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About Zygote Quarterly

Editors

Marjan Eggermont

Norbert Hoeller

Tom McKeag

Contributing Editors

Adelheid Fischer

Raul de Villafranca

Kristen Hoeller

Manuel Quirós

Offices

Calgary

Mexico City

San Francisco

Phoenix

Toronto

Madrid

Contact

info@zqjournal.org

Cover art

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Design

Marjan Eggermont

Colin McDonald

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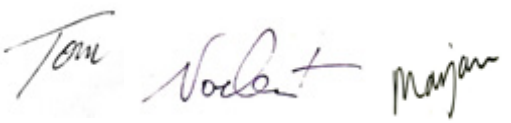
In Collaboration With

The National Aeronautics and Space Administration, founded in 1958, has occupied an iconic place in American culture since the days of the space race, when bespectacled engineers in white shirts, crew cuts and avuncular speech guided men to the moon. Innovation has always fueled their successes in space and nature has often been the inspiration. Indeed, NASA's early adoption of Velcro led to the popular misconception that the organization had invented it.

Today, NASA has many missions and nature has continued to provide models for invention in robotics, aeronautics and propulsion, vehicle design, structures and solving the challenges of living in hostile environments.

One section in particular, the NASA Glenn Research Center in Cleveland, Ohio, has made the study of nature a studied path to its objectives in its Virtual Institute for Bio-inspired Exploration (VIBE) program.

Join us for this special issue of *Zygote Quarterly* as the engineers and scientists of NASA mix it up with academics and industry experts in an uncommon event of cross-fertilization co-sponsored by the NASA Glenn Research Center, Great Lakes Biomimicry, and the Ohio Aerospace Institute. ×



Tom McKeag, Norbert Hoeller & Marjan Eggermont

The first Biomimicry Summit and Education Forum for Aerospace was intended to establish a convergence of diverse practitioners, disciplines, bio-inspired philosophy, tools, and research to benefit NASA, the nation and the planet:

- by bringing awareness of NASA's mission to biomimicry/bionics/biophysics and related communities,
- providing NASA researchers with access to biomimetic resources including subject matter experts, research and collaboration tools,
- and to develop a biomimetic framework for a healthy, relevant and sustainable biomimicry collaborative between NASA, academia, industry and other government agencies.

The proceedings of the summit are to be published on VIBE (Virtual Institute for Bio-inspired Exploration | https://www1.grc.nasa.gov/research-and-engineering/vine/). VIBE was founded by NASA's Glenn Research Center to fulfil NASA's missions (https://www.nasa.gov) through nature-inspired exploration on Earth and in space for the benefit of all life. The summit is intended to be the first in a series of summits that will serve as checkpoints for progress on collaboration activities as well as a dissemination and collaboration mechanism. ×

Organizing committee

Howard Thompson and Terri Deacey, Ohio Aerospace Institute

Trisha Brown, Great Lakes Biomimicry

Rebecca Kwiat, Alcyon Technical Services

Vikram Shyam and Aloysius Hepp, NASA Glenn Research Center

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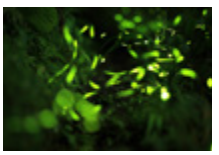
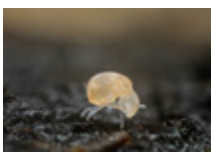
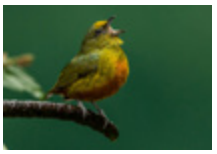
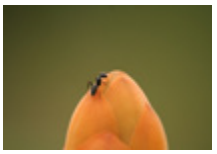


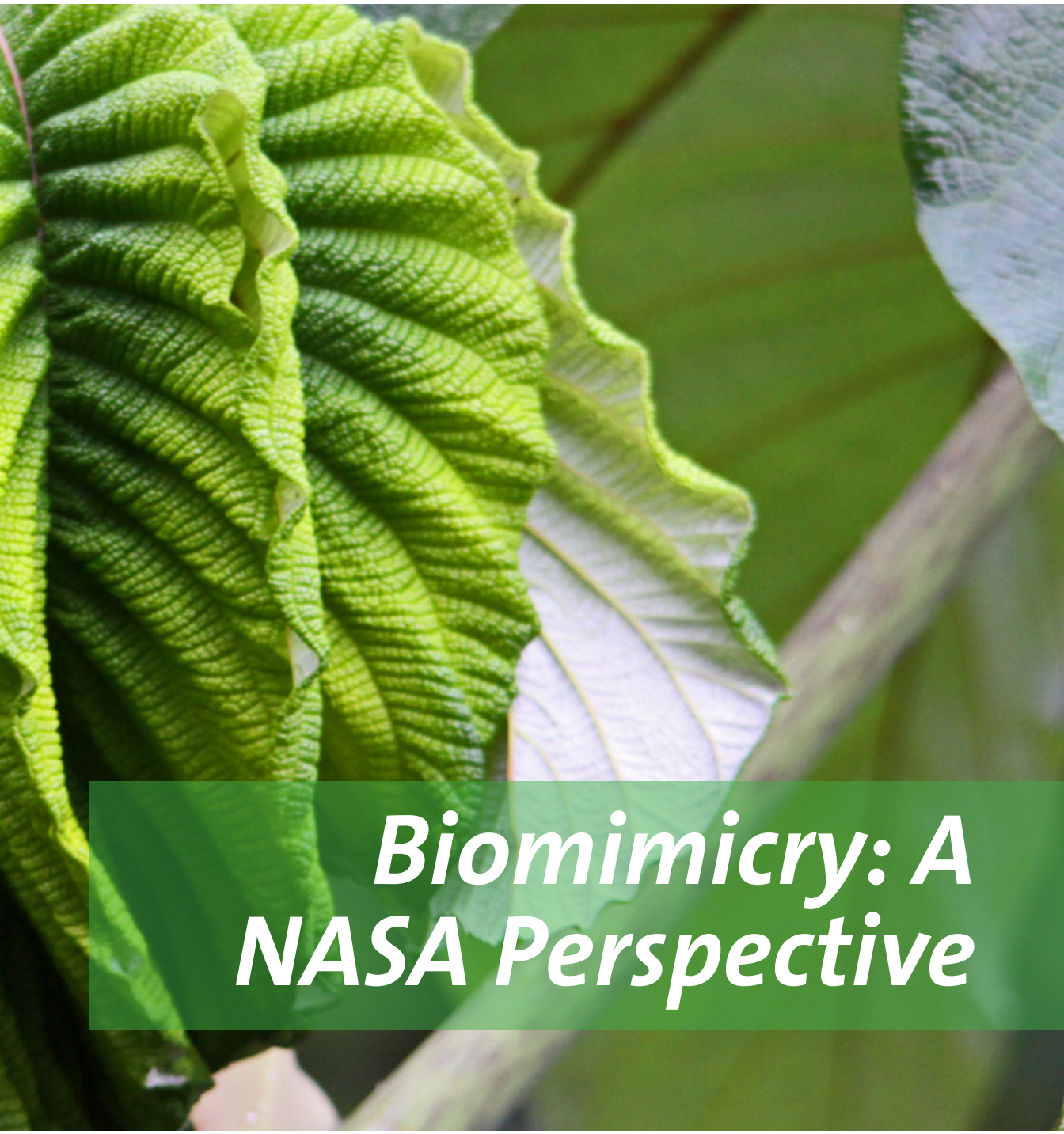






unfolding

Photo: vil.sandi, 2013 | Flickr cc



Biomimicry: A NASA Perspective

Vortex plants

Photo: Tom Bech, 2011 | Flickr cc

Interview

Vikram Shyam

special issue | **People:** Interview | **Author:** Vikram Shyam

Vikram Shyam is a propulsion flow dynamicist in the Turbomachinery and Turboelectric Systems branch at the NASA Glenn Research Center (GRC) in Cleveland, Ohio. He received his PhD in Aerospace Engineering from The Ohio State University in December 2009. Vikram leads NASA GRC's turbine technology development to reduce fuel burn and emissions for future generation aircraft engines. He is the founder and lead of NASA GRC's biomimicry group (Virtual Institute for Bio-inspired Exploration) that applies nature's principles to solve technical and institutional challenges at GRC. Vikram and fellow collaborators are studying the application of harbor seal morphology to wind turbine struts and gas turbine blades, probes, sensors and other objects that are subject to vortex induced vibrations or variable operating conditions. Other research areas and interests include energy harvesting, multifunctional structures, development of new concepts for in-space exploration, long range planning and STEM education. Vikram was recently awarded the Presidential Early Career Award for Scientists and Engineers (PECASE). He has received NASA's Early Career Achievement medal, the NASA Group Achievement award as a member of the GRC Creativity and Innovation (C&I) team, and the ASEI young engineer award.

Presentation title: *Aerospace Biomimicry and Other Cool Things*

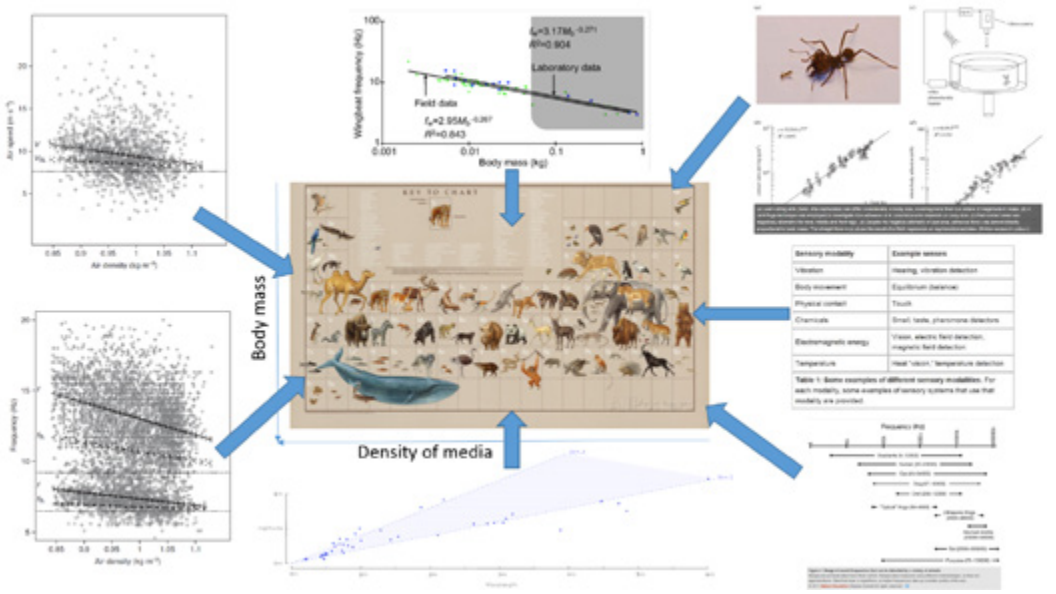
Abstract: Biomimicry, one of the hottest design philosophies of the day, has revolutionized the world we live in. We will explore NASA's biomimicry vision in the context of emerging fields like synthetic biology, artificial evolution, hybrid manufacturing and big data analytics. We then look to our distant past to learn how pterosaurs, stegosaurs and graptolites could help insure our sustained and healthy existence on Earth and beyond. Glenn's excursions into biomimicry will be highlighted with a focus on the technologies and collaborations that are needed today to achieve our vision of a future that is truly out of this world.

What are the key takeaways from your conference talk? How would you summarize your presentation?

My presentation was an introduction to the summit. It provided a high level overview of the purpose of the summit, the composition of the sessions and identified broadly some of the areas (tools and philosophy) that need to be considered to move biomimicry forward. It is important for practitioners of biomimicry to broaden their horizons and to look beyond biomimicry as we know it to solve the challenges that face life on Earth. NASA will play a vital role in this as an integrator that brings together academia, industry and other government agencies to take new ideas and develop them to a point where industry can take over. There are several emerging technologies - synthetic biology, artificial evolution, hybrid manufacturing, big data analytics, 3D scanning and replication – that lend themselves to realizing the vision of biomimicry. This vision, in my mind, is a sustainable future for all life while giving us the freedom to pursue our dreams and to enjoy all the comforts we are accustomed to and will come to reply on. This will require tools that enable users to seamlessly and systematically ideate, collaborate, design and create biomimetic solutions. The time is right to create a bright, sustainable future for all life by bringing together emerging technologies, multidisciplinary research that includes the liberal

Martian Dunes Flying in Formation | Photo: NASA/JPL-Caltech/University of Arizona

special issue | **People:** Interview | **Author:** Vikram Shyam



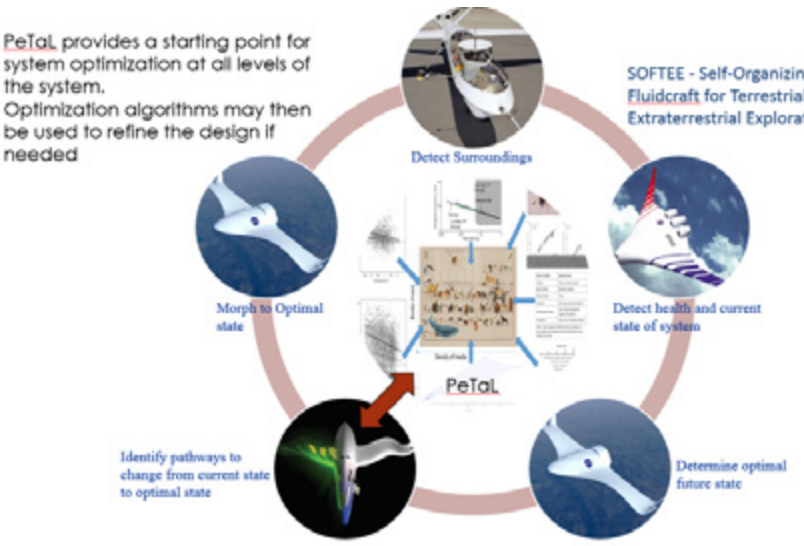


Figure 1 (top). A 2D slice of the multi-dimensional "periodic table of life." Classes of organisms are grouped by size, environment and interaction modes such that similar properties manifest in a group that are not necessarily of the same genus
Figure 2. Self-organizing Fluidcraft for Terrestial and Extraterrestial exploration

arts and various versions of bionics, biomimicry and nature inspired practices. Some key takeaways from my talk:

VIBE

NASA Glenn is leading an effort to bring biomimicry into aerospace through VIBE (Virtual Institute for Bio-inspired Exploration) and is seeking collaboration. This summit was a way to initialize this collaboration.

Tools

It may be possible to create a Periodic Table of Life (PeTaL) that captures the way life evolves in response to environment and ecosystem. Such a periodic table would predict the existence of lifeforms yet to be discovered, inform us about extinct species based on the properties that are known to us and enable us to design beyond the envelope of life as we know it. PeTaL would contain correlations of various types between functions (move, distribute, absorb...) and forms (size, shape, color...) in nature such as flapping frequency and body size or adhesive strength and contact area for a given range of environmental conditions or context (density, temperature, pressure, geological period...). Natural processes and capabilities can be 'sorted' based on independent variables such as habitat media, light, atmosphere, length scales and interaction methods. Figure 1 shows published trends that have been observed for select special cases that will serve as validation datasets. PeTaL could potentially enable aircraft and deep space exploration vehicles and habitats to autonomously adapt to optimal states for their environments (Figure 2) based on an extensive goal-oriented biomimicry database. The database would also contain relationships between organisms (information, energy, water etc.).

Philosophy

It is important to include extinct species in our study and practice of biomimicry. Life has survived numerous extinction events separated by millions of years. Organisms can only evolve within the framework of conditions available to them. Adaptations to deal with extinction events such as asteroids, megavolcanoes or sudden and drastic climate change are thus not an obvious evolutionary objective. The organisms that go extinct are no less 'fit' than the ones that survive except in their ability to cope with rapid climate change, or random proximity to volcanoes, earthquakes or celestial disturbances. While looking for solutions to problems that do not need to take into account such dramatic events, it is therefore justifiable to look at all life for inspiration and not merely the ones that survive in the holocene. Moreover, the periods between each extinction event harbor unique ecosystems, geographical and atmospheric adaptations that could apply to technology for harsh environments on earth and beyond. It is sometimes difficult to deduce the behavior and function of extinct creatures merely from their fossils but comparisons to similar living organisms could provide the link between extinct form and modern function. This is called paleomimesis.

It is important to consider our ancestors who lived without technology, sophisticated tools or high levels of bureaucratic organizations that exist today. This is called anthropomimesis.

Using modern simulation tools and through controlled testing, it is possible to simulate artificial environs and to create new ecosystems and evolutionary traits that may be of benefit to extraterrestrial exploration and terrestrial problems such as energy and resource conservation. This is termed artificial evolution.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hope it will get people to think beyond the current definitions of biomimicry and to begin to collaborate with natural history museums and anthropologists and of course, with NASA through VIBE.

What stood out at this conference and what did you learn?

The outstanding breadth and depth of research, development and entrepreneurship that is flourishing around biomimicry and the diversity of speakers. There is truly a critical mass to make this ecosystem thrive.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

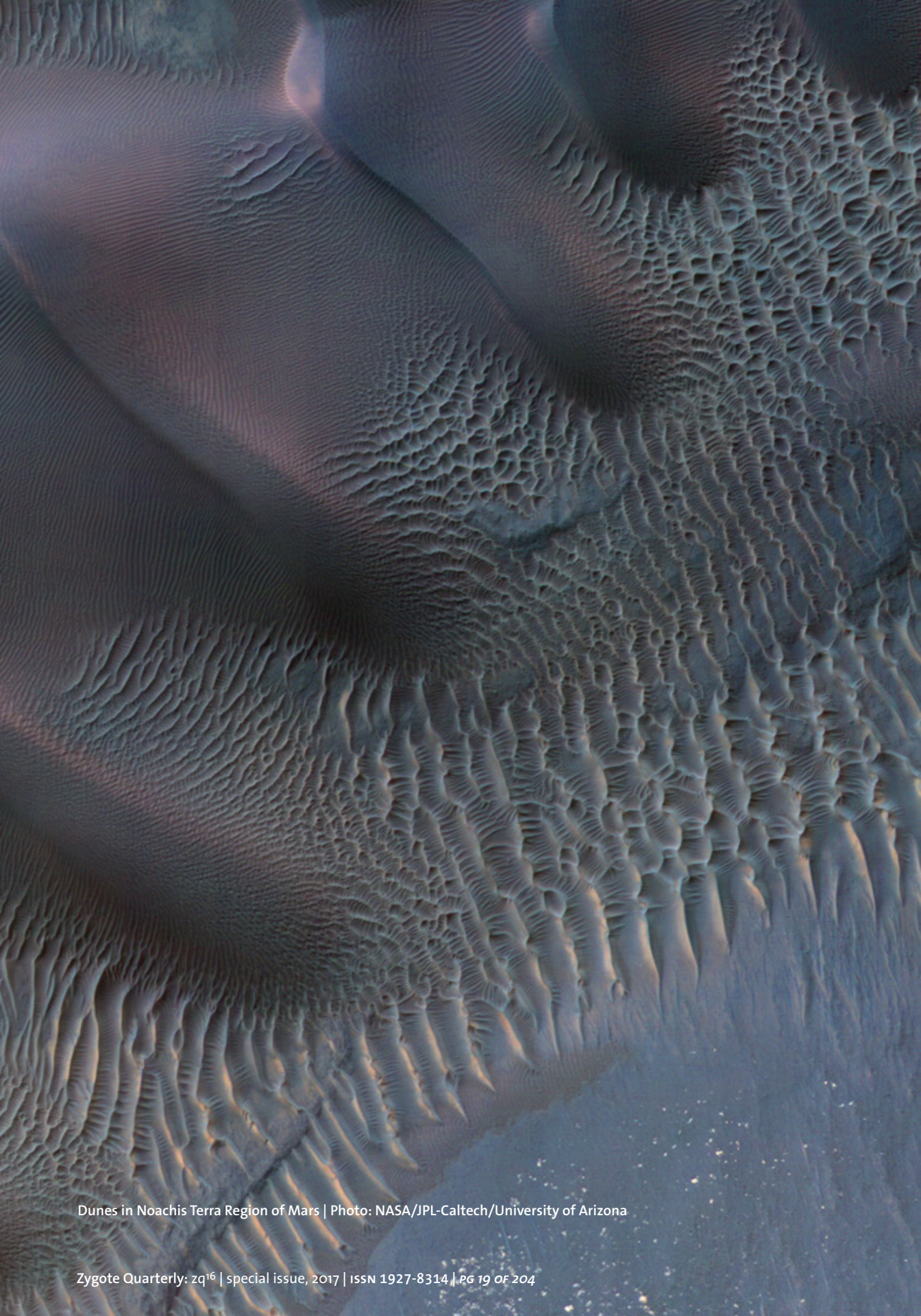
There were numerous discussions during the breaks and several collaborations have already begun to take shape that bring architecture, design and aerospace together to benefit humanity's journey to Mars.

Any action items after this conference? Things you will do, would like to do?

Follow up on collaborations and establish VIBE as the hub for biomimicry in aerospace. And complete a paper describing a new philosophy of biomimicry and how we should pursue it in a systematic way through a 'Periodic Table of Life'.

What are your impressions of the current state of bio-inspired design?

My impression is that bio-inspired design is in a nascent state, based on subjective methods, abstractions and conjectures rather than objectivity and hypotheses that can be subjected to predictions and retrodictions (predictions of the past). We live in a world of cycles. Interest in biomimicry has risen and fallen. Each time a different set of practitioners and motivating factors manifest themselves and practice and need have tended not to be in sync. While biomimicry has been around in various forms for millennia, the age of the internet and celebrity has resulted in some ways in evangelism when it comes to biomimicry. We are currently in a phase where there are sufficiently hard problems like the effects of climate change and water shortage that there is a need for the scientific community to look beyond their conventional arsenal of tools. The populist interest is thus quite timely and should not be looked at in a negative light for it will sustain the infrastructure of entrepreneurism, so-



Dunes in Noachis Terra Region of Mars | Photo: NASA/JPL-Caltech/University of Arizona

cial consciousness and political will needed to allow the sandpaper-like scrutiny of scientific methods to sharpen biomimicry's teeth.

There is much terminology being bandied about and we need to figure out how and where all the pieces fit together so that specialists can develop the puzzle pieces and give the big picture better resolution. Terminology is the generalist's biggest enemy but is essential to accomplishing the generalist's goals.

