also have ribbed edges that protrude in a consistent width-to-height ratio. This formation is miniscule: each diamond-shaped segment is about 25 microns wide (one-fifth the thickness of human hair) and only 3 microns deep.[6] This uneven platform is able to hinder biofilm attachment because bacteria such as *S. aureus* need a flat surface on which to form a biofilm and survive.

Studies have shown a significant difference in biofilm growth between sterilized, flat surfaces and material with the Sharklet pattern. *S. aureus* took seven days to form a viable biofilm on a flat surface, whereas it took twenty-one days for biofilm to form on the Sharklet surface.[7] Furthermore, the biofilm on the Sharklet surface was clearly disrupted and very thin, forming small, multilayered colonies with very low chances of survival and lower chances of causing infections.[7] Compared to the Sharklet surface, a much more substantial amount of biofilm formed on the flat surface. Relying solely on the power of its pattern, Sharklet may be embedded into many plastic materials that are common in medical devices.[6] Since the surface structure is so miniscule, a catheter with the Sharklet pattern (image to the left) would neither feel nor function any differently than an ordinary catheter. Medical equipment has thus been manufactured with the Sharklet surface and proven to have reduced the occurrence of nosocomial infections.[8]

Sharklet is the first bacterial treatment that can inhibit infections while being safer for humans and the environment. It is simply the topography, not the composition of the material, that inhibits bacterial growth, meaning no bacterial resistance can develop to counteract Sharklet material or sharkskin itself. A revolutionary product, Sharklet offers to reinvigorate the field of healthcare in the fight against bacteria.

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Interview With George L. Collins

Fernando Arias

Dr. George L. Collins spent 30 years in corporate research and small business technology addressing critical technical and strategic business issues related to the physical behavior of commercial molecular materials. He has spent the last 10 years in the academic environment as Research Professor in the Department of Biomedical Engineering at New Jersey Institute of Technology (NJIT) and is currently Senior Scientist at the Medical Device Concept Laboratory (MDCL). He has over thirty patents and over forty publications, but, most importantly, he has been an exemplary mentor for many young minds at NJIT. Dr. Collins' research focus is on mimicking the extracellular matrix of articular cartilage using natural polymers for articular cartilage regeneration. In his lab, they use the electrospinning process to create nanofiber scaffolds using these polymers to mimic the extracellular matrix of articular cartilage.

When did you start working as a researcher in this field?

Dr. Collins: Specifically in the field of biomimicry, three years ago. We put in all this effort to electrospin collagen…because you really cannot spin collagen since it is not soluble unless you denature it. We went through quite an effort to isolate collagen from bovine tissue. We were doing this ourselves at the time. Other people were taking it and putting it in trifluoroacetic acid to electrospin. We knew it was not native collagen when it came out because it was soluble. So after the paper, "Electrospinning Collagen. Just an Expensive Way to Make Gelatin," was published, we said why don't we just electrospin gelatin? That's how we started electrospinning gelatin from water. Then we started looking at corn protein because it is something you can grow, and the cost of extracting it is much less than extracting animal protein. So next we were mixing gelatin with sodium cellulose sulfate, and Gloria (PhD student in the lab) has been doing a lot of work on that. There is a suggestion that by using gelatin with sodium cellulose sulfate, she has produced this mass that she suspects to be the elusive cartilage-like tissue. So once we were doing that, we started taking seriously the idea of possibly mimicking the extracellular matrix [of cells], using plant-derived materials. The first effort towards this was by Jessica Cardenas (PhD student). She electrospun corn protein and carrageenan. Carrageenan is a plant derived from seaweed, has just the right amount of sulfate groups, and very closely mimics the chondroitin sulfate of cartilage. She electrospun zein protein and cross-linked it so we had something that was a mimic of the fibrous proteins in animal tissue, and the carrageenan has this advantageous property of being thermally sensitive. At a high temperature it is a liquid, but as soon as it gets to temperatures like 37-38° C, it gels right away. So she was able to take her electrospun corn protein, disperse it while it was hot, and just let it cool. Boom! We had this fiber-reinforced hydrogel with plant proteins that we were saying was mimicking the collagen of animal protein…all this in a plant hydrogel that was mimicking chondroitin sulfate. This was our first serious "total mimic" of the extracellular matrix using all plant-derived materials. Jessica put mesenchymal stem cells on the hydrogel, and sure enough these cells were attaching to the fibers.