What is working well for the current state of bio-inspired design?

Energy and enthusiasm from the non-scientific community that is providing a springboard for entrepreneurs and for the scientific community to build on. Several practitioners are recognizing the need for a more objective approach to biomimicry and are developing a great number of tools and paradigms.

What do you see as the biggest challenges?

Complacency: while biomimicry 'feels' like the right thing to do it is incumbent on practitioners to prove (or disprove) that this is in fact true.

Competing viewpoints: while competition is good, the community must come together to achieve common goals, standards etc. and identify a path forward to establishing metrics of merit or goodness.

What areas should we be focusing on to advance the field of bio-inspired design?

Tool development to move from systems requirements to design using an objective, systematic approaches. PeTaL is one such attempt but may not be the solution. Others must therefore be attempted.

Biomimicry should not become an excuse for people to test on organisms in the name of science. Ethical practices and non-invasive methods to study life – this is not a moral argument (alone) but a scientific one – a bird with sensors on it behaves differently from one without. As Da Vinci used his powers of observation to deduce the secrets of flight, we must use our observation skills, augmented by advanced sensors and non-invasive techniques to study systems in natural settings to uncover the true mechanisms of nature.

How have you developed your interest in bio-inspired design?

I have been interested in nature from an early age and in understanding the interactions of living and non-living things. I was introduced to biomimicry in 2000 through my undergraduate fluid dynamics professor, Dr. Joseph Haritonidis at the Ohio State University when he asked us to study the lift and drag characteristics of birds in formation flight. I have since attempted to apply natural solutions to my area of work mainly through literature surveys and not through any formal tools. I often use nature slideshows or just look around for inspiration rather than focusing on details. I have tried to develop my understanding of bio-inspired design by studying

Dunes in Herschel Crater on Mars | Photo: NASA's Marshall Space Flight Center, 2012 | Flickr cc

history, psychology, philosophy, physics, chemistry, biology and nowadays by just surfing the internet and talking to people.

What is your best definition of what we do?

A systematic way of applying successful strategies from natural history to human processes

By what criteria should we judge the work?

Results, repeatability, scalability

What are you working on right now?

I am a propulsion flow dynamicist. I work with several other researchers on reducing the fuel consumption, noise and emissions from aircraft engines. I am currently working on defining areas and strategies to focus on in biomimicry to achieve objectivity and metrics of goodness, to enable practitioners to identify biological systems that are truly beneficial to sustaining human presence in the universe.

What is your favorite bio-inspired work of all time?

There are so many that it is unfair to choose just one.

What is the last book you enjoyed?

Cosmosapiens: Human Evolution from the Origin of the Universe by John Hands

Who do you admire? Why...

Ancient humans who survived challenging environments to give humans a chance to be the first extinction-proof species on the planet.

What's your favorite motto or quotation?

I find this funny (but don't agree with it!) - "I'm not a vegetarian because I love animals, I'm a vegetarian because I hate plants" - Alan Whitney Brown

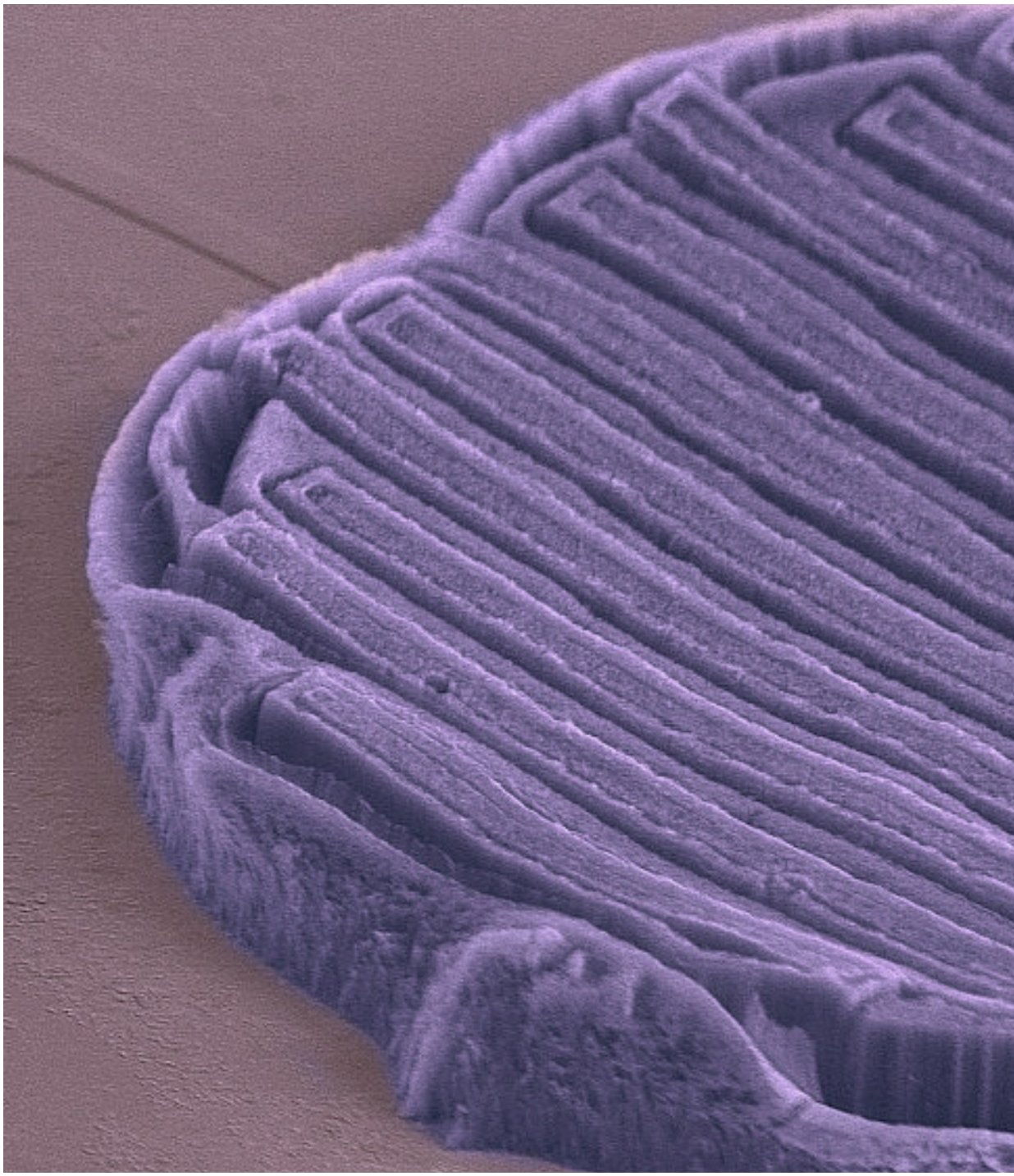
What is your idea of perfect happiness?

Being a leaf on a stream of your choosing.

If not in your current profession, who/what would you be?

My profession doesn't determine what I'd be doing necessarily or who I am. Everything is connected to everything else. So I'd still be working on the same things, maybe from a different perspective. ×

Ganges River Delta | Photo: NASA's Marshall Space Flight Center, 2014 | Flickr cc



Vertically aligned multi walled carbon nanotubes

Photo: Dilek Ozgit and Andrea De Luca, ZEISS Microscopy, 2015 | Flickr cc

Interview
Aloysius F. Hepp

special issue | **People:** Interview | **Author:** Aloysius F. Hepp

Dr. Aloysius F. Hepp is a senior research scientist in the Photovoltaics and Electrochemical Systems Branch at NASA Glenn Research Center (GRC) in Cleveland, OH. He was born in Pittsburgh, PA and reared in Old Saybrook, CT. He graduated at the top of his class from Carnegie Mellon University with a B.S. in Chemistry in 1978. He earned a Ph.D. in Chemistry from Massachusetts Institute of Technology in Organometallic Photochemistry in 1983 under Prof. Mark S. Wrighton, currently the Chancellor of Washington University St. Louis. He has worked at NASA Glenn Research Center for thirty years of his 33-year career in the areas of biomimicry, energy conversion and storage, precursors for spray pyrolysis of metal sulfides and carbon nanotubes, thin film and nanomaterials for photovoltaics and batteries, materials processing of local resources for exploration and colonization of the solar system, and flight experiments for Mars and small satellites. He has 200 publications in refereed journals, conference proceedings, technical publications, and book chapters. His six patents have resulted in the formation of two companies to exploit gallium arsenide passivation (Gallia, Inc.) and low-temperature chemical vapor deposition of multi-walled carbon nanotubes (Nanotech Innovations, LLC). He has held multiple academic appointments and has served on advisory boards, for research and teaching at: Harvard University, Kent State University, University of Tulsa, University of Texas, Arlington, University at Albany, Cleveland State University, and Baldwin Wallace University. He has been quite active in his entire career to support diversity in educational programs and mentoring of students from diverse backgrounds. He was elected to Sigma Xi, is a Sequoyah Fellow of the American Indian Science and Engineering Society, and is currently a member of the Materials Research Society. He is on the Editorial Advisory Board of Materials Science and Engineering B, an Elsevier journal. He was a consulting editor (2010-2011) and Editor-in-Chief of Materials Science in Semiconductor Processing (2012-2015); he is currently Editor-in-Chief, Emeritus and Chair of the International Editorial Advisory Board. He was awarded a NASA Exceptional Achievement Medal in 1997.

What are the key takeaways from your conference?

Biomimicry is still evolving as a multi-disciplinary field with tremendous potential for both nature-inspired insights into science and practical technological advances.

How would you summarize your event?

I sensed a very positive energy due to a creative environment resulting from a fertile combination of provocative ideas and highly creative people. I was very pleasantly surprised at how much enthusiasm was engendered by the presentations by so many participants.

What impact do you hope/expect/intend your conference to have on your profession and/or others?

It is too early to tell if we had any over-all impact. However it seems as though we have built some bridges between like-minded individuals in research, education, and industry. We have also had very positive feedback from our NASA colleagues and the regional technology community.

How will it advance the field?

My hope is to facilitate collaborations and enhanced interactions for individuals, groups, and teams who may see common themes for problems from different disciplines or applications.

Where does your conference fit within the bigger picture of bio-inspired design?

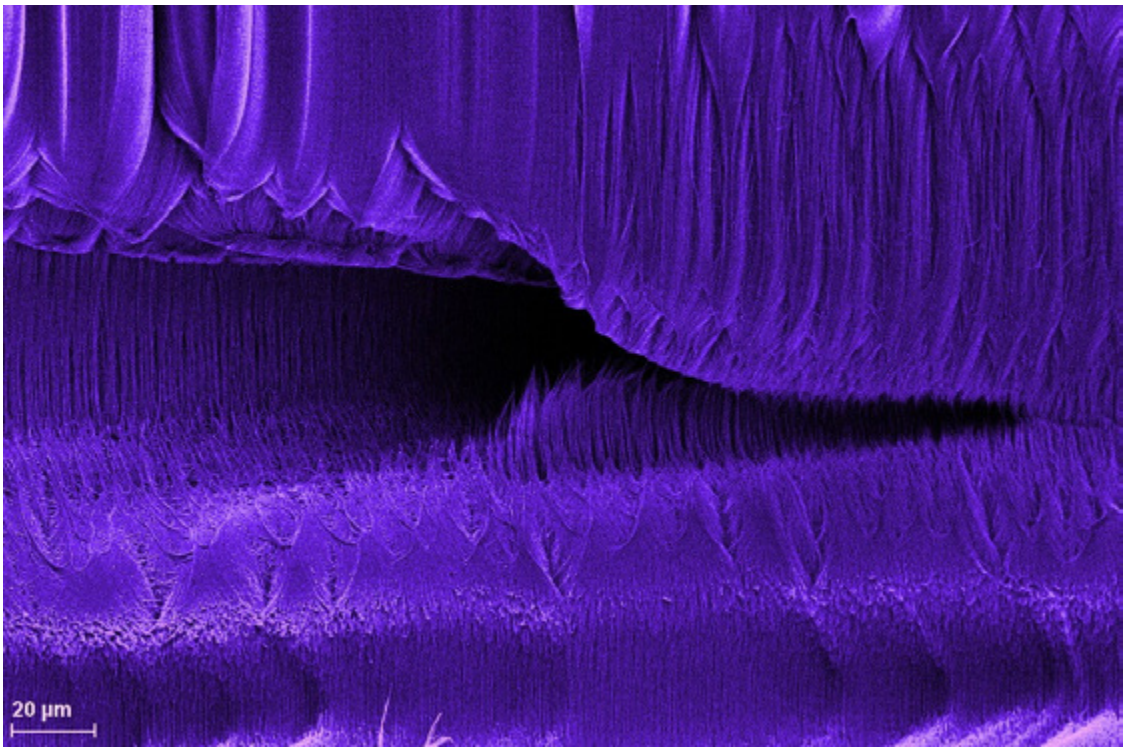
The goal was to create an environment to enhance cross-fertilization

What stood out at this conference and what did you learn?

I saw people enjoying each other's company regardless of where they were from or their particular discipline or their approach to biomimicry. I learned that you can't plan to the nth degree; you just get good, creative folks together and get out of the way!

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Honestly, there are too many to list here! We have barely scratched the surface and already



"Zipper"(Nanocarbon tubes)

Photo: ZEISS Microscopy, 2013 | Flickr cc

have numerous inquiries and interactions among attendees. I'm sure that there are ongoing discussions outside our circle.

Any action items after this conference? Things you will do, would like to do?

There are numerous action items involving numerous colleagues and co-workers. Personally, I am involved with sustainable space exploration and human settlement of the solar system, small satellites, and materials processing for energy conversion and storage.

What are your impressions of the current state of bio-inspired design?

The field is still developing but it is already showing great promise in enabling new, high-performance technologies for aerospace, sustainability, and consumer products.

What do you see as the biggest challenges?

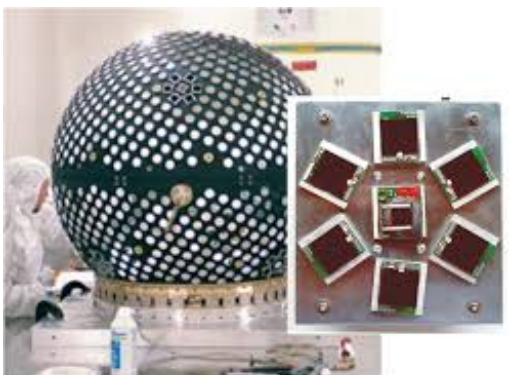
Overcoming pre-conceived notions, becoming mainstream and not being seen as a "boutique technology" that belongs in an academic setting.

What areas should we be focusing on to advance the field of bio-inspired design?

Energy and power, communications, navigation, and guidance, robotics, propulsion, and advanced (multifunctional) materials and devices.

How have you developed your interest in bio-inspired design?

My undergraduate training involved chemistry, engineering, biology, and applied math. I was involved in carbon dioxide fixation as an undergraduate. I began my research career as a bioinorganic chemist and moved into photochemistry. So early on I was interested in artificial photosynthesis and the inorganic chemistry of the active sites of metalloproteins and catalysis in enzymes.



What is your best definition of what we do?

Understand the fundamental phenomena resulting in enhanced efficiency or performance of natural systems, develop appropriate computer, physical, or chemical models, and then engineer natural or artificial materials, structures, and devices with improved properties and performance over current state-of-the-art.

Starshine 3 launched in 2001 with inset showing six high-efficiency solar cells and a demo-ed integrated power device that combined a battery and solar cell that both harvested and stored energy. | Image courtesy of Aloysius F. Hepp

By what criteria should we judge the work?

We should look for insights, lessons learned, and technologies derived from the study of natural systems.

How did you get started in bio-inspired design?

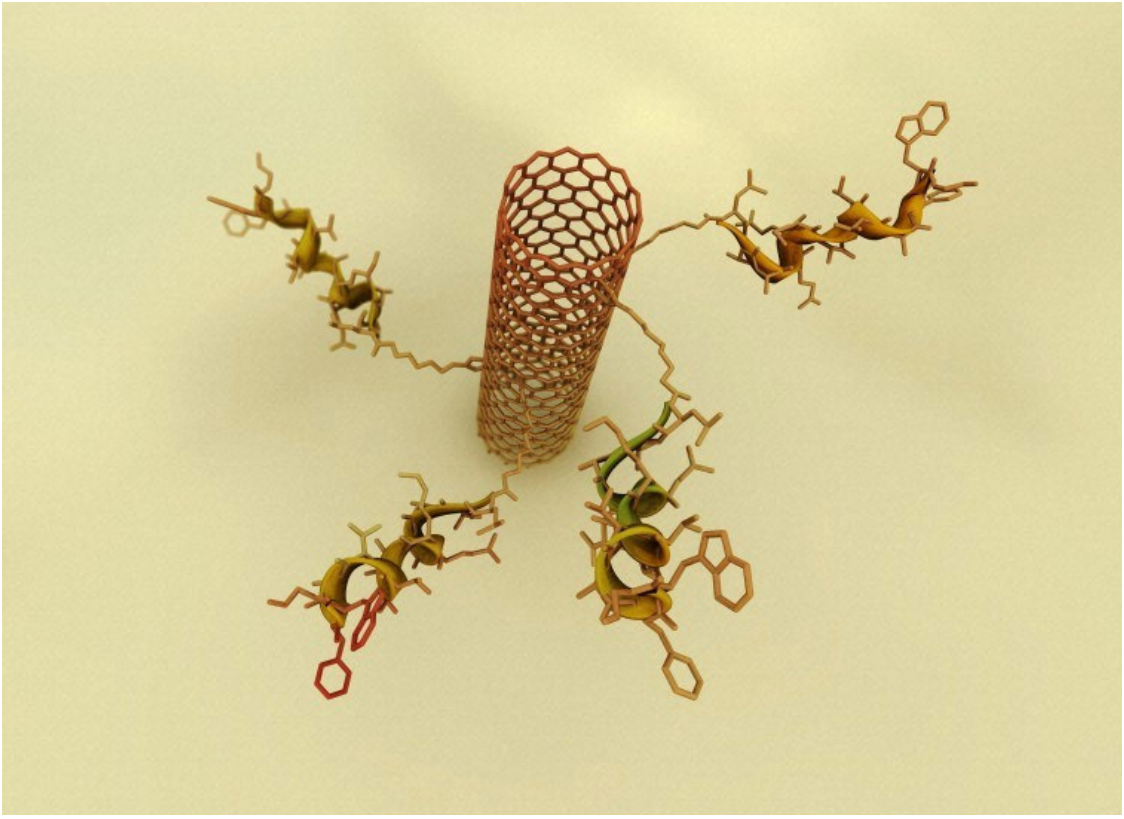
At NASA, it started with artificial photosynthesis and devices that combined energy conversion and storage.

What are you working on right now?

Small satellites and advanced energy conversion and storage materials and devices inspired by nature.

Which work/image have you seen recently that really excited you?

Work on swarms and images of Mars habitats derived from sand dunes shaped by winds.



Functionalised Nanotube

Photo: Anna Tanczos, Wellcome Images, 2014 | Flickr cc

Astronaut John H. Glenn Jr. looks into a globe, technically the "Celestial Training Device" at the Aeromedical Laboratory at Cape Canaveral, Florida, 1962.

Photo: NASA

What is your favorite bio-inspired work of all time?

The chemical models of the active sites of iron sulfur proteins and nitrogenase by Prof. R.H. Holm of Harvard.

What is the last book you enjoyed?

The Smartest Kids in the World — and How They Got That Way by Amanda Ripley.

Who do you admire?

John H. Glenn. Why... He was fearless, curious, and humble

What's your favorite motto or quotation?

"Chemistry is all about getting lucky." Robert Curl (1996 Nobel Laureate)

What is your idea of perfect happiness?

Doing work that is curiosity-driven, having the freedom to be creative and to produce new and practical science and technology.

If not in your current profession, who/what would you be?

Louis Pasteur or a historian and writer like David McCullough. ×

Paper wasp starting a nest

Photo: siamesepuppy, 2013 | Flickr cc

Biomimicry: An Evolving Discipline

Blue Tiger | India

Photo: challiyan, 2007 | Flickr cc

Interview

Ashok K. Goel

special issue | **People:** Interview | **Author:** Ashok K. Goel

Ashok K. Goel is a Professor of Computer and Cognitive Science (http://www.cc.gatech.edu/aimosaic/cogsci/) in the School of Interactive Computing at Georgia Institute of Technology in Atlanta. He is also Director of the School's Design & Intelligence Laboratory (https://dilab.gatech.edu), and a Co-Director of Georgia Tech's Center for Biologically Inspired Design. Born and brought up in India, Ashok emigrated to the U.S. for graduate studies. He conducts research into artificial intelligence and cognitive science, with a focus on computational modeling, design, and creativity. He is an Associate Editor of *IEEE Intelligent Systems*, *AI for Engineering Design, Analysis and Manufacturing, and Advances in Cognitive Systems*, and serves on the editorial boards of *AI Magazine*, *Advanced Engineering Informatics,* and *Biologically Inspired Cognitive Architectures*. He recently co-chaired two workshops on A Research Agenda for BioInspired Design (http://designengineeringlab.org/BID-workshop/NSF_BID_Workshops.html) sponsored by the US National Science Foundation, and is presently co-editing a volume on *Computational Methods and Tools for Biologically Inspired Design*. His recent TEDx talk (http://www.youtube.com/watch?v=wiRDQ4hr9i8) summarizes some of his research on biologically inspired design.

Presentation title: *Cognitive Challenges of Biologically Inspired Design*

Abstract: The paradigm of biologically inspired design espouses the use of biological systems as analogues for inspiring the design of technological systems as well as standards for evaluating system designs. Over the last generation, this paradigm has transformed into a design movement as evidenced by a rapid proliferation of educational programs and courses in biologically inspired design. Yet, our understanding of the biologically inspired design paradigm remains modest. We have been studying biologically inspired design practice for almost a decade. During this time, we have conducted in situ studies and developed information-processing theories of biologically inspired design. We have also developed a digital library of case studies of biologically inspired design, as well as a suite of computational techniques and tools for supporting its practice. In this talk, I will summarize this decade long research in terms of the fundamental cognitive challenges of biologically inspired design. I will posit that these cognitive challenges may provide the core principles for organizing both pedagogy and practice of biologically inspired design.

What are the key takeaways from your conference talk? How would you summarize your presentation?

In my talk, I reviewed recent progress on developing a science of biomimicry. I posit that two of the main challenges in making biomimicry successful as a design movement are repeatability and scalability: we want to develop a methodology that is demonstratably useful across design tasks and domains, and we want to develop a supporting information technology that is usable by design teams across the world. Fortunately, we as a community are making progress towards both goals, though we still have much work to do.

Floating flowers | India | Photo: Tom Olliver, 2009 | Flickr cc

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I would be delighted if my talk helps further focus the attention of the community on developing a science of biomimicry by insuring its repeatability and scalability. I believe that we can expect significant investments from government and industry only after we have demonstrated the repeatability and scalability of biomimicry as a design methodology.

What stood out at this conference and what did you learn?

I was thrilled by two major lessons I learned at the conference. First, this is the first time I saw the top leadership of a major organization – NASA Glenn Research Center in this case – not only endorse biomimicry in principle but also embrace it in practice. I hope that this is a harbinger of other government agencies to follow. Second, the conference confirmed my earlier impression about the success of Great Lakes Biomimicry in bringing together academia, government and especially industry in an impactful way. I think that Great Lakes Biomimicry offers a productive model for the rest of the world.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Yes, indeed! We had several interesting discussions with NASA scientists and engineers on the sidelines of the conference, mostly focusing on information technologies for biomimicry. Further, we have followed up on some of these conversations since the conference. I would love to work with NASA colleagues to develop information technologies to support biomimicry in aerospace.

Any action items after this conference? Things you will do, would like to do?

First, thank you for bringing this special issue of ZQ based on the 1st NASA Biomimicry Conference at the Ohio Aerospace Institute. Second, yes, I would like to talk with colleagues at NSF to see if NSF might be interested in starting a research program in biomimicry. I think the NASA conference indicates the community is ready for it!

What are your impressions of the current state of biomimicry/bio-inspired design?

The growing movement of biologically inspired design is pulled by the need for sustainable design and development, and pushed by the desire for design creativity and innovation. Unfortunately, we do not yet understand any of these big sounding phrases: we have yet to build a principled methodology for design creativity, or biologically inspired design, or sustainable design. It is interesting that we have made considerable progress in the natural sciences such as biology. Thus, there is a broad agreement among most biologists about many fundamental principles of biology. However, we have made relatively little progress in what Herbert Simon called the "sciences of the artificial," such as design, economics, management, sociology. Much of biologically inspired design in practice appears to be based on serendipity, and there is significant debate about even its most basic elements.

Serendipity | Photo: the golden eternity, 2013 | Flickr cc

Thus, perhaps the biggest question in biologically inspired design is how do we transform a promising paradigm into a scientific discipline.

What do you see as the biggest challenges?

I think we have three big challenges. I already have alluded to the first challenge. At present, there are not many successful case studies of goal-directed, problem-driven biologically inspired design in which a designer or a design team started with a design problem and then used one or more biological systems as analogies in addressing the problem. Thus, the first challenge is how do we collectively build a design methodology, and supporting practices, services and tools, for goal-directed, problem-driven biologically inspired design?

Secondly, industry and business by and large are not yet willing to accept biologically inspired design. This is because of several reasons, such as cultural inertia, risk and cost of a new design paradigm, and skepticism about biologically inspired design. Thus, the second challenge is how do we collectively persuade industry and business to adopt biologically inspired design as a fundamental design process.

Thirdly, parts of the popular media in general, and the popular science media in particular, are unnecessarily hyping up biologically inspired design. This leads first to high expectations, then to disappointment at unmet expectations, and next to skepticism about biologically inspired design. Thus, the third challenge is how do we collectively keep doing serious work on biologically inspired design without being distracted by all the noise and changing fashions.

How have you developed your interest in biomimicry/bio-inspired design?

I have been fortunate in having been a part of Georgia Tech's Center for Biologically Inspired Design (http://www.cbid.gatech.edu/). The Center has enabled me to collaborate with colleagues from biology and engineering, as well as to systematically study biologically inspired design in practice. I have also had the opportunity to co-organize two NSF-sponsored workshops on biologically inspired design. These workshops have allowed me to get acquainted with the work of several leading scientists and institutions engaged in biologically inspired design. Now I serve on the Boards of Biomimicry 3.8 Institute (http://biomimicry.net/about/biomimicry38/institute/) and BioInspired! (http://bioinspired.sinet.ca/), a bio-inspired design community of practice. These boards give me a broader perspective on the biologically inspired design movement as a whole.

What are you working on right now?

For the last few months, in a project sponsored by the NSF we have been attempting to understand the problems faced by design practitioners, consultants and managers, and trying to relate our research on biologically inspired design to their tasks, problems and needs. We have interviewed more than seventy design professionals about biologically inspired design. My observations about the current state of biologically inspired design and the challenges the movement faces are based partly on our conversations with these design professionals. Another lesson I have learned from this exercise is that while it is critically important that as "academic

scientists" we develop a principled methodology of biologically inspired design, it is useful if some of us also act as "public intellectuals" who promote the paradigm. I believe this is one of roles played by this magazine, *Zygote Quarterly*.

How did you get started in biomimicry/bio-inspired design?

I started working on bio-inspired design in the early summer of 2006 for both professional and personal reasons. Professionally, since the mid-eighties I had been conducting research on artificial intelligence and cognitive science theories of design and creativity, such as analogical thinking and systems thinking. Because biologically inspired design is creative and entails both analogical thinking and systems thinking, it provides me an important arena for exploring and applying artificial intelligence and cognitive science techniques. From a more personal perspective, I am very concerned about environmental sustainability, but also quite excited about the potential of biologically inspired design to help address some aspects of sustainable design and development.

Thus, working on biologically inspired design allows me to imagine that I am promoting sustainability.

Who do you admire? Why...

Buddha and Gandhi, for much the same reasons: both were men of peace, who gave up their worldly possessions, sought the path to truth, struggled for justice, and changed the world. I sometimes think that man makes God in his image. If this is true, then a God in Buddha's and Gandhi's images would be a God I could be happy with, at peace with.

What is your idea of perfect happiness?

I am happiest and most peaceful when my two sons and I are together. However, since my older son has gone to college, this happens infrequently. Soon my younger son will go to college as well. I know that all this is a natural, normal part of life, but I do miss us being together.

If not a scientist/designer/educator, who/what would you be?

Perhaps a social worker or a policy maker. I have always wanted to make a difference, to have an impact. Public policy and social work often make a difference to people's lives, have an impact on the world. Of course so do many other professions such as politics and business. Unfortunately, I am not very good at either politics or business. So I will settle for public policy and social work. ×

Reprinted in part from ZQ Issue 4

Dung Beetle | Addo Elephant Park | SouthAfrica

Photo: MichaelZeroMayer, 2013 | Flickr cc

Interview
Yoseph Bar-Cohen

Dr. Bar-Cohen is a physicist specializing in electroactive materials/mechanisms and ultrasonic nondestructive evaluation (NDE). He has extensive experience initiating and leading multidisciplinary tasks while partnering with experts from academia, industry and other R&D organizations. His efforts and leadership led to the development of a novel ultrasonic drill, multi-radiation ferrosource, piezoelectric motors, piezoelectric pump, ultrasonic NDE methods, real time sensing, geophysical probing techniques, haptic interfaces, electroactive polymer actuators (artificial muscles), and high power ultrasonic techniques.

Presentation title: *Planetary Exploration Using Biologically Inspired Technologies*

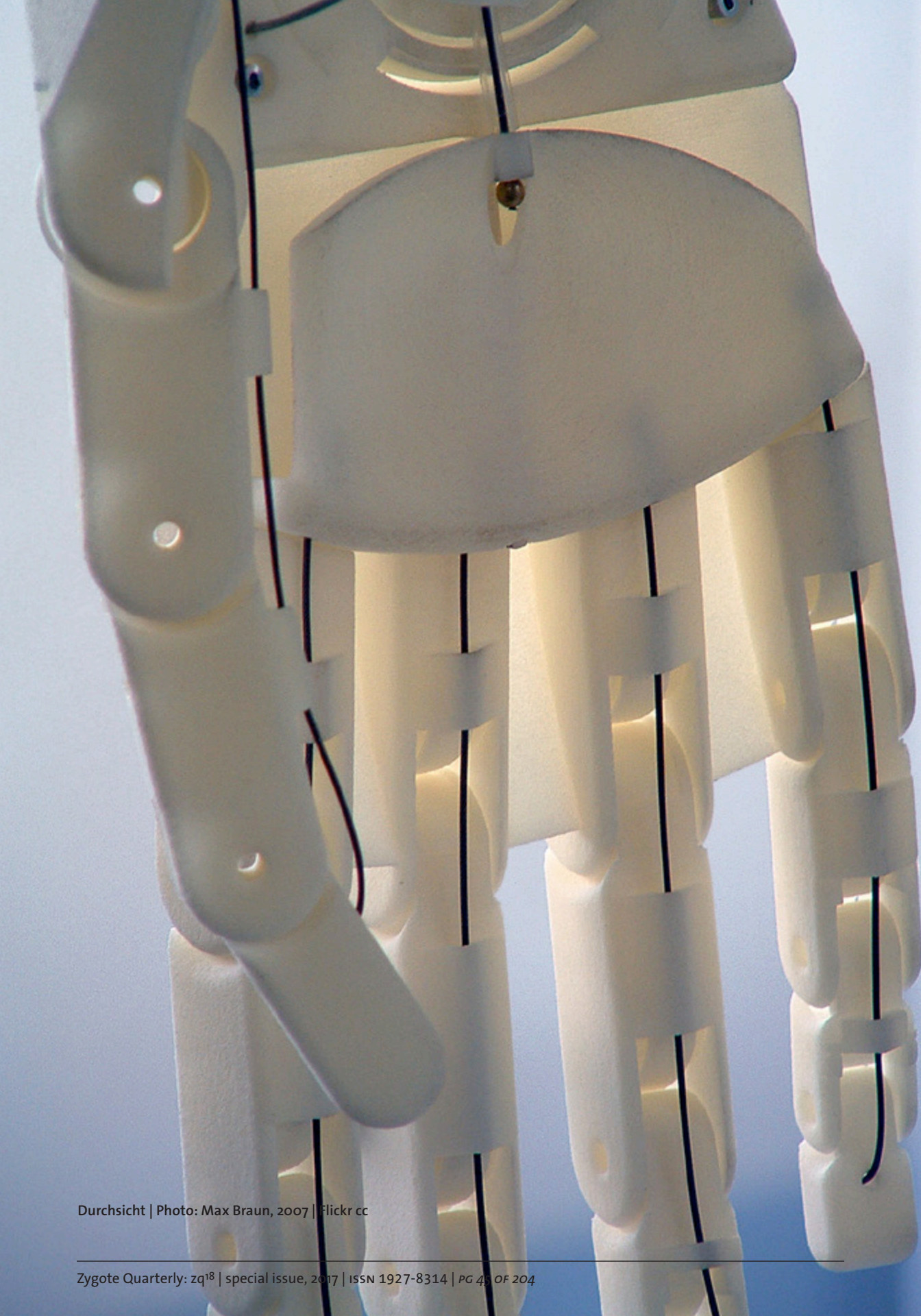
Abstract: A key objective of the NASA's solar system exploration of planetary bodies is the search for preserved bio-signatures and habitable regions. In support of this objective, various biomimetic approaches having a range of technology readiness levels (TRL) are being investigated. The efforts include an artificial nose that was tested on the International Space Station, a biomimetic optical sensor for real-time measurement of aircraft wing deflection, artificial muscles as actuators, parallel processing algorithms, as well as snake-like robotic device that can be articulated to traverse through narrow openings and passages to conduct maintenance and inspection functions. The development of electroactive polymers (EAP), also known as artificial muscles, is at version TRLs but they are still far from being used to actuate flight hardware. In 1999, in an effort to promote rapid development of EAP worldwide, the author posed an arm wrestling challenge (https://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm).

At his lab, the author has a task focused on deep drilling using piezoelectric actuation and the developed drill is called Auto-Gopher. The drill is biologically inspired by the gopher method of digging holes and underground tunnels. It requires relatively pre-load making it effective at low gravity environments and its piezoelectric actuation makes it applicable for operating at extremely include low or high pressures and temperatures.

To explore future directions for the field of biomimetics, the author will cover in his paper the topic of humanlike robots as the ultimate challenge. While for many years such robots were considered a science fiction, they are increasingly becoming an engineering reality and they are able to perform impressive functions and tasks. In 2012, DARPA posed a Robotic Challenge to produce such robots that operate in disaster scenarios that would make society more resilient. Another significant development in this field is the fact that major US corporations have entered into the race to produce commercial humanlike robots. As a result, one can expect significant advances in the coming years.

What are the key takeaways from your conference talk? How would you summarize your presentation?

As far as my presentation – I believe we need to think of breakthrough ideas. These may include the use of hibernation as a way to help manage the logistics of human exploration of the deep space. Keeping the astronauts sleeping in a hibernate state would save enormously in terms of the life critical supplies and requirements of missions to Mars and beyond.



Durchsicht | Photo: Max Braun, 2007 | Flickr cc

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

Having a workshop about biomimetics that is sponsored by NASA and space exploration objectives has been an important step in bringing new thinking into potential future NASA missions capabilities and objectives

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

We still have a long way to go.

What do you see as the biggest challenges?

Areas such as energy harvesting from food, the ability to grow limbs like a lizard growing a tail, being able to hibernate and sustain life like a bear and many others.

What areas should we be focusing on to advance the field of bio-inspired design?

We need to have discussion on the selection of "low hanging fruit" projects that can provide quick benefits with minimal investment.

How have you developed your interest in bio-inspired design?

I am one of the pioneers of the field of electroactive polymers. The way these materials function similar to biological muscles propelled my interest in biomimetics.

By what criteria should we judge the work?

I prefer to judge by the benefit of the resulting capabilities rather than by the degree of similarity to the biological model.

What are you working on right now?

I am using electroactive actuators and developing such mechanisms as the Auto-Gopher that allow reaching great depths in subsurfaces.

How did you get started in bio-inspired design?

It has been an evolutionary process resulting from related innovation.

Which work/image have you seen recently that really excited you?

Seeing the image on the right and thinking "who invented the wheel first?"

What is your favorite bio-inspired work of all time?

Velcro. ×

Dung beetle @ work

Photo: Andi Gentsch, 2011 | Flickr cc

Pill millipede

Photo: wildxplorer, 2008 | Flickr cc

Life in Hostile Environments

Buffalo Springs NR, Kenya, Red-and-yellow barbet (*Trachyphonus erythrocephalus*)

Photo: Peter R Steward, 2013 | Flickr cc

Interview

J. Scott Turner

special issue | **People:** Interview | **Author:** J. Scott Turner

J. Scott Turner has contributed to the theory of collective intelligence through his fieldwork on the South African species of termite *Macrotermes michaelseni*, suggesting the architectural complexity and sophistication of their mounds an instance of his theory of the extended organism. His theory was reviewed in a range of journals, including *Perspectives in Biology and Medicine*, the *New York Times Book Review*, *EMBO Reports*, and *American Scientist*. Working at the interface between physiology, evolution and design led Turner to formulate the idea of the Extended Organism, reviewed in a range of journals, including *Nature*. Turner's current research focuses on the emergence of super-organismal structure and function in mound-building termites of southern Africa (*Macrotermes*). His extended organism idea was inspired by his work on termite mounds that clarified how the mound functions as an external lung for respiratory gas exchange for the colony as a whole. His prior work on the thermal capacity of incubated birds' eggs showed that an egg with an embryo and an incubating parent function not as two separate organisms but as a coupled physiological unit. Prof. Turner is an adviser to the Microbes Mind Forum and Professor of Biology at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) in Syracuse, New York. Under a grant from the Templeton Foundation, he has been a visiting scholar at Cambridge University, writing his third book, currently titled *Biology's Second Law: Evolution, Purpose and Desire*, which builds the case that evolution operates through the complementary principles of Darwinian natural selection (biology's "First Law") coupled to homeostasis (biology's "Second Law").

Presentation title: *What's So Inspiring About Life? Physiomimetics, Adaptation and Persistence of Life in Novel Environments*

Abstract: Biomimicry is based upon an optimistic and idealistic understanding of nature and its evolution. It presumes that natural selection has produced an abundance of ingenious solutions for the many problems of life, including those of human existence. It presumes further that humans can live more sustainably and harmoniously within nature if only we can apply these solutions to our own lives. This idealistic picture runs quite contrary to the Darwinian logic that supposedly produced these wonderful solutions. Life is often wasteful, extinction is the norm, competition is vigorous and "sustainability" often equates with stagnation. By what logic does this lead to living nature as an inspiration? There is a logic to biomimicry, although the logic is not Darwinian, as is commonly supposed. It is, rather, Lamarckian and Bernardian (after the great 19th century physiologist Claude Bernard). That is to say, the logic of biomimicry is physiological, homeostatic, process-oriented, adaptationist and driven by striving of dynamically unstable living systems to persist. This is the only sound basis for a logic of biomimicry, or what may be called physiomimetics. It also underscores how far we are from realizing it in practice, and I will outline why. The logic of physiomimetics also leads to a contrarian picture of the nature of adaptation and how living systems persist in novel, and even harsh, environments.

What are the key takeaways from your conference talk? How would you summarize your presentation?

One takeaway is that the overall field of biomimicry is not really clear on precisely

Plaster cast of the internal structure of a termite mound. In collaboration with Dr. Rupert Soar

Photo courtesy of Dr. J. Scott Turner

what it is about living nature that we should mimic. The central claim of the "biomimicry idea" is that living nature is a multi-billion year R&D program, honed by natural selection, to produce a cornucopia of inspiration for how to live more harmoniously in nature. This is a form of idealism that draws more from 19th century natural theology than it does from Darwinism, and this has led, in my opinion, to a variety of bad intellectual habits: of "bio-bling", the tendency to decorative embellishments that emphasize biological form over the process that gives rise to the form; of plastering life onto structures and calling it biomimicry; of ingenious designs that cast only a perfunctory glance toward the life that inspired it. That's not to say, of course, that living nature cannot be the source for inspirational ideas for better use of energy and materials, just to say that there has to be some discerning method for evaluating putative examples. Natural selection has produced a living world that is full of wasteful or illogical designs: how do we select the ones worth emulating? I argue that it is adaptation that should be the lens we use to do so, and this means it is living process that we really should be emulating—physiomimetics—rather than life per se—biomimetics. The bad news there is that biologists are themselves not very clear on what exactly adaptation is. I lay out an argument that adaptation is essentially a thermodynamic process informed by life's fundamental trait—homeostasis—and that this will be the foundation of a science of biomimicry. I lay out three examples of plants adapting to harsh environments—Lithops or stone plants; Welwitschia in the Namib desert; and water balance of desert lichens—to illustrate how this works.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hope that my presentation will get people to think more critically about what biomimicry is. Even though biomimicry as a design philosophy is burgeoning and is very popular, its lack of coherency diminishes the "brand"—if all things are biomimicry then nothing is biomimicry. Without a coherent idea of what in nature is worth emulating, it also is likely to be an inefficient source of inspiration.

What stood out at this conference and what did you learn?

One thing that stood out was the absolutely brilliant diversity of approaches to drawing inspiration from nature. Some of the presentations just took my breath away. Perhaps the lack of a coherent philosophy of biomimicry is not such an obstacle! Nevertheless, I was also struck by the sometimes tenuous connection to living nature that was on display. I was also struck by the breadth of the biomimicry infrastructure that had been built up over many years by Great Lakes Biomimicry (GLB). As a design philosophy, GLB has it covered from basic engineering to new product development to marketing and sales. Again, perhaps a coherent philosophy is not so necessary!

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

There were tons of interesting discussions during the breaks! I've made connections to some

interesting collaborative efforts, including an interview with one of the mavens of biomimetic architecture, Mick Pearce, architect of the iconic 'termite-inspired' building, the Eastgate Centre in Harare, Zimbabwe.

Any action items after this conference? Things you will do, would like to do?

One thing that is happening immediately is enlisting the help of some of the conference organizers in helping my home institution, SUNY ESF, develop and launch its own biomimicry initiative.

What are your impressions of the current state of biomimicry/bio-inspired design?

I see biomimicry/bio-inspired design as being in a bit of a transitional phase right now. After the original flush of excitement, arising largely from publication of Janine Benyus' book, *Biomimicry*, there is a kind of sobering up going on, so to speak, as engineers and biologists really are starting to talk with one another, and realizing just how different they are, how different the questions and intellectual traditions each come from are, and the challenges in melding them constructively.

What do you see as the biggest challenges?

Well, I'm coming into this from the perspective of a biologist / physiologist / evolutionist, but I'd say that the biggest challenge is going to be answering the deceptively simple question: what, precisely, about living nature should inspire us? In biomimicry's early days, there seemed to be this overarching presumption of the perfecting power of natural selection. Biomimicry's initial enthusiasm and optimism streamed from the assumption, I think, that there were solutions lying around everywhere in living nature, just waiting to be picked up, that would give us more effective, efficient and environmentally friendly uses of energy and materials. Yet, I can point to any number of living systems where that's not true, indeed, I can point to living systems where wanton use and waste of resources is an evolutionarily viable strategy. So, from my point of view, I think biomimetics could stand to take some of the stars out of its eyes, and start looking critically at what it is we think living nature can tell us.

Before feathers get too ruffled, let me hasten to add that there are challenges for my own "side" as well. In general, we biologists are culturally very averse to any discussion that invokes principles of design, principles that architects and engineers have long been comfortable with. It brings up bad memories of the supposedly dark, pre-Darwinian days. That's also an unfortunate cultural bias, because it means that despite being literally immersed in good living designs everywhere, we biologists don't have a good understanding of just where, and how, the well-functioning organism arises. So, we biologists have a lot to learn ourselves.

What areas should we be focusing on to advance the field of biomimicry?

I think the most fertile area of inquiry will be in understanding precisely how good design in living nature actually comes about. I'm likely to

Scott Turner in front of a plaster cast of the tunnel network of a Macrotermes mound | Image courtesy of Scott Turner

be stepping on some toes here, but there are aspects of biomimicry that ooze an almost cult-like devotion to a kind of "bio-formalism", the notion that nature necessarily provides models of "things" that, if we imitate their form, will inspire objects that function well. Living nature is not like that! Another aspect of that is what my colleague Rupert Soar has called "bio-bling", the notion that decorating our built structures with the many beautiful forms to be found in nature will produce buildings that are more in tune with nature, whatever that means.