What is next?

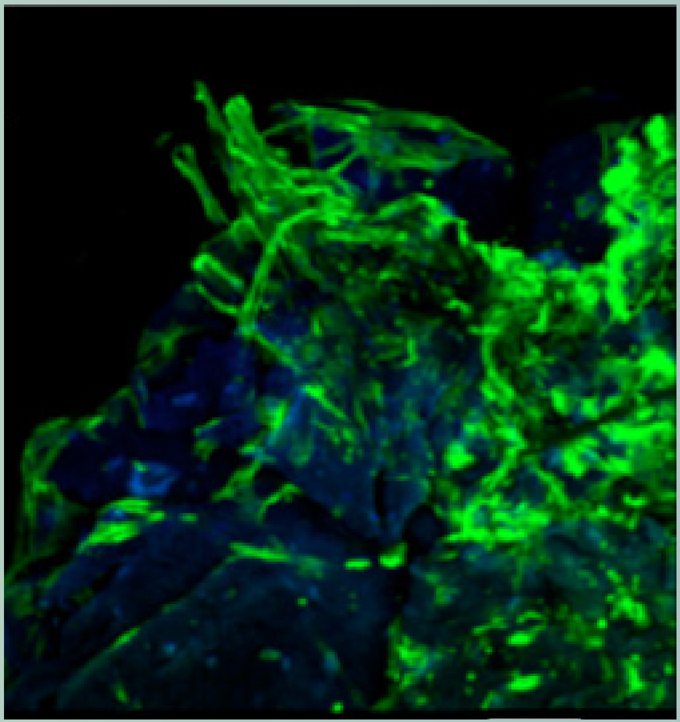
Dr. Collins: Well, we knew we did not have a high enough level of fibers. So we will have to increase the level of fibers and do the same thing again, and start to seriously add to the cellular response that was directed at this cartilage regeneration. We are using mesenchymal stem cells that differentiate into chondrocytes and produce cartilage tissue. Gloria's work has shown that there is some indication that if we do this, maybe we could find a construct to regenerate cartilage tissue. That would be the one that would make me rich (laughs)! This is a serious problem, and if we can solve this problem then we can actually get rid of having, or needing to have, so many hip replacement surgeries.

When you talk about regenerating cartilage, do you mean any type of cartilage?

Dr. Collins: No, we're talking specifically about articular cartilage: hyaline cartilage at the end of articulating bones, such as the knee, your hip, the elbow, your fingers. Our understanding of the mechanical properties of this articulating material is that it is a fiber-reinforced hydrogel. Since it is a hydrogel material, we can understand why it has this low friction. But at the same time because it is a composite material, it is very strong. Our first effort is trying to get cells to reproduce outside the body or inside the body if we give them the right cues.

What techniques do you use for creating scaffolds for tissue engineering applications?

Dr. Collins: We do a lot of electrospinning. This is an electrostatic technique for producing fibers with diameters smaller than one micron, so into the nanofiber range. Basically we take a charged solution of polymer and we use the electrostatic force between a spinneret, typically a conductive needle, and a grounded collector. Because it is charged, as it travels to the grounded plate, the charges on it repel each other and because of this electrohydrodynamic phenomenon, the fluid actually stretches out. This happens very rapidly because the electrostatic forces are pretty high. The drawing force allows the filament to go from about half a millimeter – we spin with needles that are maybe half a millimeter in diameter – and then we end with filaments after the solvent has evaporated anywhere from 500 to 150 nanometers. In the spectrum of nanomaterials, this is an "easy" way to make fibers at the nanoscale level. It is an easy experiment to conduct; difficult to control sometimes and difficult to understand in terms of why it happened, especially when it doesn't happen the way we want.



Can you talk about another project you've worked on, maybe in collaboration with another colleague?

Dr. Collins: I've worked with Dr. Arinzeh on bone work that she has done involving the electrospinning of fibers with nanoparticles of hydroxyappetite and other ceramic materials. She found that this facilitates the differentiation of stem cells to osteocytes, bone cells, and to add to that, it also accelerates bone growth.

What are some other things that are being done here at the MDCL?

Dr. Collins: Dr. Jaffe is involved in the development of raw materials for industrial polymer applications. For example, replacing bisphenol-A (BPA). It is a crosslinker that has been used industrially for years. It turns out that BPA has these properties – interactions with biological systems – that cause the production of estrogen. There are also plasticizers which are used in polyvinyl chloride that are considered carcinogenic, but they use them in blood bags. So Dr. Jaffe has been working on an isosorbide-based plasticizer for polyvinyl chloride, which would not have toxic properties.

In your opinion, how important is stem cell research to the field of biomimicry?

Dr. Collins: It is very important because we have to make materials that will give these stem cells the proper cues to differentiate in the directions we want them to go. For example, mesenchymal stem cells can differentiate into chondrocytes that will produce cartilage, or osteocytes that will produce bone. So controlling these differentiation paths has to do with not only the types of cues you give them chemically, like growth factors, but also with what you use as a scaffold. In its most optimistic realization you have a device – a scaffold that you can either inject or implant into a cartilage defect and have cartilage grow. That has such a big impact. If you can accelerate bone growth with some device that you can implant or inject, that would be an important development.

As the average life expectancy continues to rise, what kind of impact do you think this type of research will have on the health care field?

Dr. Collins: I used to have a lot of pain in my knees from actively playing baseball, basketball, tennis, and running track. I used to do all that stuff and as a consequence, I wore out the cartilage in my knees. As you get older you have these problems and if we could solve this cartilage regeneration problem that will have a big impact. There is currently no remedy to that because native cartilage tissue does not repair itself. This is because it's aneural, avascular, and alymphatic. So there are no new cells coming in to [repair the cartilage]. That is a big problem. As people live longer, the damage to their cartilage becomes more painful. Let's say there are 250,000 hip replacement surgeries in the US. It is one of the most common surgeries in the US and it is radical. They cut off the top of your femur; they stick this metal prosthetic into it; and then they have to reshape your acetabular cup to put in this ultra-high molecular weight polyethylene cup that the ball of this metal femur sits in. Your femur is not going to grow back so you're wedded to that prosthetic for the rest of your life. And the only reason they have to do it is because the cartilage between the femur and the acetabulum has been damaged or worn away. It is the thin layer of tissue that goes away that provoked the necessity of this radical surgery. So if we could regenerate or replace that thin layer of tissue – that will have a big impact.

Where do you see the field of "biomimicry" going in the next 20 years?

Dr. Collins: If the things we are working on are successful, we create a situation wherein we are able to treat serious disorders, serious loss of function, in a facile way. If this works for cartilage, for instance, it will allow a simple treatment for a profoundly painful loss of function. In general, we are looking at being able to produce something that can simply be put in the body to restore function. The simplest example is the intraocular implant. If you have the late stages of cataracts, you cannot see. So they replace your natural lens with a polymethyl methacrylate-based lens and you can see again. This can be done in about 30-45 minutes. You are not actually fully anesthetized, and when you walk out of the hospital that day, you can see again. It is amazing. They used to have complicated procedures to try and remove the cataracts from your lens, but now they just remove the lens completely. This has become the new standard. So in twenty years, many complicated procedures will become simple procedures that will restore function.

Do you have any final thoughts?

Dr. Collins: Yes, I do. If any of this comes to pass, since I am part of this aging population, it will come to pass because you have learned about it, you understand it, and you start making these breakthrough therapies which will then just become THE therapy. So this is why we teach biomedical engineering here at NJIT. At the edge in knowledge. Thank you.