So, I think we would do well to understand how good design in living nature comes about in the first place. My own thinking is that the roots of a sound theory of biomimicry are likely to be found in physiologically inspired thinking, "physiomimetics" if I can use the word. In living nature, good design more often than not seems to come, not from some genetic specifier (the biological side of the formalism cult), but from managing the dynamic disequilibrium that is inherent in the widely misunderstood concept of homeostasis. If we could build homeostasis into the bio-inspired designs we make, we would have something like a "true" biomimicry.

How have you developed your interest in biomimicry/bio-inspired design?

Well, as most people who've read this far will have already concluded, I'm not really a biomimeticist, I'm a physiologist. And of social insects to boot! But the origin of good function is one of the fundamental questions in physiology, and pursuing that question wherever it leads has been the central theme in developing my own thoughts about life, what it is and how it works. Specifically, look at the termite mounds that are the current focus of my study. These things are more than a pile of dirt, heaved up from the soil by the termites that build them. The mound is, in fact, a remarkably sophisticated organ of physiology, just like the heart and lungs are in more conventionally defined organisms like ourselves. Yet, they emerge at a scale unlike any other organ of physiology on the planet. How does that happen?

The connection to biomimicry/bio-inspired design is an obvious one, since the biomimetics that I'm tangentially involved with seeks to do the same things with our buildings and artefacts. In making the connection, though, it's vital that we first understand the workings of the source of our inspiration.

What is your best definition of what we do?

Hmm, I'm hardly qualified to say, but I would venture this definition anyway:

Biomimicry/bio-inspired design seeks inspiration in living nature for structures and processes that are ecological in nature.

By what criteria should we judge the work?

Now that's an interesting question. On one level, I suppose it has to be what works for the clients that are paying us. Whether the "client" is a private company or investor, or the tax-paying public, biomimicry is ultimately an aesthetic claim on that investor's attention. In that sense, biomimicry is not a scientific principle, but an aesthetic one. On another level, biomimicry makes a specific scientific claim: that looking to

nature will give us objects and processes that are more efficient, more beautiful, and more in tune with nature, which includes the human user of our designs. The last criterion is an especially interesting one, because good bio-inspired designs needn't be scientifically sound. Some of the early "termite-inspired" buildings, for example, were using a functional model for how the mound works that was probably completely erroneous. Yet, the designs worked beautifully, although not for the reasons that inspired them.

What are you working on right now?

Mostly, I'm working on a large multidisciplinary project, involving colleagues from England, the United States, India and Namibia, with expertise ranging from advanced fluid mechanics to swarm intelligence to natural history. The aim of this project is to work out the fundamental principles of how termite mounds work and how they come to be. We already have the broad outlines of this, but being able to apply it to things like climate management of buildings will mean getting to the bottom of some tricky basic principles. That work is being funded by the Human Frontiers Science Program, based in Strasbourg.

The other big focus of my work is a third book, with a working title *Biology's Second Law: Evolution, Purpose and Desire*, which I hope to have ready to go sometime early in 2017. The book explores some of the cultural origins of modern evolutionary thought, specifically around the implied intentionality of design. The title is meant to be a contrast with Jacques Monod's famous book *Chance and Necessity*.

How did you get started in biomimicry/bio-inspired design?

I stumbled into it, actually. As I've said, I'm a physiologist by training and disposition. Even though termite mounds opened up my eyes to the whole issue of biomimicry and bio-inspired

Endocasting in practice

Photo courtesy of J. Scott Turner

design, the work on termite mounds came about more-or-less by accident. When I was teaching at the (then) University of Bophuthatswana (now the University of Northwest in Mafikeng), in the now defunct South African homeland of Bophuthatswana, I was tasked with developing a laboratory presentation. There were lots of termite mounds around the campus, and the story of air flows within them was so well-established that I thought that demonstrating the air flows would be a simple way to discharge my task. Imagine my surprise (and embarrassment) when the air flows turned out to be nothing like what the accepted story said they had to be! It's fair to say I've spent the last twenty years trying to recover from that embarrassment.

The mushroom *Termitomyces reticulatus* photographed in Namibia

Photo: Candice, 2009 | Wikimedia Commons

Which work/image have you seen recently that really excited you?

I quite admire what Julian Vincent is doing to try and build a rational basis for bio-inspired design.

What is your favorite biomimetic work of all time?

Has to be the lotus leaf!

What is the last book you enjoyed?

Quartered Safe Out Here, by George MacDonald Fraser. Fraser is better known as the author of the Flashman series of books, which I discovered while living in South Africa. The Flashman books are brilliant examples of what I call "ribald history", wonderful examples of history as literature, but packaged in a racy, and decidedly politically incorrect wrapper. I could describe them, but better that I recommend you read them. *Quartered Safe Out Here* is Fraser's war memoir of the Burma campaign that sought to sweep the Japanese Empire out of Southeast Asia. What I liked about it was the same qualities he brings to the Flashman books: a wonderful

ability to develop characters and their stories, from a perspective that is true, but rarely polite or politically correct.

Who do you admire? Why...

I admire a lot of people, but after giving this question a lot of thought, I think I'd have to say that Lynn Margulis, who died just two years ago last November, sits at the top of that list. On a scientific level, I think I've never met a more courageous thinker. All through her career, from her work on the evolution of the eukaryotic cell, to some of her more recent controversial ideas on topics ranging from Gaia to the failings of Neodarwinism to HIV and AIDS, she was always someone who would champion the outlier and intellectual outcast, sometimes seemingly just so that idea would have a defender. That diminished her, in some eyes, but I have to disagree—even if she was espousing an idea that I couldn't agree with substantively, she always posed the disagreement in a provocative and intellectually honest way. Science needs that: once science pretends to consensus, it ceases to be science, in my opinion. On a personal level, I came to know Lynn when I was writing my first book—my publisher had contacted her for help with reviewing the book manuscript and for a publication blurb, and her generosity and open-mindedness toward me was truly mind-blowing. As I got to know her a little better as a person, and saw the joy she took in students, and saw her as she often was, in the midst of the tumultuous swirl of students and fellow scholars that always seemed to be drawn into her orbit, I saw in her something of the beau ideal of the intellectual life.

What's your favorite motto or quotation?

Progress every day.

What is your idea of perfect happiness?

I pretty much have it now. I have a loving family and kids that have grown enough for me to start enjoying them as people. And I can't think of a better career than scholar/scientist/professor. What obligations I do have, namely teaching (which is really having conversations with students about science), are pretty enjoyable, even if they leave me spent sometimes. And having the freedom to pursue what interests me, and get paid for it, is a treasure beyond measure.

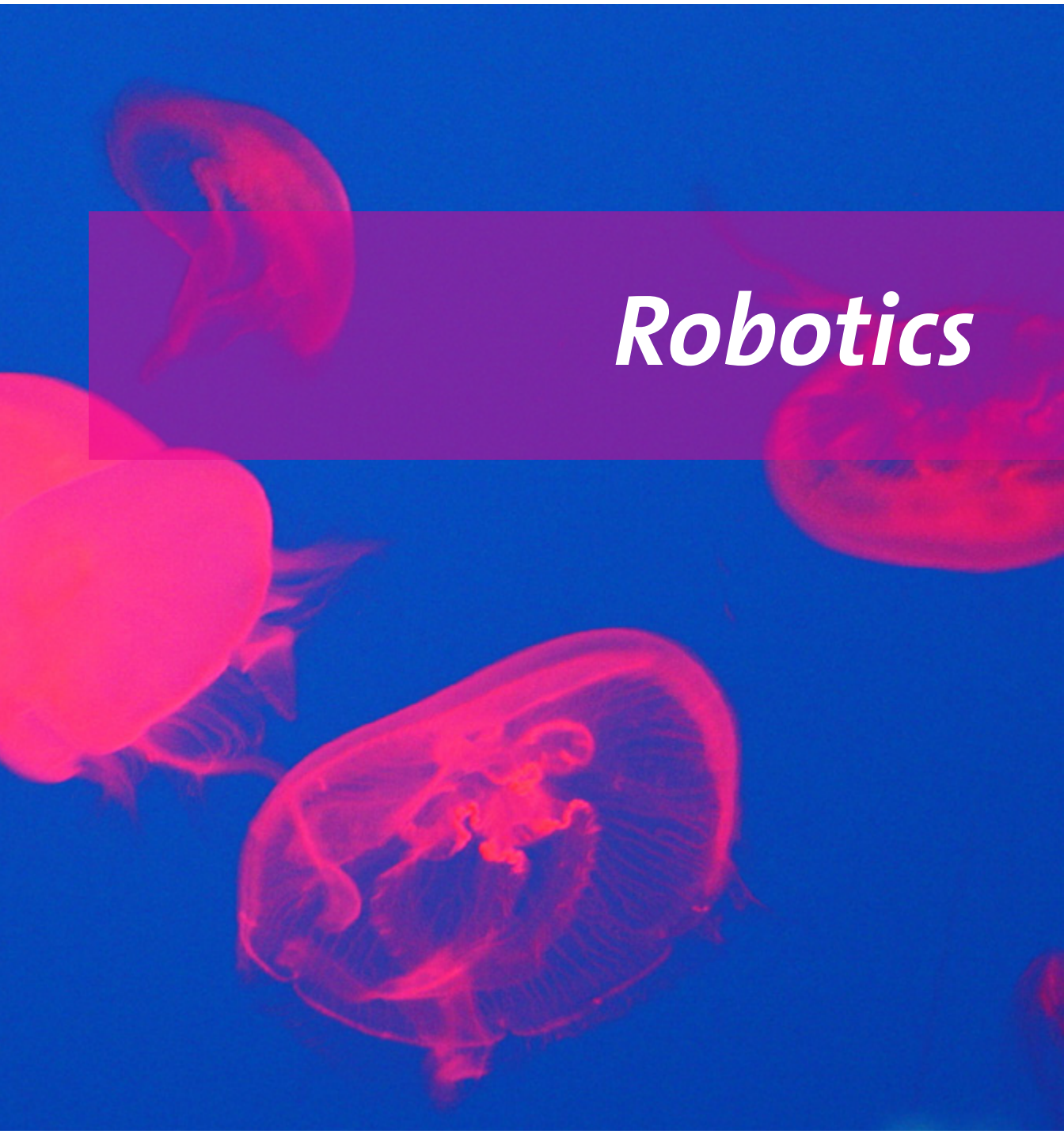
If not a scientist/designer/educator, who/what would you be?

I probably would have been a historian. After a misspent youthful interlude as a college drop-out, when I returned to college to pursue a degree, I was torn for a while between studying history and studying biology. What finally decided it for me in the end was that biology seemed to have more field trips and girls. It was that shallow. ×

Reprinted in part from ZQ Issue 8

Jellyfish

Photo: Erik Steinebach, 2008 | Flickr cc



Robotics

Turning Frogs into Katydids (Mormon Cricket)

Photo: rick cameron, 2011 | Flickr cc

Interview
Nikolaus Correll

special issue **People:** Interview

Author: Nikolaus Correll

Nikolaus Correll is an Assistant Professor in Computer Science at the University of Colorado at Boulder with courtesy appointments in Aerospace, Electrical and Materials Engineering. Nikolaus obtained a degree in Electrical Engineering from ETH Zurich in 2003 with visits at Lund Tekniska Hogskola, Sweden, and Caltech, and earned a PhD in Computer Science from EPFL in Lausanne, Switzerland in 2007. He did a postdoc at MIT CSAIL from 2007-2009. Nikolaus is the recipient of a 2012 NSF CAREER award and a 2012 NASA Early Career Faculty Fellowship. He has received multiple best paper awards at international conferences including DARS (2006, 2012) and SAB (2008).

Presentation title: ***Material-integrated Intelligence for Robot Autonomy***

Abstract: Advances in miniature electronics, distributed algorithms and manufacturing technology have enabled a new generation of smart composites that tightly integrate sensing, actuation, computation and communication. Such "robotic materials" are inspired by multi-functional natural structures such as the skin of the cuttlefish that can change its color and patterning, bird wings that can change their shape, or the human skin that provides tactile sensing at high dynamic range. I will describe a series of recent results that best illustrate the benefits of material integrated computation: high-bandwidth sensing for texture recognition and localization in artificial skins, distributed optimization for controlling shape change, distributed classification for recognizing gestures drawn onto a modular facade, and feedback control of soft robotic actuators. I will then describe current challenges in robotic grasping and manipulation, and demonstrate how robotic materials can provide critical sensing and control during a series of manipulation tasks with applications to warehouse automation, manufacturing and lab automation.

What are the key takeaways from your conference talk? How would you summarize your presentation?

Bio-inspiration should not be limited to form or function, but to the tight integration of sensing, actuation, computation and communication ubiquitous in most biological systems (think about the skin, the eye/retina or an octopus arm). Taking inspiration from such systems, my lab has created a series of first-of-its-kind smart composites that integrate sensing, actuation, computation and communication in a way that is scalable to the number of units and robust to failure of individual units. Examples include a skin that can sense, localize and recognize texture, a beam that can change its shape and solves the inverse kinematics problem inside the material, and smart robotic fingers that sense proximity and force. The latter actually goes beyond bio-inspiration, which should not be a limiting factor.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I believe what I call "robotic materials" to have the potential to transform not only robotics, but also civil engineering and aerospace (think self-monitoring and repairing structures), architecture (think buildings that adapt their appearance and function) and of course robotics, which

Giant Pacific Octopus Arm | Photo: Michael Bentley, 2011 | Flickr cc

Mormon cricket, female laying eggs | Photo: Upupa4me, 2015 | Flickr cc

is still dominated by joints, links and gears, ignoring how nature is able to produce highly dynamical, agile, and sensitive systems.

What stood out at this conference and what did you learn?

I found the diversity of the program to be outstanding, ranging from swarms to robotics, synthetic biology, evolution and the cognitive challenges that bio-inspired design poses. In addition to the many applications of bio-inspired design that were new to me – for example to think about extra-terrestrial life by systematically studying life in the least habitable regions on the planet – I appreciated bio-inspiration as a design approach that is not limited to my own field, robotics and mechanisms in the broader sense.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

I was fortunate to finally meet one of the inventors of Particle Swarm Optimization, Russell Eberhart who shared his experiences on how the perception and appreciation of his algorithm has been changing over the past decades. These ex-

Octopus Suction Cup | Photo: Michael Bentley, 2011 | Flickr cc

periences seem to represent bio-inspiration as a whole, which is often at odds with formal methods, providing impressive performance without us fully understanding why. For bio-inspiration to be ultimately successful, we will need to continue improving conventional design and analysis tools to close this gap and achieve provable performance guarantees.

Any action items after this conference? Things you will do, would like to do?

It was exciting to meet others who have been thinking about bio-inspiration from a smart composites perspective, evidence that the world is indeed flat (to quote Thomas Friedman's book of the same title). Interestingly, all of us have the same problem: being excited about the challenges to mimic the tight integration of sensing, actuation, computation and communication is not enough, but we will need to show the advantage of this approach from a cost-benefit perspective.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

The conference encouraged me to believe that bio-inspiration is on another up-cycle after the last peak that I believe to have been in the late 1990's, fading out in the early 2000s. What always has been working well for bio-inspiration is piggy-backing on the fascination people have with complex natural systems – often unbeknownst at first sight. I'd say this fascination is responsible for 90% of us engaging in this profession.

What do you see as the biggest challenges?

This fascination is unfortunately not enough in a production engineering environment, which requires formal methods describing its success. This is particularly obvious in the field of "swarm intelligence" – bio-inspired computational algorithms – that are very intuitive and successful, but remain esoteric in mainstream computer science as they are difficult, if not impossible, to analyze formally. I believe that this is the challenge: to transcend bio-inspiration, which must remain tinkering and trial-and-error without the right tools.

What areas should we be focusing on to advance the field of bio-inspired design?

In addition to advancing our understanding of bio-inspired model systems using conventional analysis and tools from engineering, I feel bio-inspiration needs to transcend form and function, and literally dig deeper into how biological materials actually work. After all, biological systems consist of billions of cells that work in concert, which is the opposite of the monolithic systems we engineer.

How have you developed your interest in bio-inspired design?

As many others, I was simply flabbergasted by the order and apparent intelligence that can emerge in a swarm of very resource-limited insects. While I am still fascinated with termite mounds, ant networks, and slime mold, these systems are not very interesting compared to

the human brain (or a human as a whole) which also consists of nothing but individual cells communicating with each other.

What is your best definition of what we do?

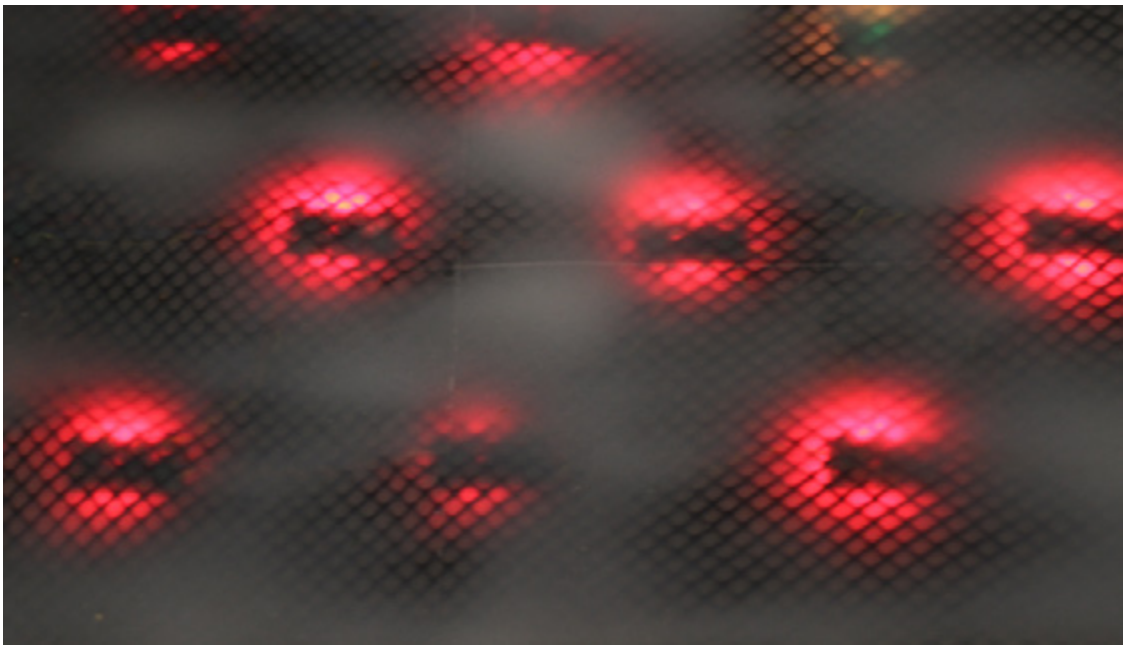
We are keeping our eyes open for intriguing and potentially useful behavior in nature to provide often surprisingly simple solutions to hard engineering problems.

By what criteria should we judge the work?

This is a great follow-up question in that it is not clear to me where bio-inspiration stops. Is the dung beetle's sphere a wheel, and so cars are bio-inspired? While I'm tempted to judge work for its creativity when it comes to leveraging a natural phenomenon for an as-far-removed-as-possible engineering problem, the bottom-line in judging a design will remain its function.

What are you working on right now?

With the hopes to demonstrate functionality that cannot be achieved any other way than by tightly integrating sensing, actuation, computation and communication, my lab is heavily focusing on tactile sensing and robotic grasping. I believe that contact sensing is critical for efficient manipulation and is underappreciated in robotics. Here, co-location computation bears the potential to perform both signal processing and control in the hand, letting the robot itself focus on high-level aspects of the platform.



Flexible robotic skin with integrated networked computation. Each computational element is equipped with a microphone to measure high-frequency vibrations induced by objects with different textures rubbed over the skin. All signal processing is performed on-board and the frequency spectrum is transmitted to a central computer, thereby mimicking the Pacinian corpuscle and the nervous system. | Image courtesy of Nikolaus Correll

How did you get started in bio-inspired design?

I joined the Collective Robotics group at Caltech in 2003, working on "swarm robotic inspection of jet turbines". While this application potentially has many better solutions that are easier to accomplish, I got stuck with the fascination for swarms, which have eventually become the smart materials I'm currently working on.

Which work/image have you seen recently that really excited you?

I tasked students from my swarm intelligence class to collectively work on a Google Doc, each contributing a single slide describing a swarm-intelligent system of their choice (with uniqueness the only requirement). What they came up with, a slide deck from mogul creation on a ski-slope to the insanely fascinating Mormon Crickets, was in itself a great example of self-organization. The Mormon crickets stood out in that they live solitary lives until resources in their environment begin to deplete. They then form a dense swarm to travel to new grounds, living by cannibalizing themselves. Once arrived in a more hospitable region, they disperse again. There certainly is ample material in this behavior for bio-inspired sociology or history!

What is your favorite bio-inspired work of all time?

I'm fascinated by flying, which is so counter-intuitive to humans. Seeing birds and insects performing this stunt all the time surely has been nagging at mankind for centuries.

What is the last book you enjoyed?

I just finished (listening) to *Fahrenheit 451* where books are banned not to suppress undesired ideologies, but to prevent readers from being offended. Given that almost every kid in America is reading this book in highschool, I'm a little surprised how forgotten the notion of the importance of getting challenged has become.

Who do you admire? Why...

I'm a big fan of George Heilmeier's catechism: "What are you trying to do? How is it done now and what are the limits of current practice? What is new in your approach? Who cares? What are the risks and pay-offs?" And other questions of crisp, inquisitive nature, which helps me and my students to solve almost any assignment. Heilmeier has been very successful as an engineer, and keeping focus – which is a constant struggle – has surely been critical.

What's your favorite motto or quotation?

"Everything should be made as simple as possible, but not simpler." (Albert Einstein)

What is your idea of perfect happiness?