Fernando Arias *is a senior majoring in biomedical engineering.*

Interview With John Wolf

Monica Torralba

Professor John Wolf is a university lecturer in the Department of Humanities and Social Sciences at New Jersey Institute of Technology. In the course, "Science, Technology, and Society," Professor Wolf helps students make connections and find relationships between society and technology. Through an exploration of history and hands-on assignments, students can see that technology also affects and is affected by politics, economics, and culture. We must see these sides of this technology in order to gain a more thorough understanding of biomimicry and its impact on us.

Do you think that the economy is growing because of this biomimicry trend or degrading?

Professor Wolf: If we look at biomimicry as part of a larger trend, in the West especially, I would say yes. We are witnessing this huge boom in that sector of business and technology. In the last two decades we have had the natural and organic food movement, hybrid cars, alternative fuel sources, wind power, and global warming. Several presidents ago, they wouldn't have talked about this in the election cycle and now you really can not get through an election cycle without someone addressing the green movement, global climate change, or the effect we are having on earth. So if we situate biomimicry in that sphere, I think certainly there's a robust economy sub-sector that's growing.

Do you think the East Coast will adopt this green movement as much as the West Coast or are we too industrialized?

Professor Wolf: I mean in some ways we have adopted it, right? In some ways we haven't thought about. Just think of city living. Not everyone can have a car; and so that's a lower impact on the environment because it is an urban space. There's also public transportation. In some ways we have adopted it, but we're just not labeling it as part of the green movement. It feels in some ways that the West Coast presents itself as environmentally friendly but cities like Los Angeles

and San Francisco continue to build out. They may use hybrid cars but is that a solution to our problem or is that a Band-Aid to a wound that is going to continue to grow?

When I think about the financial world, I think people can take advantage of other people's sensibilities. A good example of this would be saying phrases like "all-natural ingredients". Well, corn syrup is technically a natural ingredient. It is just a fructose that is made from distilling corn, but we know that in large quantities, it's terrible for you. So I think you can be deceptive in other times in trying to capitalize on what the green movement is all about. This is what is going on with the whole GMO labeling movement. People don't want genetically-modified organisms in their food. When you look at what's happening in the EU – they require it by law for GMO's to be labeled. No one wants to have the conversation of what GMO's can possibly do to biodiversity or our food source.

I hear NJIT's foreign students saying that "tomatoes are not that big in my country" or "apples are not this big." It could be a good thing because it feeds more people.

Professor Wolf: Absolutely, I think it's important to get that information out there. Consumers should get the last decision. That's why I support the GMO movement. No one's saying you can't sell these products but it's saying the consumers should be able to have the choice to buy the product that they want to support. So much of our food is engineered. Going back to your question about the east coast and west coast, I think that they can have better produce because of their seasons. The East Coast also has the greatest concentration of people in the smallest area. There's a huge carbon footprint to ship all our food here - either globally or from the more temperate West or South.

I guess their whole attitude exudes eco-friendly.

Professor Wolf: You do get that, don't you? I feel like the West is a lot more friendly – just the whole idea of it. And I think that's consistent with a lot of stereotypes we have about the West compared to the East. You look at the east as a hub of finance and economic activity. I think the East can earn itself a reputation for becoming a great center hub if someone can justify to capitalists that there's a way to make money in doing it – being green. It has to make economic sense.

I guess it will just take time is what you're saying?

Professor Wolf: There are ways in making money. I have friends who work as sustainability consultants or sustainability specialists for large government operation sites. I have friends who live in cities and they have met such resistance because they do small things that additively make a big difference. Things like the type of light bulbs you use to non-idling vehicles to changing paper types to distributing digital platforms for document distribution so you don't have to photocopy 500 things.

Why did people resist them?