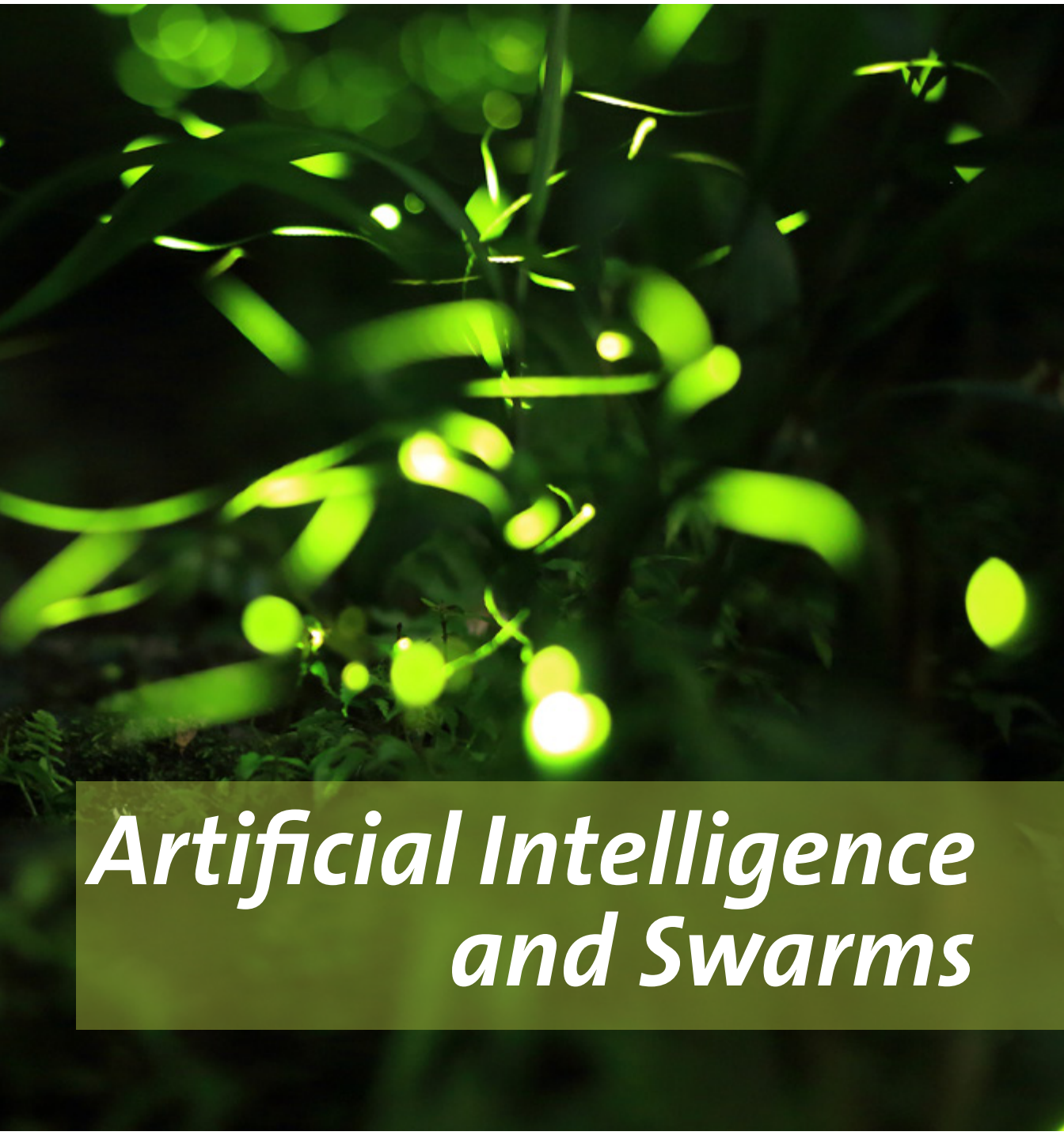
Living off the land (without the work!) with my family.

If not in your current profession, who/what would you be?

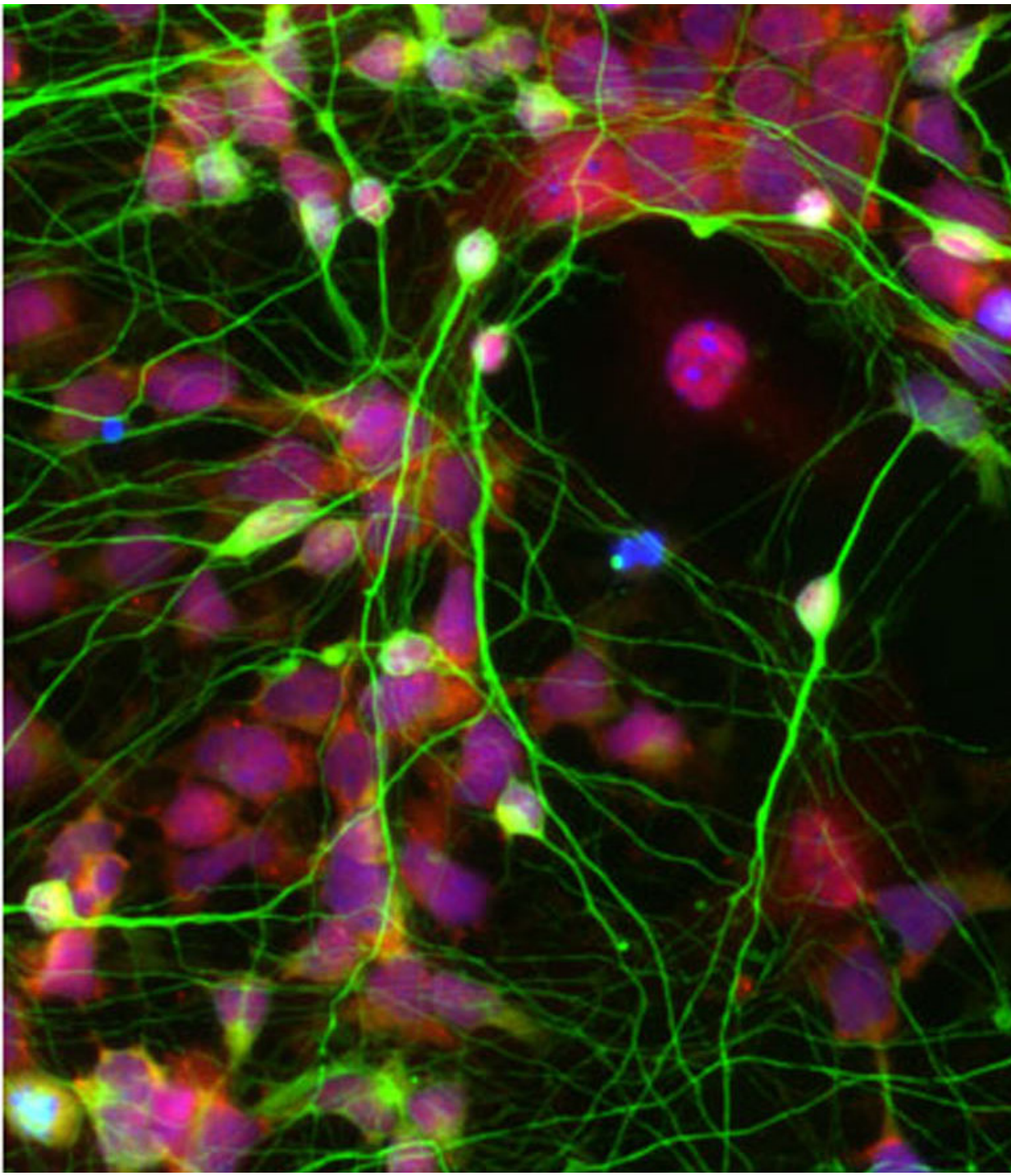
Becoming a doctor to better understand allergies and the immune system. ×

Firefly

Photo: johnnythelee, 2014 | Flickr cc



Artificial Intelligence and Swarms



Microscope view: stem cells reprogrammed from adult skin cells (red blobs), morphing into human brain cells (green blobs) | Photo: pennstatenews, 2013 | Wikimedia Commons

Interview

Amir H. Gandomi

special issue **People:** Interview

Author: Amir H. Gandomi

Dr Gandomi is currently a distinguished research fellow in an NSF center for the study of evolution in action (BEACON) located at Michigan State University, MI. He used to be a lecturer at several universities. Dr. Gandomi has published over one hundred journal papers and four books. Some of those publications are now among the hottest papers in the field, and collectively have been cited more than 5,500 times (h-index = 39). He also served as an associate editor, editor and guest editor in several prestigious journals. His research interests are nature-inspired computation and its applications in (big) data mining and engineering optimization.

Presentaiton title: *Evolutionary Computation for Real-World Optimization Problems*

Abstract: Evolutionary Computation (EC) has been widely used during the last two decades and has remained a highly-researched topic, especially for complex real-world optimization problems. Evolutionary optimization methods are inspired from biological systems or nature in general. The efficiency of EC is due to their significant ability to imitate the best features of nature which have evolved by natural selection over millions of years. The main theme of this presentation is about nature-inspired optimization techniques and their application to engineering optimization problems. At first, applied EC in optimization field will be presented, and then some nature-inspired algorithms will be explained such as Krill Herd and Interior Search Algorithms which I proposed recently. Then, some of my studies on applications of these algorithms on complex and nonlinear engineering problems will be presented. Additionally, optimization results of large-scale structures (e.g. tower structures) using biologically inspired computing (BIC) will be illustrated which show the applicability of BIC for real-world problems. It will also be explained how such algorithms have been adopted to the real-world problems and how their advantages over the classical optimization problems are used in action.

Would you please tell us about nature-inspired computation?

Nature-inspired computation (NIC) has been widely used during the last two decades and has remained a highly-researched topic, especially for complex real-world problems. The NIC techniques are a subset of artificial intelligence, but they are slightly different from the classical methods in the sense that the intelligence of NIC comes from biological systems or nature in general. The efficiency of NIC is due to its significant ability to abstract key principles of evolution in nature, which has shown its capability over millions of years.

What are the key takeaways from your conference talk? How would you summarize your presentation?

In the talk, I tried to briefly show how natural processes can be represented mathematically and considered as tools to solve real-world problems. In particular, I showed some case studies that the conventional methods could not solve, but that we have handled by using nature-inspired computation. A key point from the talk is that although the NIC approaches are pretty simple processes, they can be used to solve the very complex problem. Another key point here is that NIC uses different sources of information, such as evolution and swarm behavior, not mathematical information such as derivatives.

Starlings over Brighton | Photo: susie2778, 2016 | Flickr cc

Therefore, they do not need particular mathematical representation of the problem, and they can even solve gray/black box problems.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

First, I hope I could encourage people to consider natural computing for their problems. I have shown nature-inspired computation applications in three main stages of engineering systems including modeling, optimization, and monitoring, and I intended to express its applicability to a wide range of problems such as engineering optimization and (big) data mining. To me, all real-world problems can be defined as optimization problems as we have objective(s) and variables in all of them. Therefore, I hope people also will get a sense that nature-inspired computation can be used for their problems even if they are dealing with a complex and black-box system. Finally, I would like to encourage researchers to look at nature as a well-trained system and consider it as a source of inspiration no matter what their topics.

What stood out at this conference and what did you learn?

In general, I can say that it opened my mind to different views and different nature-inspired aspects in particular. From now on, I think, I will care more about different aspects as well as the details of natural systems.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Of course, most of my studies have been based on collaboration. I am an engineer who knows the nature-inspired tools. In other words, I have already worked on both the problem side and the algorithm side. Therefore, I have had the opportunity of completing many successful studies in several different fields. In the conference, I have also had many interesting talks with people who had different backgrounds and, in nearly all cases, we could find a way of possible collaboration. After talking to several NASA researchers, I found that the cutting edge research there could include excellent topics for expanding my studies, and I am eagerly looking forward to it. I know VIBE is making some technology clusters for future collaboration, and I am keeping in touch with several people from the conference for possible collaboration. I have already been invited to co-advise a Ph.D. student, to join two NASA clusters, and also to contribute to a project.

Any action items after this conference? Things you will do, would like to do?

I will more closely follow the NASA and GLBio missions, and VIBE in particular.

What are your impressions of the current state of bio-inspired computation?

Nowadays and after reporting successful cases, more researchers are interested in bio-inspired computation, and several centers have emerged recently focusing on these topics. Our

center (BEACON Center) is an NSF science and technology center which focuses on bio-inspired approaches and bio-inspired computation in particular. This center is a consortium of five different universities which shows high interest in such a topic which also increases every day.

What is working well for the current state of bio-inspired computation?

I think researchers in this field have made a very good foundation for the bio-inspired computation. However, there are many things that need to be addressed in this field.

What do you see as the biggest challenges?

I think the gap between theory and application is the biggest challenge in the bio-inspired computation field. There are several approaches that have been proposed, but most of them are only tested on the simple benchmark problems. However, in the industry, the problems are usually very complex and have mixed variables.

What areas should we be focusing on to advance the field of bio-inspired computation?

One of the main advantages of bio-inspired computation is that they are flexible which means they are adaptable for different problems. I think researchers have to think more about problem-specific algorithms rather than developing new general optimization algorithms. For example, large-scale problems and big data could be a good target for the specific algorithms.

How have you developed your interest in bio-inspired computation?

As a structural engineer, I first started working on some inverse structural engineering problems which could not be solved with regular algorithms/frameworks. I heard about these algorithms in one of my courses, so I started my research regarding these algorithms. Then my interest made me spend more and more time in this field, and good results encouraged me to continue the research.

What is your best definition of what we do?

I think I am not qualified to talk about biomimicry in general. However, my personal definition of bio-inspired computation is that "the computational algorithms model natural phenomena" which are able to solve problems.

By what criteria should we judge the work?

Nature-inspired computation is currently judged with mathematical benchmarks which could be an initial step. In the next step, they should be tested by some complex real-world problems. If an algorithm is designed for a specific problem, it can be benchmarked with conventional and mathematical algorithms. And if there is no benchmark available, it can be simply evaluated against the current solution.

What are you working on right now?

I am working on solving complex engineering problems using nature-inspired algorithms such

Antarktický krill | Photo: Norkrill, 2012 | Wikimedia Commons

as large-scale and highly constrained problems. I am working on both algorithm and problem sides and their adaptation.

How did you get started in bio-inspired computation?

I heard about these algorithms in one of my courses when I was looking for a method to solve some problems which could not be solved effectively by regular deterministic algorithms. After a few years of learning and applying different techniques, we came up with a bio-inspired optimization technique from Krill swarm behavior and in 2014 I published another new nature-inspired algorith called the Interior Search Algorithm.

Which work/image have you seen recently that really excited you?

One of my colleagues at MSU recently solved a billion variable problem using an evolutionary computation algorithm which was really interesting for me.

What is your favorite bio-inspired work of all time?

I like many different bio-inspired studies, but if I wanted to choose one, I would pick genetic programming, which is based on the genetic algorithm and is different from other methods and has some unique and exceptional features.

What is the last book you enjoyed?

I just read a book in Persian entitled *Memories of the prince of the public*. It includes some true short stories which gave me the feel of life.

Who do you admire? Why...

I admire many people, but I think the ones who dedicate themselves to others are my real heroes no matter what.

What's your favorite motto or quotation?

It is difficult to choose the best question. However, I really believe in this Einstein quote:

"Look deep into nature, and then you will understand everything better."

What is your idea of perfect happiness?

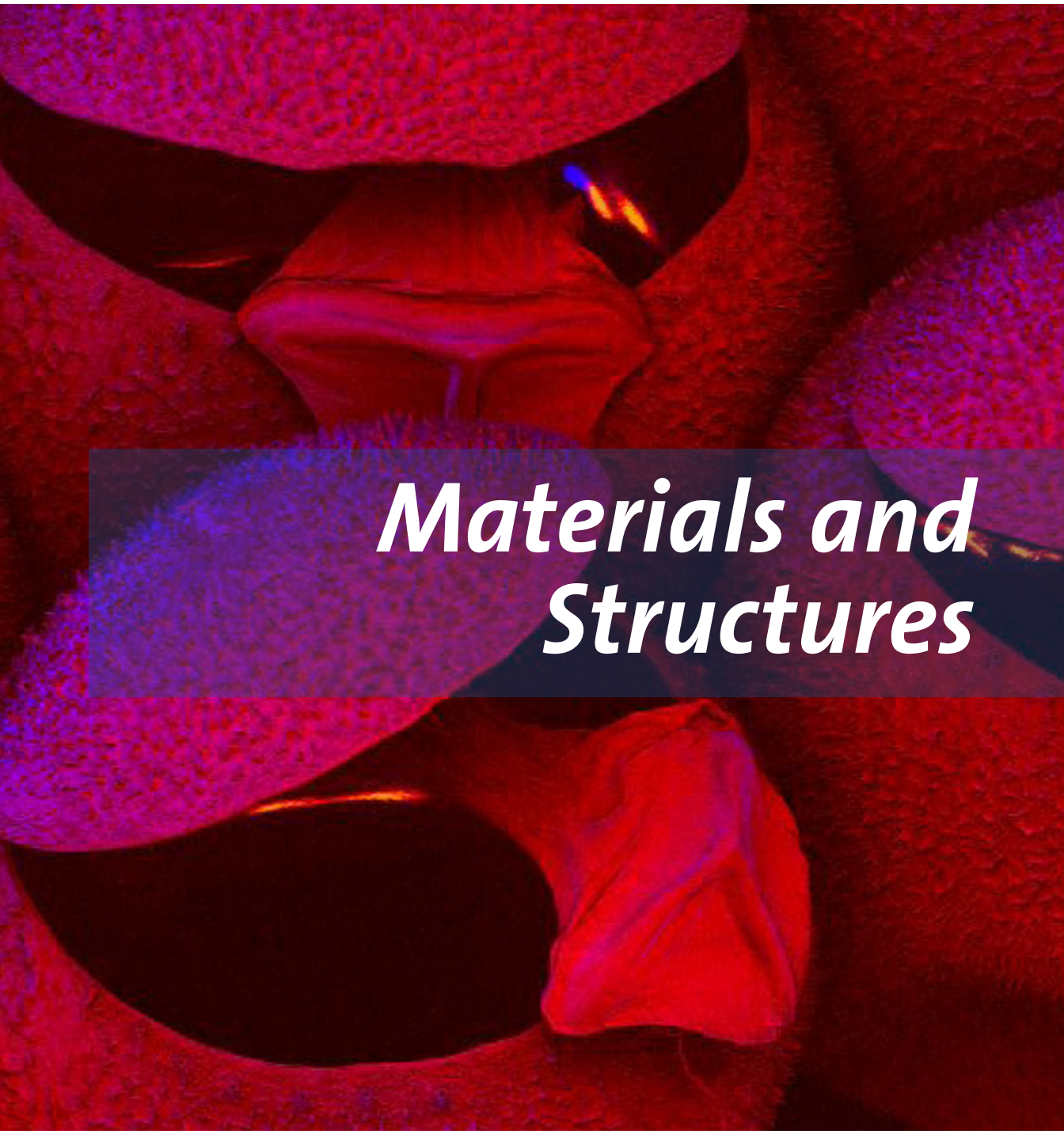
I think happiness is in our mind, and we could be happy no matter what is happening and what the life situation is. I have been so lucky to have a lovely wife and family who complete my happiness.

If not in your current profession, who/what would you be?

When I was a college student, I was really into music. I was playing in a band and had some performances. I think if I were not excited by the research, I would be a musician. In this case, I think I would still follow the nature-inspired music as I had already been excited by pieces such as "the four seasons". ×

'Angry birds' | Hatched eggs of stink bugs/shield bugs

Photo: ZEISS Microscopy, 2015 | Flickr cc



Materials and Structures

Wilbur Wright in prone position on glider just after landing, its skid marks visible behind it and, in the foreground, skid marks from a previous landing; Kitty Hawk, North Carolina.
Photo: Orville Wright? 1901 | Library of Congress, Public Domain | Wikimedia Commons

Interview
Paul Kladitis

Dr. Paul Kladitis has over 25 years of developmental engineering and leadership experience in various roles for the United States government and industry including program management; basic, advanced, and applied research and development; and installed system and flight developmental and operational test and evaluation.

Dr. Kladitis is currently the leader of the Multifunctional Products Group in the Multi-Scale Composites and Polymers Division at the University of Dayton Research Institute, Dayton, OH. Prior to this, he retired as a Lieutenant Colonel in the United States Air Force. During his Air Force tenure, he served as a program manager developing and transitioning advanced technology for the National Reconnaissance Office. He also served as an Associate Professor of Electrical Engineering at the Air Force Institute of Technology, Director of Staff for a deployed combat airlift wing, operational and developmental bomber flight test engineer, Director of Operations for an electronic warfare test squadron, and intelligence analyst. Prior to this, he also served in the United States Army Infantry.

Dr. Kladitis' experience in innovating new nanotechnologies, especially with regard to new forms of carbon, was recognized by appointment to national committees including the National Nanotechnology Initiative (NNI), Nanoscale Science, Engineering and Technology Subcommittee, Washington D.C.; Co-Chair of the NNI Signature Initiative on Sustainable Nanomanufacturing, Washington D.C.; and Co-Chair of the NNI Nanotechnology, Industry Liaison and Innovation Working Group, Washington D.C.. He has also served as the Chair, Treasurer, and Secretary of the Dayton, Ohio Section of the IEEE Executive Committee. He has published 44 technical papers and holds 4 patents.

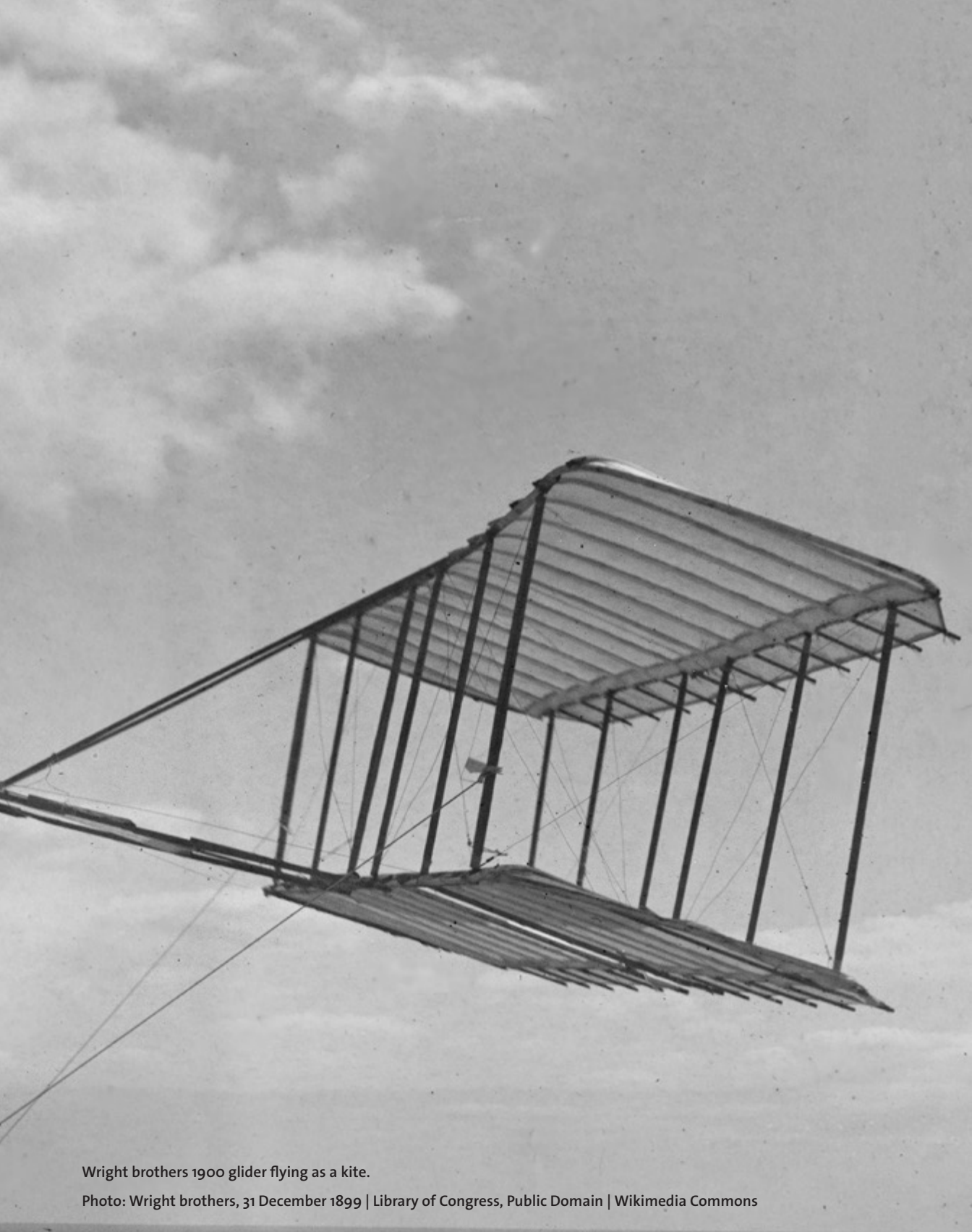
What are the key takeaways from your conference talk? How would you summarize your presentation?

In my conference talk I wanted highlight that without exception all structure found in living organisms has more than one function besides just being passive structure. In other words, all structures found in living organisms are "multifunctional." Also, it turns out that the living organisms in nature are typically optimized in terms of size, weight, and energy consumption. I attribute multifunctionality as the fundamental enabler for this optimization. Therefore, an ultimate mimicry of nature should be in the prolific development and incorporation of multifunctional structures in our man-made systems, especially in launch and space vehicles. Size, weight, and power (SWaP) are extremely precious commodities for aerospace and space travel since it costs roughly $10K/pound to get a payload into low earth orbit (LEO), and much more potentially surpassing $100K/pound to go further than LEO.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I am hoping more attention will be paid to developing multifunctional structures which is currently a tough problem since our manufacturing paradigms currently support singular function components for systems.

Great grey shrike | Photo: Smudge 9000, 2015 | Flickr cc



Wright brothers 1900 glider flying as a kite.

Photo: Wright brothers, 31 December 1899 | Library of Congress, Public Domain | Wikimedia Commons

What stood out at this conference and what did you learn?

Since I am newcomer to the biomimicry community, I appreciated the intense devotion of this community to not reinvent the wheel, and learn first lessons from the incredible designs already present in nature. This has always been my philosophy in engineering, but I was not previously cognizant of the already existing biomimicry community. I also was delighted to see that folks in art, industrial design, and architecture were serious about biomimicry.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

One interesting discussion that I learned about is that there is apparently a persisting fallacy among biologist where there is a constant temptation to simplistically subdivide biological systems into separate functional components. Where in fact most if not all parts of a biological system are so intertwined that it is truly difficult to say where one function ends and another begins. Apparently, my talk unwittingly highlighted this intimate "intertwinement" and sparked some discussion. I also was invited to collaborate on co-authoring some book chapters relating to multifunctionality – new collaboration....

Any action items after this conference? Things you will do, would like to do?

I'd like to continue to stay part of the biomimicry community if they will tolerate my perspectives.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

Since I am new to this community, I don't have a well formed opinion yet. Possibly, I did notice much talk about harnessing the bio-realm to grow things we currently manufacture – like batteries.

What do you see as the biggest challenges?

Developing comprehensive multifunctional structures.

What areas should we be focusing on to advance the field of bio-inspired design?

Multifunctional structure and material building blocks that enable multifunctional structure.

How have you developed your interest in bio-inspired design?

It happened naturally (no pun intended) as I matured as an engineer. I seemed to instinctively look to nature first for inspiration on engineering solutions I would happen to be looking for. So far, I have not been disappointed.

What is your best definition of what we do?

We look to nature for initial or primary inspiration for man-made solutions. We assume nature-inspired solutions will integrate more compatibly with our environment and eco-cycle.

By what criteria should we judge the work?

Good question, but not quite sure what you are asking. Assuming scientific integrity is satisfied (i.e. objective reporting of actually observed and quantified results), possibly a balance between societal benefit, environmental compatibility, and intrinsic morals?

What are you working on right now?

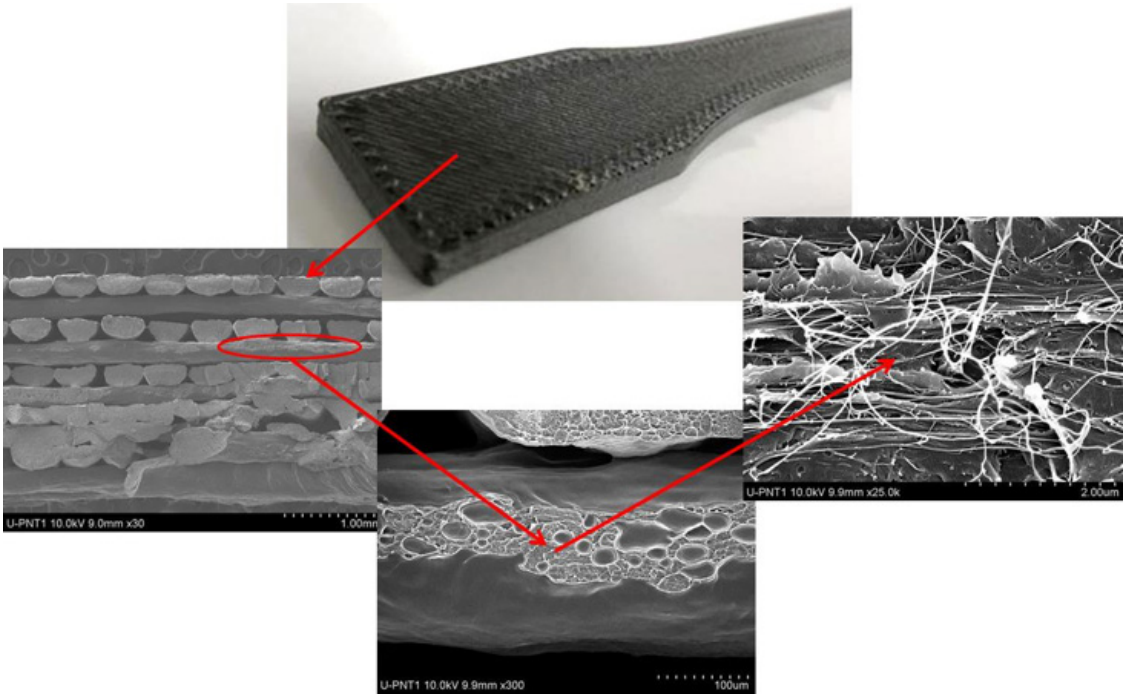
The name of the group I lead is the Multifunctional Products Group. I am working on projects ranging from developing multifunctional materials, multifunctional structures, and scaling up manufacturing processes for nanotechnology-based multifunctional materials.

Which work/image have you seen recently that really excited you?

Hmmm, that is hard to say. A lot of things since I am a somewhat a generalist, and enjoy working on multidisciplinary projects.

What is your favorite bio-inspired work of all time?

That is another tough question. I keep seeing bio-inspiration everywhere even when the people performing the work were not aware of it. To me this question is like asking what my favorite food at a good Chinese buffet is. Possibly the de-



First demonstration of FDM 3-D printed tensile test "dog-bone" using ultra-long carbon nanotubes (CNTs) enabling bridging of printed rasters leading to higher strengths and electrical conductivity. This breakthrough enables plastic to be a useful material for 3-D printed multifunctional structures. | Image courtesy of Paul Kladitis

velopment of flight – the Wright Brothers work – I'm possibly biased since I grew up a poor boy in Dayton, Ohio.

What is the last book you enjoyed?

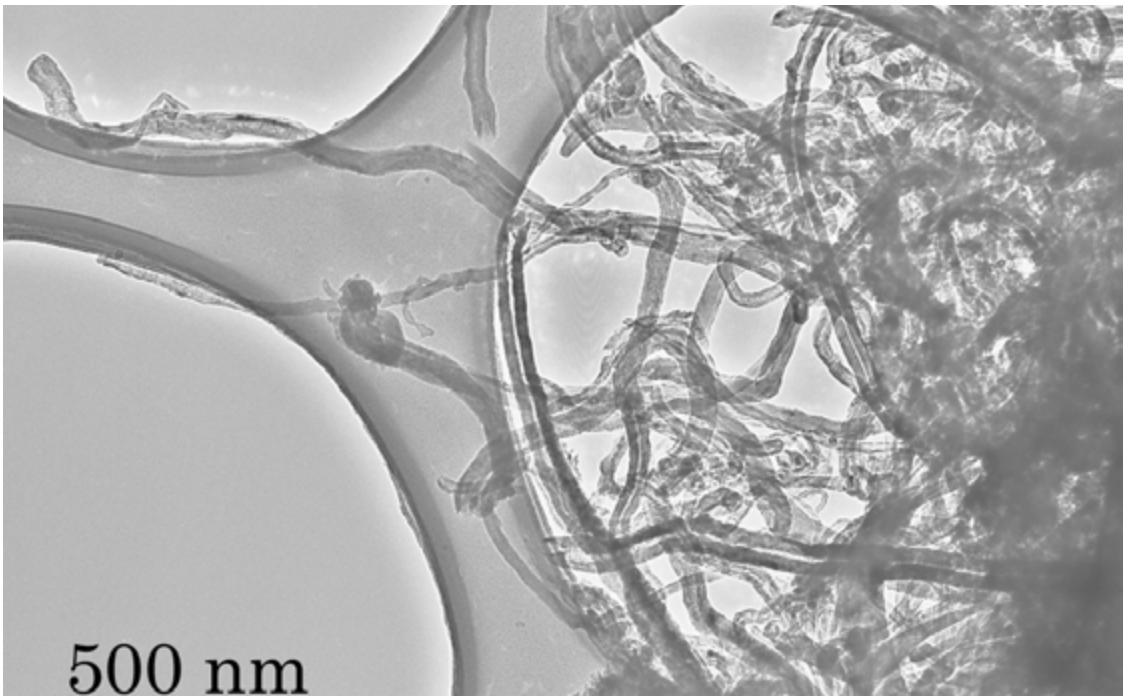
I am a bit of a history buff and enjoy reading original writings of historical figures. I am always dipping into George Washington's writings – such a nobler time than today. I am currently slogging through Isaac Newton's *Principia*.

What is your idea of perfect happiness?

Being in a place where all people love each other; all sickness and death is gone; and precious children live, play, and grow in complete safety, innocence, and wonder.

If not in your current profession, who/what would you be?

Maybe a full-time professor, farmer, mechanic, or explorer. ×



Carbon Nanotubes: Nanotubes can grow on graphite in an unruly mass according to "space's recipe." The overlapping segments on a single nanotube are a telltale sign of the cup-stacked structure.

Photo: Yuki Kimura, Tohoku University | NASA Goddard Photo and Video, 2010 | Flickr cc

Neelus murinus

Photo: andy badger, 2014 | Flickr cc

Aeronautics and Propulsion

Poison dart frog

Photo: martinbuck119, 2009 | Flickr cc

Interview

Konrad Rykaczewski

Konrad Rykaczewski is an assistant professor at School for Engineering of Matter, Transport and Energy at Arizona State University. He received his BS (2005), MS (2007) and PhD (2009) in mechanical engineering from the Georgia Institute of Technology. Prior to his appointment at ASU, he was a research scientist at Massachusetts Institute of Technology and National Research Council postdoctoral fellow at National Institute of Standards and Technology. He has co-authored over 50 journal publications and is currently pursing research on fundamentals of nano/microscale thermofluidic and interfacial phenomena, novel in situ and cryogenic electron and ion beam microscopy methods, and nanoengineering of biomimetic functional surfaces with special wettability for various applications.

What are the key takeaways from your conference talk? How would you summarize your presentation?

In general my research revolves around engineering of surfaces to modify how liquids interact with them in order to achieve some technological goal. In my presentation I gave a very short overview of three projects in which my group has both explored some new phenomena in nature as well as mimicked known mechanisms in nature to achieve a technological goal.

One of these goals is to prevent icing of the airplane wings, which can rapidly change their shape leading to loss of lift, and airplanes dropping out of the sky. This is how about 600 aviation accidents happened in last 20 years of 20th century. Typically this problem is combatted by spraying a large amount of antifreeze liquid on the airplane before or during flight. This process can be expensive and environmentally unfriendly, and also simply unreliable when we run out of the liquid (this is what often happens during snowstorms). So having a coating that would prevent ice from forming would have safety, environmental, and economic benefits.

Since ice can form from large supercooled droplets, one idea is to make a coating that prevents drops from sticking to the wing. In very simplified terms, "if it can't stick, it will not freeze". There are numerous examples of such "superhydrophobic" plants in nature, for example the lotus leaf, the prickly pear cacti, and just plain Kale that grows in my backyard. Another type of a "slippery surface" is based on the pitcher plant, which has a mushy coating that captures a water film when it rains to make ants slip into it. One can "slip off" ice and water drops if the right engineered texture is infused with oil. In some of my older research I found that these two types of bioinspired anti-icing surfaces repel large droplets well, but become "sticky" when they are frosted over or exposed to small drops like freezing fog. What occurs is that condensate or frost filled up the little nano/microscale valleys that make the surfaces superhydrophobic, and then they become "sticky" and ice over. In case of the SLIPS surfaces, the oil wicks out into the frost.

A couple of years ago I came up with a different idea while going on a jungle tour with my wife in Panama, where we saw this little poison dart frog. Being an experimentalist I really wanted to touch it, but the guide said that is probably not a good idea, as they are, well, very poisonous. I later found that out that the frogs need to eat a specific type of an ant to get the chemicals that are needed to make the poison. They synthesize it in a little gland in their dermis. To conserve the toxin, they "squeezing it" out onto the

Red Striped Poison Dart Frog | Photo: [Rossco], 2014 | Flickr cc

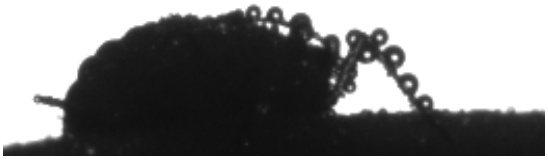
dermis only in response to a predator. The toxin then spreads diffusively in the mucus, that covers their body. That gave me an idea: how about squeezing out only little bit of antifreeze out of a coating to minimize the amount that is used. So back in lab, we literally took the two-layer porous skin idea—except the "epidermis" was a porous superhydrophobic coating and inside the "dermis" was a "wick" filled with antifreeze. Droplets bounced off this coating like off a normal superhydrophobic coating, but when frost fills up the valleys, the antifreeze was released. At least in our laboratory tests this turned out to work very well, saving estimated 2-8 fold in antifreeze as compared to systems that continuously flood the airplane with antifreeze during flight (e.g. "weeping wing" system). We also discovered that the unique combination of hygroscopic antifreeze filled micropores inhibited nucleation in-between the pores through what we call the "integral humidity sink effect". We are still studying this process, but overall this shows that it is often worth trying new systems, in this case inspired by nature, as one might discover unexpected beneficial processes.

The next two examples that I talked about were curiosity driven projects focused on how droplets interact with our local Arizona plants (literally front yard and backyard research). While watering a prickly pear cactus (Opuntia microdasys in this case) in my front yard I observed that indeed new cladodes were superhydrophobic, but the older cladodes were completely wetted by the impinging drops. With financial help from Biomimicry Center at ASU and the Desert Botanical Garden (collaborator: Dr. Lucas Majure), we found that this behavior is common in at least 30 species of prickly pears. Our first thought was that the external nanostructured epicuticular wax changed chemically due to UV or other weathering. Interestingly, we found that did not happen at all. Instead, the wax had these deep microcracks that penetrate down to the inner layers of the cucitle, which are highly hydrophilic. We found that droplets completely pin to these microcracks, which causes them to spread into a film after impact. We think that the cracks might modulate how water diffuses through the cucticle barrier when the cacti shrink and expand during dry and wet periods. Interestingly, somebody just recently published a paper about a "smart" nano-cracked membrane based on the stomata opening mechanisms in cacti that ended up making fuel cells more efficient (see http://www.nature.com/nature/journal/v532/n7600/full/nature17634.html). Consequently, we think our research and our follow up study might provide some interesting insight into how such dynamic 3D micro-cracks might be used to regular transport properties.

The last project that I talked about was very personal. Every winter my amazing wife grows really healthy kale for us and our rabbit in our backyard. Unfortunately, every year little pesky insects called aphids arrive and preferentially eat the kale. So before making dinner, I very thoroughly wash the leaves, only to find out later that despite my efforts my salad wasn't fully vegetarian. As leaves of the lotus plant, the leaves of kale completely repel water drops because of the nanostructured surface wax, implying that bugs should also be easily washed off with rolling drops. So this is a nice example of how my meal turned into a very interesting scientific question. Here's a few images from a high speed movie we did in lab showing that indeed

Aphid | Photo: amuderick, 2008 | Flickr cc

only about 1 in 10 of these bugs comes off (Figure 1). Long story short, we found that aphids have same type of waxy coating on their backs and legs, which makes them also water repellant. We



confirmed this process by exposing one victim to fog—you see drops balling up. This is exactly what happens when droplets hit them—the backs shield them, diverting water to the leaf. It actually helps them stick!

Based on the aphid adhesion mechanism that we discovered, we came up with several solutions to this pesky problem. First we found that soapy water gets under the insects because of its lowered tension and washes them off. In addition, we found that blowing them off with air is by far most effective route of their removal, as this fluid easily penetrates under the insects, irrespective of the underlying plant surface

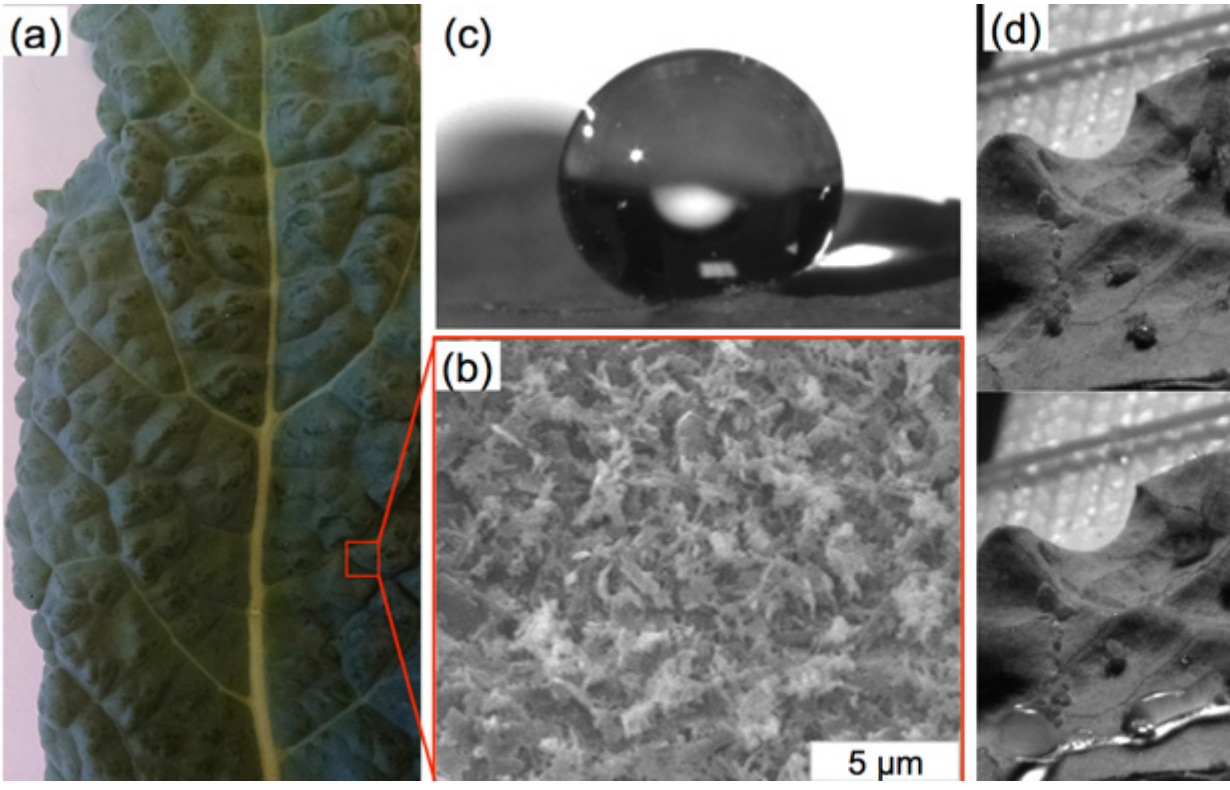
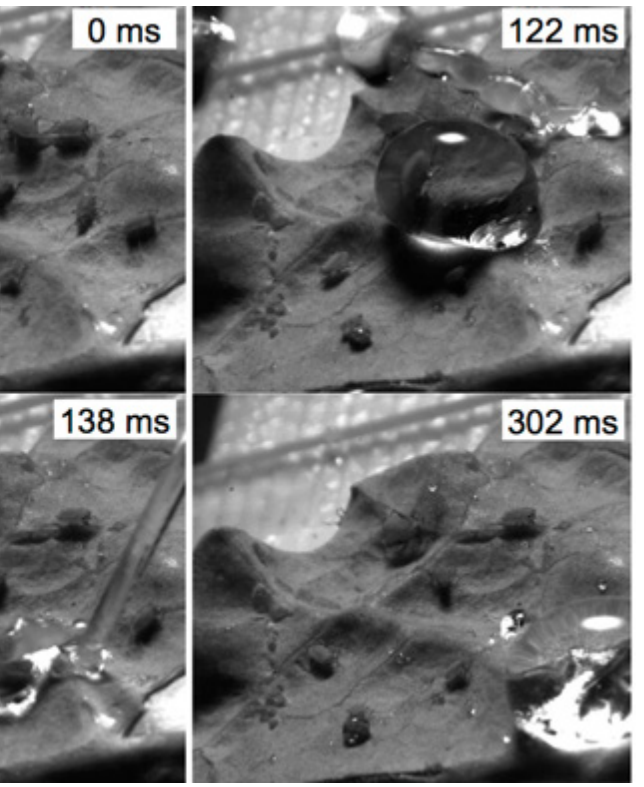


Figure 1

Images courtesy of Konrad Rykaczewski

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hope that with these 3 brief project got people excited about looking at nature, both for understanding what is happening and mimicking already known mechanisms for applications ranging from safe aircraft flight to keeping salads vegetarian.