Professor Wolf: Why? Because people are used to doing things the way they are used to doing things. If they had to devote time and resources to studying and implementing new quote unquote green policies, yes, it might save them a little bit of money or over time a lot of money; but in the immediacy, there is no huge pay-off or return for doing that. If you are a business and your bottom line is to make money and you want to help the environment too but that's not what your business does, you know. So until someone comes up with this model or incentive or formula to make people want to implement green policies then I think change will happen. Otherwise, it's going to be slow and not for a very long period of time. I mean, I don't use paper towels. People self-justify all the time. It is funny what we call eco-friendly; like those are things we don't think about, right? I once had a friend – he would get so mad when people threw away aluminum cans. Meanwhile he's coming home from the store with a 16-pack of paper towels. That is not eco-friendly. We consume and use paper towels like crazy. It is because it is so easy and convenient. Supposedly there's a huge garbage dump in the middle of the ocean. It is an atrocity, yet I go to Duane Reade and I get my plastic bag when I have about fifteen canvas bags in my apartment that I could have easily used. We should be introspective about this but I think it's also important for us not to feel self-righteous if you say "Well, I am the person who is going to buy a hybrid car or design a house that is green". I mean that's great, but there are still so many ways in which we live our lives that are not compatible with that sort of philosophy. But we don't, for whatever reason, take that into consideration.

I will have to confess that I can't live without paper towels. The questions I have asked you in terms of living an eco-friendly life make me realize that I must look into what I do on a daily basis.

Professor Wolf: Yes, I don't know what the intervention is there. Sometimes I think it is not the press's job to fix this. I think people just need to be enlightened. I am not proposing a solution. It is just – are you aware of all of this? And your individual role in all of this?

Do you think the effort to mimic nature in technology is beneficial to society?

Professor Wolf: I think it is beneficial – with an asterisk. We shouldn't become too sanctimonious about this area that we don't think about complications in other areas. When it comes to the creation of all of these digital devices, you hear companies say we can use iPhones and iPads to replace printing costs. At first it seems like a huge expense but over time it saves you a lot of money. There is this substance used in making smart phones and it is a rare earth metal. The harvesting of this substance has been such a controversy. Small and unstable governments in different parts of the world have rich deposits of this metal. They were being exploited for their ability to power these devices. What I am trying to say is it's good for technological progress but at the same time it created this potentially harmful cycle for this whole other group of people. Maybe at the end of the day, it's about net gain. If the net gain is for the good or the bad then that's how we evaluate decisions. There is never going to be a decision that doesn't somehow have bad side effects. In STS 201, this is parallel to our study in perspective towards the effect of technology on the world - if it is good or bad. You can't just assign a blanket value judgment to a technology. That would be an oversimplification. Everyone is going to have a different relationship with technology. It's all about perspective, ultimately.

Do you think biomimicry must be green or is it simply the application of nature in technology?

Professor Wolf: I think it could be both. I would think that because biomimicry is the replication of nature in a way that seems natural, it might not necessarily mean it's going to be "green" - either because of the process via which it is made, the result of it at the end, or how the product is used.

I think that the chemistry department or the environmental science department would say it must be environmentally-friendly because the irony of it would just be ridiculous.

Professor Wolf: This makes me think of the Haber-Bosch process. You can take this guy, Haber, and look at what he did as biomimicry. Discovering that the bacteria in the soil is what makes the soil nutritious, he finds a chemical process that would replicate the bacteria's ability to bring nutrition back to the soil. Unfortunately, in time the process was used for making explosives when it was at first used as a fertilizer.

What do you think about a universal course in green engineering for all engineering students? Should it be mandatory? Would it be beneficial?

Professor Wolf: I think it will be worthwhile. Part of the reason why I think it could be worthwhile is because engineers in particular are so great with logic. No doubt they will be great in what they do, but I think it's great for them to be forced to step outside of what feels safe and logic. They should know about the effects their technology has on the world. I'm not saying all those effects will be bad but we shouldn't just talk about the good or just about the bad. With anything that encourages introspection, I think it will be extremely beneficial.

Do you have questions of your own that you would like to pose to the public? According to your knowledge of society-technology relationships, what do you think the public should know or should ask themselves?