What stood out at this conference and what did you learn?

I personally really liked Peter Niewiarowski's presentation on biomimicry and trying to clarify some issues. For example, nature provides *a solution*, but it does not have to be optimal or efficient by our standards. Often it turns out to be a pretty good solution, but we can always try to improve on it. That provides room for creative engineering, otherwise it feels like cheating.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Sure, nothing materialized yet, but hopefully sometime in the future.

What are you working on right now?

Surfaces, lots of surfaces...and in general "smart/dynamic/composite/hierarchical materials"

How did you get started in bio-inspired design?

I worked on superhydrophobic surfaces for a few years, but that never really felt bio-inspired, since it was not me who actually described this process. The projects I described were the first three areas revolving around nature in some way or another that I worked on. In all cases they were initiated from a personal observation "in the field".

What is the last book you enjoyed?

Environmental Biology of Agaves and Cacti by Park S. Nobel ×

Seal whiskers

Photo: Satriver, 2014 | Flickr cc

Interview
Wei Zhang

special issue | **People:** Interview | **Author:** Wei Zhang

Dr. Wei Zhang earned her Ph.D. in Mechanical Engineering (specialty: Fluid Engineering and Thermophysics) from Xi'an Jiaotong University, Xi'an, China. Prior to joining CSU, Dr. Zhang has conducted research on a wide variety of topics ranging from large-scale systems such as atmospheric turbulence, tornado vortex dynamics and wind-blown sand saltation (two-phase flows), to small-scale laminar-turbulent transition over the airfoil of micro air vehicles. Her research interests are:

1) development of non-intrusive laser and imaging based thermal/fluid measurement techniques, and

2) applications of these techniques to understand governing mechanism of complicated thermal/fluid and energy systems in nature and in industry.

Dr Zhang's current focus include turbulent flows over heterogeneous earth surface, wind-farm wake modeling, and bio-inspired flow control and design.

Presentation title: *How Seal Whiskers Suppress Vortex Structures: Effects of Phase Shift Angle*

Abstract: Certain seal species' whiskers have been reported to be capable of reducing vortex induced vibration and drag force, which is attributed to the peculiar three-dimensional morphology of the whisker surface. The whisker can be described as a loft through elliptic cross sections of varying major and minor axes along the whisker axis. The plane of the major and minor axis of the ellipses also changes its orientation with respect to the axis, resulting in undulating leading and trailing edges. While the effects of the dominant parameters of whisker morphology have been studied, this work focuses on the role of the phase shift angle (i.e., the angle between the elliptic cross sections and the whisker axis) on the vortex development in the wake. CT scan data of multiple seal whisker samples indicates the phase shift angle varies in a wide range, which was previously ignored. Several scaled-up whisker models are examined in the wind tunnel, concentrating on how flow structure responds to the phase shift angle of constant values (0, 5, 15 degree) and of a random distribution in a preset range. Knowledge of the influence of these morphology parameters can provide insights to design whisker-like underwater flow sensors and geometries that effectively reduce drag.

What are the key takeaways from your conference talk? How would you summarize your presentation?

Working together with Dr. Vikram Shyam at NASA GRC, we are studying how unique morphology features of the harbor seal whiskers contribute to its exceptional flow sensing and wake suppression capability, in particular the parameter of cross-sectional twisting angle's effect. We are also interested in the way in which the 'whisker grouping' functions as a high-sensitivity flow sensor. These findings can be very useful to optimize the structure and layout of blades in wind turbines and common infrastructure components (light post, wind turbine tower, as usual examples) under the influence of wind or water.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

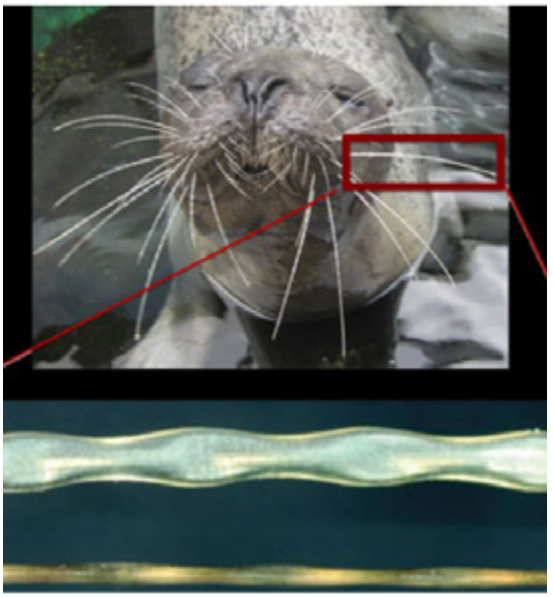
Nature has provided us excellent examples of how to swim and fly more efficiently. People have learned a lot from humming bird, dragon fly, and many other insects about flying with op-

Bewhiskered | Photo: Kiwi Mikex, 2008 | Flickr cc

timized energy consumption. As a researcher in fluid mechanics, aerodynamics and energy areas, I hope the seal whisker inspired aerodynamic design develops into a key area of research. By immersing into this field, I expect to introduce the bio-inspired design concept to our mechanical engineering program, so that our future engineers can naturally seek solutions from nature and the living environment.

What stood out at this conference and what did you learn?

It is very impressive how the variety of topics presented at the conference, from a spectrum of the academic, educational organizations and industry partners, provide a big picture of the different aspects of the bio-inspired design field.



Certain species of seals can detect minute motion of the water behind their preys. This exceptional capability is believed to relate to the peculiar morphology of their whiskers. The whisker can be seen as a wavy cylinder of elliptical cross-sections. | Photo: Hanke et al., 2010 | Provided by Wei Zhang

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

It is great to talk with people working on different research topics to understand why they are working on certain research and explore potential collaboration.

Any action items after this conference? Things you will do, would like to do?

In short term, I'd like to schedule a visit to the University of Akron and explore the potential of using our engineers' approach to quantify forces and environment conditions of gecko adhesive research. Also, I will discuss the opportunity to seek research grants via the state with Dr. Wu at the Wright State and Dr. Shyam at NASA GRC. In the long term, I'd like to be involved in further activities with this group and contribute to the bio-inspired aerodynamics research.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

I feel that the idea of bio-inspired design has been around for quite a while, although sporadically. For the field of aerodynamics, people studied birds, insects, and fish to understand how they maneuver in the fluid with optimized energy consumption. In particular, if they are in groups, how individuals work together to take advantage of "vortices" generated by others, so that the group as a whole can operate in an energy-sustainable manner. With understanding of how nature does it, we can apply similar ideas for designing certain structures, or adopt certain

layout of flow-related devices. One example is to optimize the layout of wind turbine arrays in wind farm following a school of fish, as studied by John Dabiri's group at Stanford.

It is feasible and effective to first understand how nature works and then apply this concept to designs with different constraints, through close collaboration of biologists and engineers.

What do you see as the biggest challenges?

The biggest challenge I see is how to rigorously quantify the features of the natural system that deliver certain functions. For example, as an engineer, I can come up the statistical analysis of the seal whisker morphology, with geometric parameter metrics, which are assumed to produce beneficial aerodynamic performance. However, the statistics from the collected samples are just a snapshot of the real environment and conditions. It is uncertain how what we observe in the lab relates to these complex situations. In addition, we need large samples to ensure statistically significant results, which is also challenging when dealing with inherentlylarge variations in living systems. Understanding these issues is important to be able to apply the concept to the design.

What areas should we be focusing on to advance the field of bio-inspired design?

Following up the above question, engineers should work with biologists to quantify the key features that represent the real situations in nature.

How have you developed your interest in bio-inspired design?

Since a few years ago, I've sporadically seen and observed some bio-inspired design projects: self-cleaning surfaces mimicking the Lotus-Effect, drag reduction by adopting dragonfly wing-like structure. As a researcher in aerodynamics, I've been interested in how certain tree species are more robust in strong winds and which natural system/structure can change the wind/water around it. I've been working on a new design of wind and snow fences by mimicking the multi-scale fractal structure of trees, in addition to the seal whisker research.

What is your best definition of what we do?

Use the living system around us as the prototype/base and further optimize it to transform engineering design.

Whisker drips

Photo: mikaku, 2010 | Flickr cc

Harbor seal | Photo: Kentish Plumber, 2016 | Flickr cc

By what criteria should we judge the work?

Complying with the sustainability ideal: good functionality, energy saving, and environmentally friendly.

What are you working on right now?

I conduct research and teach in the fluids/thermal and energy system area. Along the line of bio-inspired design, I've been working on a new design of wind and snow fences by mimicking the multi-scale fractal structure of trees. Another ongoing project is to understand how the morphology of the harbor seal whiskers contribute to the capability of flow sensing.

Which work/image have you seen recently that really excited you?

The image of sand dunes in Mars I saw at the Biomimicry Summit and Education Forum. I am curious about why the sand dunes form in a certain unique pattern and shape, under very strong wind conditions. This information could be very useful to design new residential structures that can survive in the "tornado alley" in the Midwestern states and hurricanes in teh South.

What is your favorite bio-inspired work of all time?

I can recall an elegant flow visualization of the leading wing vortices generated by hovering humming bird.

What is the last book you enjoyed?

Writing Science by Joshua Schimel because I am interested in improving my writing skills to better communicate science in papers and proposals.

Who do you admire? Why...

I admire people who are innovators in their field. To start a new field or a new topic usually means doubts, objections and many failures. Only people who are persistent, confident and keeping on work towards their goals can make it happen.

What's your favorite motto or quotation?

"If you can't explain it simply, you don't understand it well enough." By Albert Einstein

What is your idea of perfect happiness?

I enjoy sharing excitement with colleagues about research results and listening to my kids' telling their stories in imagination.

If not in your current profession, who/what would you be?

I would be a medical doctor to understand the cause of mental diseases and seek solutions to help people who are suffering. ×

For me?

Photo: KrysiaB, 2011 | Flickr cc

Architecture, Art and Design

Bombardier Beetle

Photo: Andrew ww, 2013 | Flickr cc

Interview
John Nottingham

special issue | **People:** Interview | **Author:** John Nottingham

John Nottingham is the co-founder and co-president of Nottingham Spirk, a leading business innovation firm with over 1,000 commercialized patents. The Nottingham Spirk "Vertical Innovation" process has helped client/partner companies earn over $50 billion in combined sales. The NS innovation team has co-created such award winning innovations as Spin-Brush, the largest selling powered toothbrush line; Swiffer Sweeper Vac, the largest selling floor care appliance; Scott's Snap Spreader System; dozens of Dirt Devil/Hoover products; Sherwin-Williams Twist & Pour, named one of the Top 10 Package Innovations of the decade; DualSaw; Medtronic CardioInsight EC Vue, the first noninvasive electrocardiographic mapping system; and ViewRay, the first MRI guided radiation therapy device.

John serves on the Cleveland Clinic Board of Trustees, CWRU Technology Commercialization Visiting Committee, CWRU Think[box] Advisory Board, boards of Global Center for Health Innovation, Great Lakes Biomimicry, Cleveland Institute of Art and University Circle Inc., as well as several private equity company boards of directors.

Presentation title: *Real World Examples of How Biomimetic Principles are being Utilized in the Product Design Process*

Abstract: I will be presenting real world examples of how biomimetic principles are being utilized in the product design process. At the Nottingham Spirk Innovation Center, we are organized organically and have a vertically integrated process that we call Vertical Innovation. We use biomimetic concepts in our process starting with human insights, creative sessions to produce product concepts, nature-centured design, engineering, prototyping, packaging and commercialization, all utilizing biomimicry. Specific-case studies will demonstrate the natural references via graphics and video.

What are the key takeaways from your conference talk? How would you summarize your presentation?

The topic was *Biomimetic Principles in Design*. Biomimicry gives us a new lens to look through as we brainstorm and solve problems. Since we have been innovating for over 40 years, continuously evolving and streamlining our process, we can look back at our results and validate many of our products through nature. As we look forward, we are looking at nature as a new reference. We are beginning to unfold the potential more and more with each case we work on.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

Biomimicry is a new and emerging field. As we dive further into it, we are noticing that our results are more complex, innovative, and sustainable. We are hoping to connect and collaborate more with companies that we can partner with and help them to innovate their businesses using biomimicry.

What stood out at this conference and what did you learn?

The wide variety of backgrounds represented. Presentations ranged from general to highly technical.

Spiral | Photo: Peter Nijenhuis, 2010 | Flickr cc

special issue

People:
Interview

Author:
John Nottingham

Nottingham Spirk building, Cleveland, Ohio

Photo courtesy of John Nottingham

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Sure. It was chance to connect with a variety of people.

Any action items after this conference? Things you will do, would like to do?

Advancing some of the discussions with possible collaborators.

What are your impressions of the current state of bio-inspired design?

An exciting and still emerging field, we are just on the cusp unlocking nature's potential.

What is working well for the current state of bio-inspired design?

The close-knit community of Northeast Ohio, GLBio harnessed the vision to create a world-wide hub of biomimicry.

What do you see as the biggest challenges?

Nature is so vast, from the microscopic to larger systems, the biggest challenges we have are knowing where to look and how to narrow down and know what to focus on. We have to educate, practice, and refine this new knowledge base so that we can use it effectively.

What areas should we be focusing on to advance the field of bio-inspired design?

Continue and expand the development of tools to allow access to nature for all without having a degree in biology. Continue and expand the education of biomimicry, youth through professional. More case studies of effective biomimetic processes and results.

How have you developed your interest in bio-inspired design?

We have a natural curiosity for expanding and improving our process; we partnered with Great Lakes Biomimicry to help explore and educate our team about biomimicry. We also partnered with University of Akron and began a worldwide search for our own biomimicry fellow. Additionally, we joined the Biomimicry Council with other corporate sponsors and began to collaborate with this eclectic group.

What is your best definition of what we do?

Expand the opportunity for nature to provide its solutions as part of a process.

By what criteria should we judge the work?

Assess solutions from a holistic lens.

What are you working on right now?

We are working on many design and engineering programs, using biomimicry in our brainstorming, problem solving, for sustainable solutions.

How did you get started in bio-inspired design?

We met Tom Tyrrell, the CEO of GLBio at a conference a few years ago. We invited him to meet our group and he gave an inspirational presentation about Great Lakes Biomimicry. He introduced us to Peter Niewiarowski and the Integrated Bioscience PhD and fellowship program. We did a worldwide search for a fellow whom we found in Portugal. She has degrees in both engineering/physics and design. Since bringing her in and collaborating with GLBio, we are integrating biomimicry into our process. We are also beginning to collaborate with the other corporate sponsors as well as other companies on new and exciting programs.

Which work/image have you seen recently that really excited you?

FLEXcon is doing a great job in integrating biomimetic materials in a variety of applications.

What is your favorite bio-inspired work of all time?

Velcro.

What is the last book you enjoyed?

The Innovator's Dilemma.

Who do you admire? Why...

Janine Benyus, for her pioneering work in giving visibility to biomimicry.

What's your favorite motto or quotation?

Motion is progress.

What is your idea of perfect happiness?

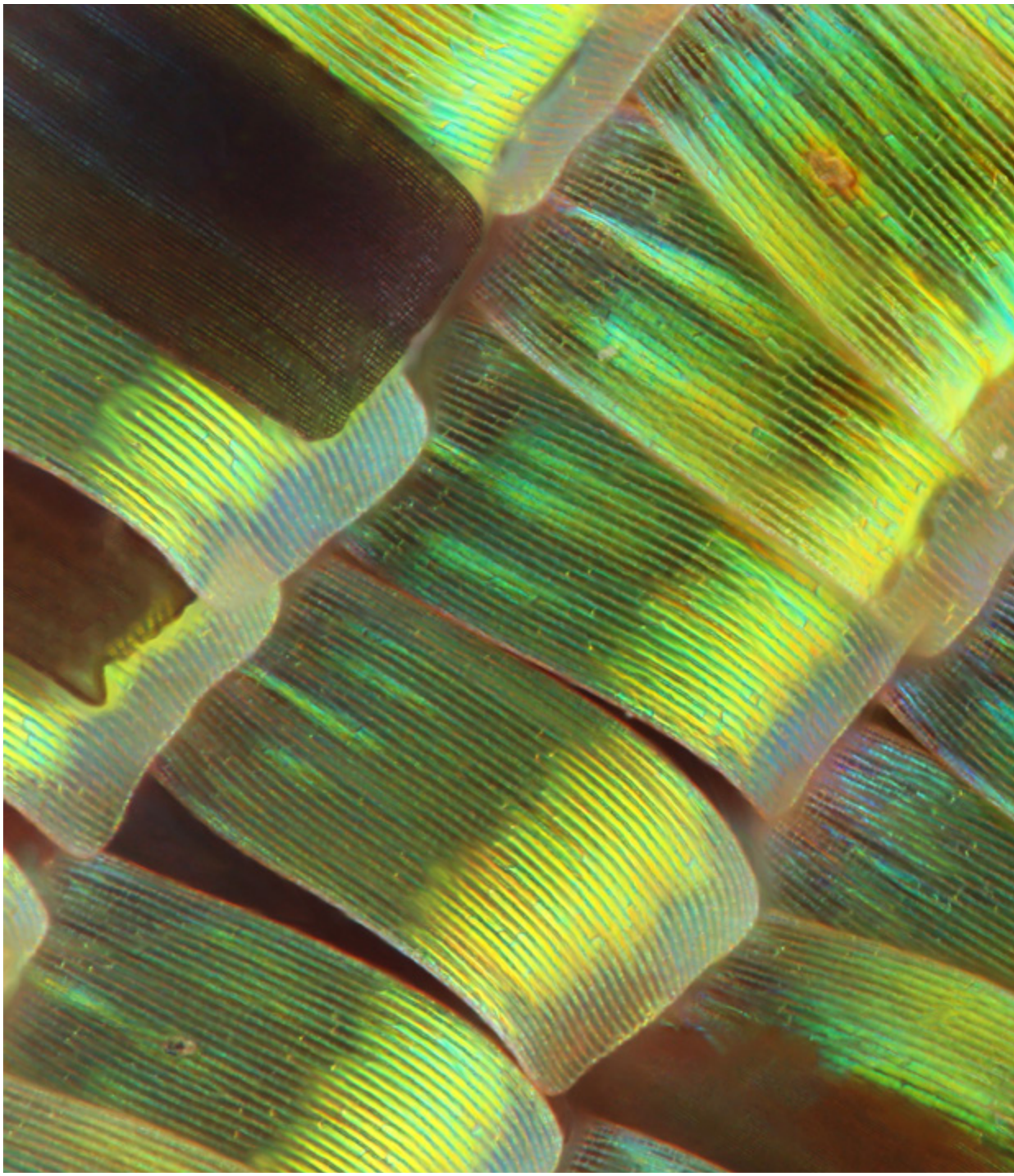
In the zone of creativity.

If not in your current profession, who/what would you be?

A venture entrepreneur. ×

Drosera rotundifolia

Photo: Free the Image, 2014 | Flickr cc



Madagascar sunset moth scales (*Chrysiridia rhipheus*)

Photo: Macroscopic Solutions, 2015 | Flickr cc

Interview
Bill Sullivan

Bill Sullivan is Vice President, Performance Products for Spencer, MA-based FLEXcon, Inc., and a Business Team (Performance Products) that is responsible for the development, marketing and commercialization of high performance adhesives, functional coatings, film castings and the creation of functional microstructures. Author of nationally published articles primarily on FLEXcon's success in helping in the creation of Sharklet®, a functional microstructure which prevents the growth of bacteria through its microscopic design capabilities, his expertise is in assisting start-up companies and enterprises with bringing their concepts and ideas to commercial reality.

What are the key takeaways from your conference talk? How would you summarize your presentation?

Manufacturers are eager to work with inventors of bio-inspired structures and chemistries to help bring their ideas to commercial successes

Manufactures often have customers and markets in unrelated spaces that might aid in the commercial success of new bio-inspired inventions.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I'm hoping to convince the biomimicry community to reach out to manufactures to advance their ideas and bring commercial success to bio-inspired ideas.

What stood out at this conference and what did you learn?

What stood out is the tremendous amount of work that is being done in the bio-inspired discipline. There are exciting new discoveries that are being developed, and some that have real life impact.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Absolutely. All of the above.

Any action items after this conference? Things you will do, would like to do?

There was some great collaboration that will hopefully result in additional commercial successes.

What are your impressions of the current state of bio-inspired design?

New and exciting and growing.