Professor Wolf: I do not know if I have a question but I am really fascinated with the idea of big data from the perspective of the individual. It is so easy to track data but you can also manually input data. I think it would be interesting if people could look at their consuming footprint for the course of a month or a year just in terms of: How many paper towels did you buy? How many miles did you drive in a year? How many train tickets did you buy this year? To look at that data collectively – people could say, "Wow, this is all me!" I think it would be arresting. We can then ask ourselves, "What can this garner about human existence in 30 years?" An app for this can exist in just terms of consumption. Apple already has this for sleep. The app can monitor your sleep cycle and show you when your sleep transitions.

Yes, so this can help with both time and financial management. You can compare the value of your consumption of paper towels to one wash cloth.

Professor Wolf: I think there is potential in this but at the same time it's scary to see your role in this. I mean, I might not want to know my role in all of this. We just have to know we're all part of this one big data we call life.

Monica Torralba *is a freshman majoring in chemical engineering.*

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Opening Image:

Page: 3
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Image of NJIT:

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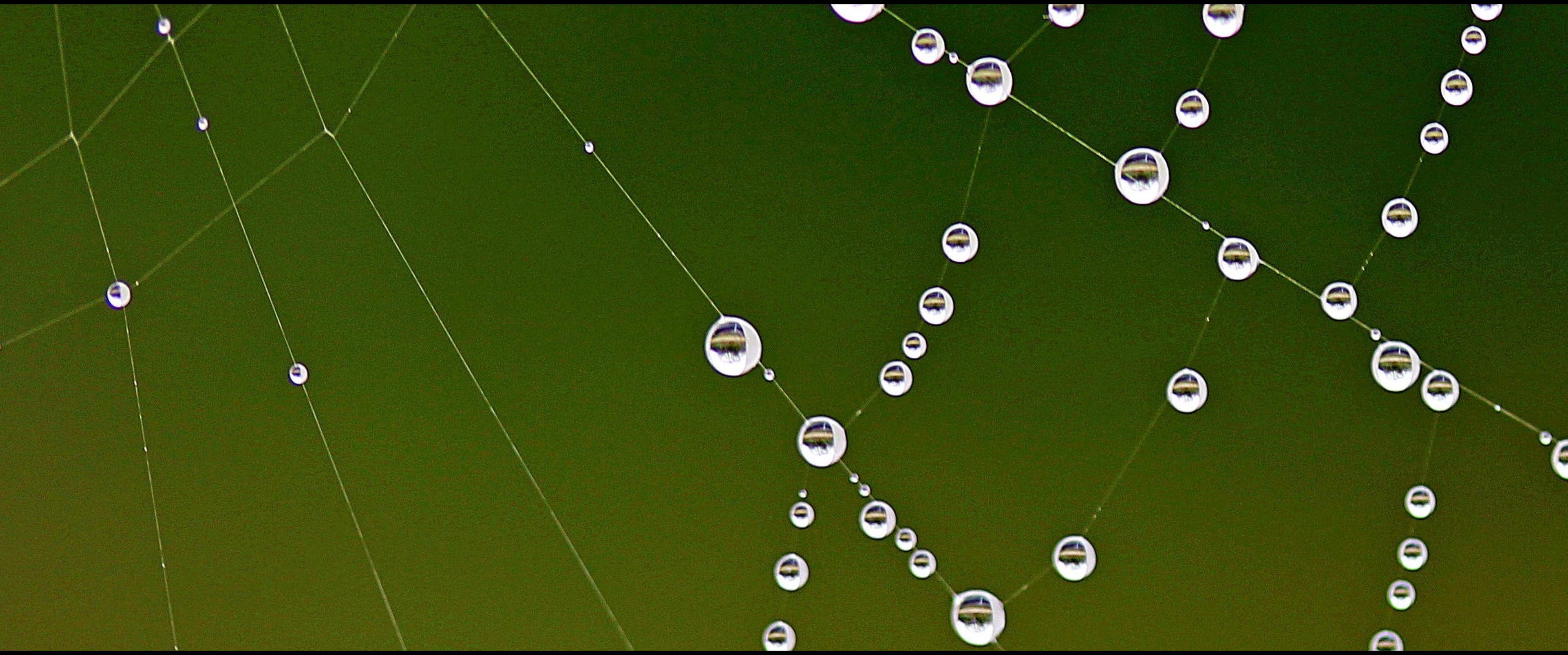
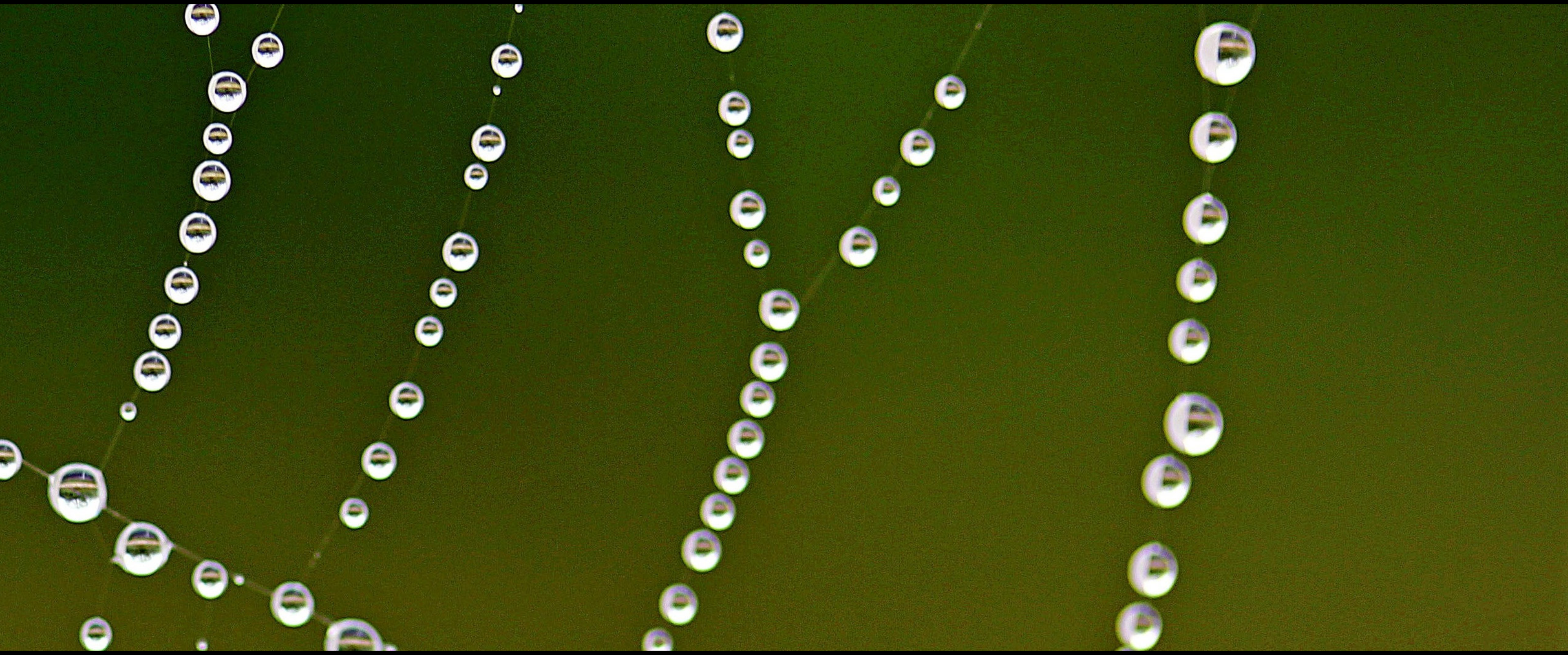
Closing Image:

Pretti, Fabricio. *Pearls Drops*. 2012. Digital image. Web.





If you have any questions, comments, or would like to join our team, please contact us at any of the following:

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