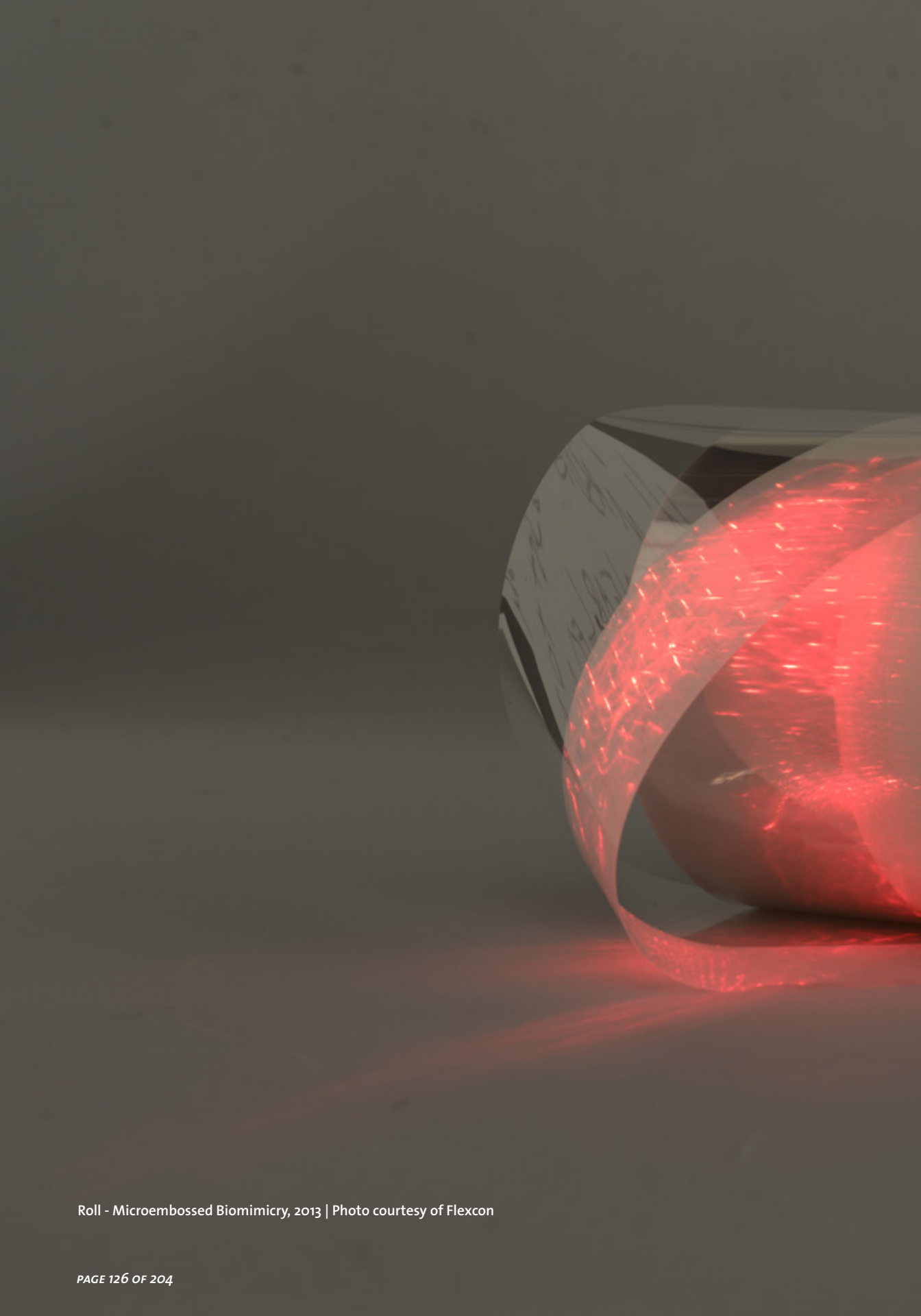
What is working well for the current state of bio-inspired design?

Continued studies and, hopefully, collaboration that will result in commercially viable products.

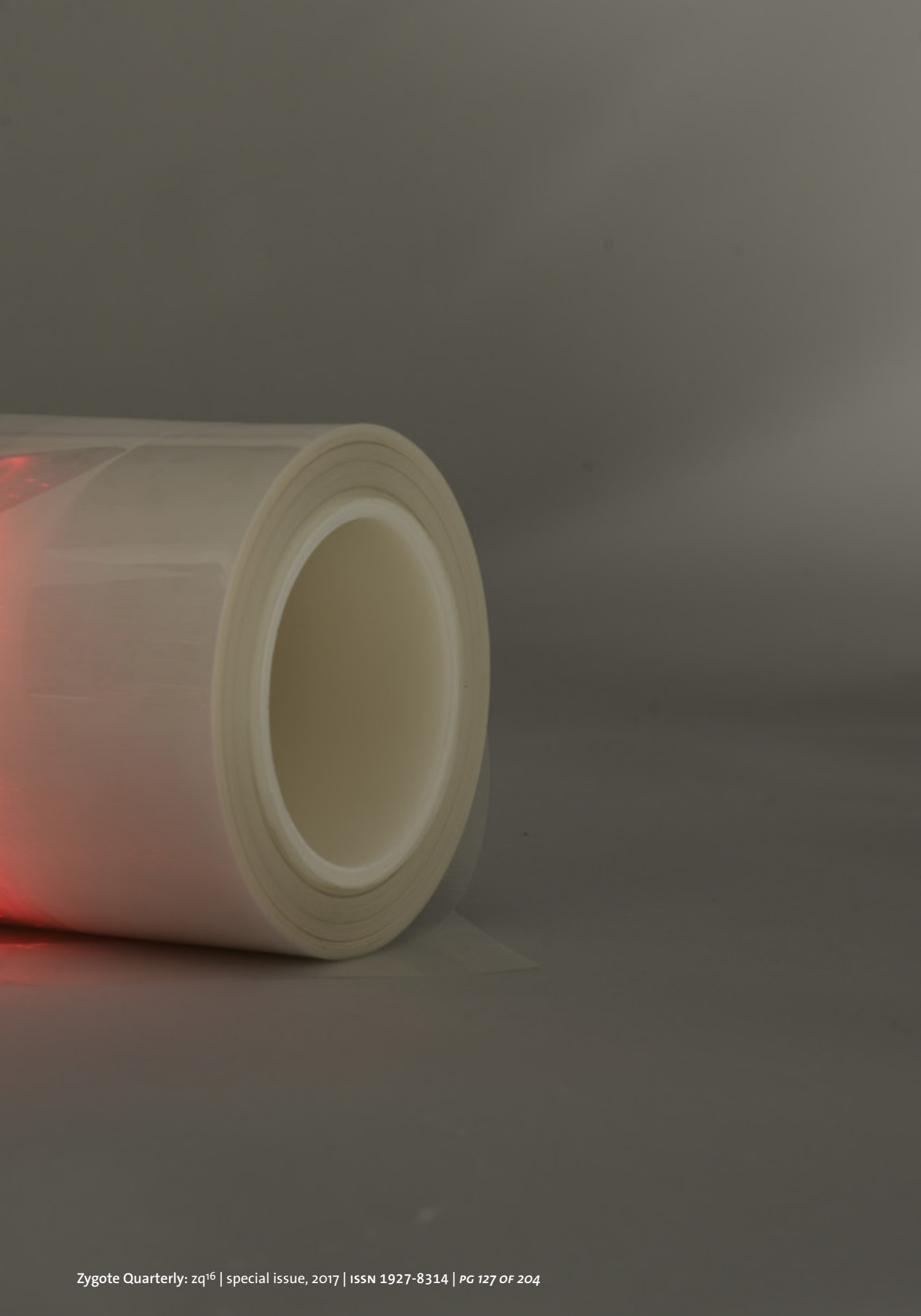
What do you see as the biggest challenges?

The biggest challenge I see is bringing together manufacturing and the bio-inspired community.

Moth face | Photo: tomhouslay, 2011 | Flickr cc



Roll - Microembossed Biomimicry, 2013 | Photo courtesy of Flexcon



special issue | **People:** Interview | **Author:** Bill Sullivan

What areas should we be focusing on to advance the field of bio-inspired design?

Networking events like this one. Bringing together industry and science.

How have you developed your interest in bio-inspired design?

It is a good business decision founded in proven science.

What is your best definition of what we do?

Using nature to solve problems.

By what criteria should we judge the work?

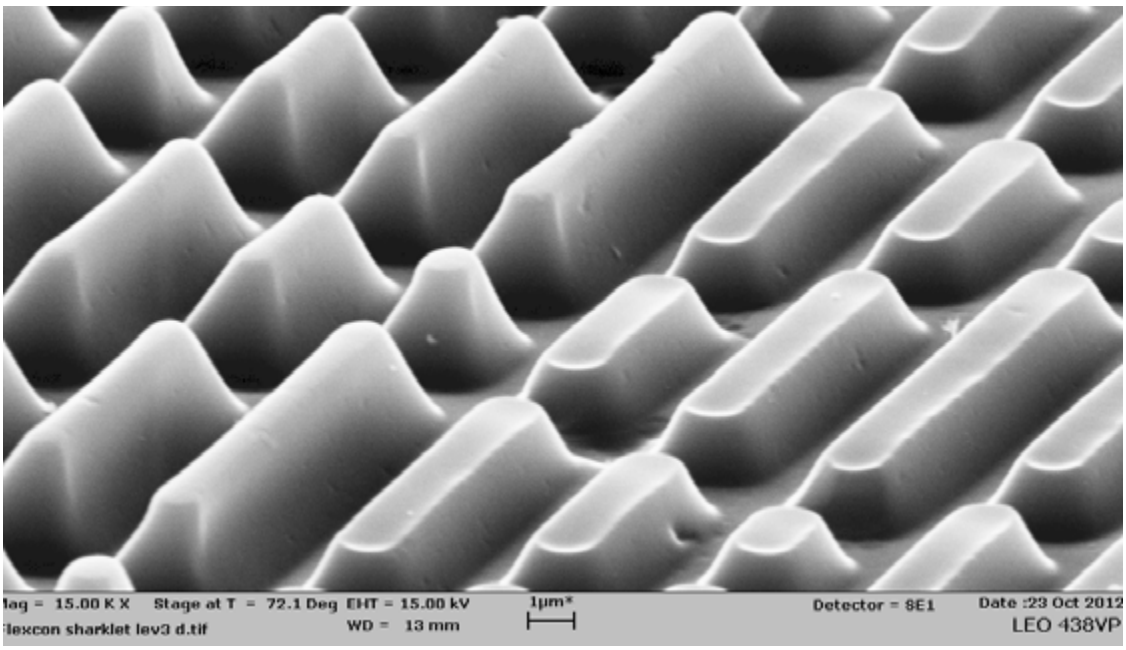
Commercial results.

What are you working on right now?

We are working with a number of technology companies with bio-inspired IP and helping them to bring their idea to commercial success.

How did you get started in bio-inspired design?

I read an article many years ago and was inspired by the natural evolution of "product development" that nature offers.



Sharklet Product, 2012

Photo courtesy of Flexcon

Which work/image have you seen recently that really excited you?

As I stated in my talk, I'm excited by the moth's eye image that we are producing and the impact it will have in the advancement of clean energy.

What is your favorite bio-inspired work of all time?

It has to be my first. The shark skin image we helped the University of Florida develop into a film.

What is the last book you enjoyed?

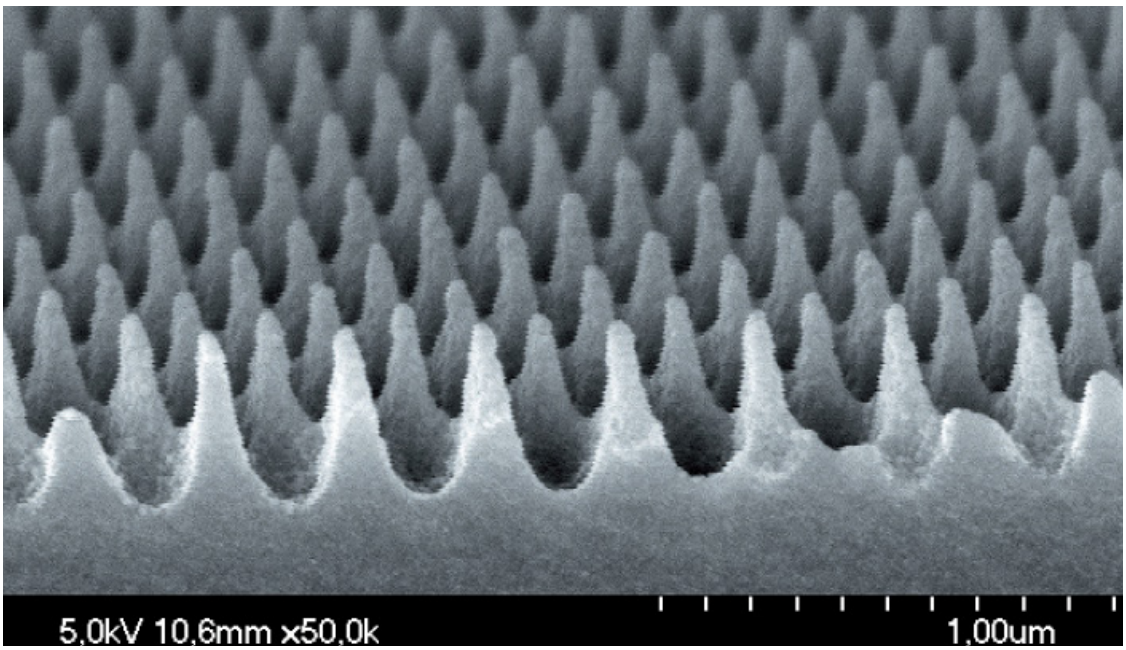
The Outward Mindset by the Arbinger Institute

Who do you admire? Why...

Creative people because they aspire and inspire.

What is your idea of perfect happiness?

Seeing ideas come to life. ×



Moth Eye Product, 2010

Photo courtesy of Flexcon

Mycelium

Photo: harrington_alison, 2014 | Flickr cc

Interview
Petra Gruber

special issue | **People:** Interview | **Author:** Petra Gruber

Dr. Petra Gruber is an architect with a strong interest in inter- and transdisciplinary design. Apart from her professional work as an architect, she holds a Ph.D. in Biomimetics in Architecture from the Vienna University of Technology in Austria. She also collaborated as a research fellow at the Centre for Biomimetics at The University of Reading, UK. She taught Biomimetics in Energy Systems at the University of Applied Sciences in Villach, Austria, and held lectures and workshops at universities worldwide. As a visiting professor for Architectural Design and Building Science, she set up a master's program in Advanced Architectural Design at the Addis Ababa University in Ethiopia. Her research spans from projects for the European Space Agency on lunar base design informed by folding principles from nature to arts-based research on the translation of growth principles from nature into protoarchitectural spatial solutions. Dr. Gruber is based at the Myers School of Arts and the Department of Biology for the Biomimicry Research and Innovation Center or BRIC.

What are the key takeaways from your conference talk? How would you summarize your presentation?

In the presentation I tried to give an overview of my work in transdisciplinary architecture and design, with a focus on the most recent projects at the intersection of arts and sciences.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hope the audience understands the presented projects as exemplary work that illustrates the options for the application of biomimetics as a method in architecture and the arts. The results of the projects "Biornametics" and "Growing as Building" are not an end in itself. Within a large area of interest, they explore several possible translations that have the potential to change and improve architectural solutions. The investigation of fuzzy areas of interest is not a random venture, but tries to integrate a broad perspective on the relationships between biology and architectural design with specific, carefully defined aims and selected biological principles found in organisms and reinterpreted in experimental prototypes. The exploration of translating principles, embedding of biological organisms in architectural structures (Mycelium material) and using organisms as co-designers (Slime mold as explorer of space) also showcases a new way of designing, promising better adaptation, integration and sustainability.

What stood out at this conference and what did you learn?

The conference offered a wide range of research presentations, and I was impressed by the diversity of approaches. The most tangible session for me was materials and structures. I was interested in NASA's approach to the topic of biomimicry and was surprised to see a broad interest that seems to allows for new ways of collaboration.

I was also impressed by the talks on artificial intelligence and data processing, because I think that the implementation of AI tools will define our future capacity to maintain and apply our knowledge.

Slime mold | Photo: mountainamoeba, 2009 | Flickr cc

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

I had interesting discussions with people from NASA and other scientists, and keep in touch with some of them to find out about potential collaborations.

Any action items after this conference? Things you will do, would like to do?

I am interested to work more on publications and collaborate on scaling up the work in biomimetics.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

Bio-inspired, biomimetic and biomimicry design have now reached the stage of of unquestioned application. In the field of architecture, a fast increase of biomimetic research and development projects happened during the last 5-10 years. In leading architecture firms and universities, it has become common practice to look at nature as a model. Especially the fields of computational and parametric design, with an interest in morphogenesis and the scope of functionalizing ar-

©GrAB: The Growing As Building project explored the use of growth principles from nature for architecture and the arts in a variety of experiments. This is an image of a 3D printed hard scaffold in organic shape, that was filled with waste material and fungus spores, and resulted in interesting outgrowth of fruiting bodies. | Image courtesy of Petra Gruber

chitecture seem to be important. The increase is based on a broader application of new computational tools and the integration of new production technologies that have become publicly accessible. 3D scanning, cutting, milling, printing and robotic fabrication have replaced the old standard model making and prototyping techniques.

What do you see as the biggest challenges?

In many bio-inspired projects, the link between biological research and principles to the design is not strong. Taking the long way from basic research to implementation is very challenging in terms of setting up interdisciplinary collaborations by finding the right partners and getting funds for ventures that are difficult to foresee. The usually long timescale of such research and developments exceeds the length of funded projects, so that continuity is based on institutionalized platforms, which are still rare. Another challenge is the integration of different organizational cultures.

The most important challenge is to establish a closer link from biomimicry to sustainable and ecological design, which requires work on a systems level. The field of built environment still lacks accessible data, instruments and tools in this area.

What areas should we be focusing on to advance the field of bio-inspired design?

For future biomimetic design projects, we should strive for a stronger link to basic science, also with a focus on specific missing research on biological systems that seem promising for translation (reverse biomimetics). This means, further strengthening of the methodology and elaboration of tools for interdisciplinary collaboration, together with efforts to institutionalize biomimetics and biomimicry at universities and in industry to allow for a longer term perspective.

The gap between prototyping and implementing products in the building industry is another challenge, that will be crucial for scaling up biomimetics in the field of the built environment. The notoriously conservative approach that building industry takes is based on existing economy and infrastructure, a diversity of building standards and regulations, and safety and security issues for people and environment. To implement innovation, those standardized ways are to be challenged and changed on the long run.

How have you developed your interest in bio-inspired design?

My motivation to embark on bio-inspired design is rooted both in my fascination for biology and an interest in space and design. The integration of those fields naturally led me into the direction of biomimetics.

What is your best definition of what we do?

Speaking for myself, I try to make other people understand what I think I have understood about the incredible qualities found in nature and the aspects of good design, and inspire them to follow along that path as well.

By what criteria should we judge the work?

Work in architectural design can be evaluated on many levels, and in the case of biomimetics the perspectives shift towards aspects like adaptivity, long term sustainability, lightness, integration, resilience and the creation of beneficial systems.

What are you working on right now?

I am working at the University of Akron for the Biomimicry Research and Innovation Center. On a generic level, we are exploring and improving the methodology of biomimicry and the integration of novel production technologies into the process. In design, we focus on the integration of qualities from biology into architectural structures. Currently we are focusing on of order and hierarchy of material structures, trying to produce new lightweight systems based on basic research in biology, and functional performance such as thermal behavior.

Which work/image have you seen recently that really excited you?

I just came across images of Marjan Colettis work, 3D printed concrete "Conoidal Coralloids" being exhibited at the Ars Electronica in Linz, Austria, another exciting integration of examples from nature and large scale printing:

https://www.facebook.com/photo.php?fbid=10153691437620388&set=pcb.10153691438895388&type=3&theater

http://marjan-colletti.blogspot.com

What is your favorite bio-inspired work of all time?

I have no favorite work, there are so many great projects. I love the “Endless House” of Friedrich Kiesler as an iconic project.

What is the last book you enjoyed?

Turn Right at Machu Picchu: Rediscovering the Lost City One Step at a Time by Mark Adams.

Who do you admire? Why...

D'Arcy Thompsons extensive work *On Growth and Form*. It is amazing that one person could create such a large and interesting body of work. I also admire Buckminster Fullers visionary approach to architecture, and the universal thinking behind it.

What’s your favorite motto or quotation?

"Scientific design is linked to the stars far more directly than to earth. Star-gazing? Admittedly. But it is essential to accentuate the real source of energy and change in contrast to the emphasis that has always been placed on keeping man 'down to earth'." - *Nine Chains to the Moon*, Richard Buckminster Fuller 1938

What is your idea of perfect happiness?

I am happy when I am doing something that is interesting, motivating and inspiring togeth-

er with other nice people, in a beautiful environment and in accordance with a good daily rhythm.

If not in your current profession, who/what would you be?

Biologist or Farmer. I love to see things grow and I like to be surrounded by nature. ×

Schizopora paradoxa (*Hyphodontia paradoxa*)

Photo: urmas ojango, 2014 | Flickr cc

Singing in the rain (male Olive-backed Euphonia)

Photo: Andy Morffew, 2015 | Flickr cc

Communications, Navigation, and Control

Chirp

Photo: tomo908us, 2010 | Flickr cc

Interview
Zhiqiang Wu

Dr. Zhiqiang Wu received a B.S. degree from Beijing University of Posts and Telecommunications, Beijing, China, in 1993, a M.S. degree from Peking University, Beijing, in 1996, and a Ph.D. degree from Colorado State University, Fort Collins, in 2002, all in electrical engineering. He had worked as assistant professor at Department of Electrical Engineering of West Virginia University Institute of Technology from 2003 to 2005. He joined the Department of Electrical Engineering of Wright State University in 2005 where he currently serves as full professor.

Presentation title: Bio-inspired Radiofrequency Steganography via Linear Chirp Radar Signals

Abstract: The chirp signal is one of the first bio-inspired signals commonly used in RF applications where the term chirp is a reference to the chirping sound made by birds. It has since been rec¬ognized that birds communicate through such chirping sounds to attract other birds of the same species, to transmit an alarm for specific threats, and so on. However, birds of a different species, or sometime even birds in a different social group within a species, are unable to connect a specific meaning to certain calls — they will simply hear a bird chirping. Inspired by such, this article provides a tutorial on a novel RF steganography scheme to conceal digital communication in lin¬ear chirp radar signals. We first provide a review of the linear chirp signal and existing communi¬cation systems using chirp waveforms. Next we discuss how to implement the RF steganogra¬phy and hide digitally modulated communication information inside a linear chirp radar signal to prevent an enemy from detecting the existence of such hidden information. A new modulation called reduced phase shift keying is employed to make the modulated chirp waveform almost iden¬tical to the unmodulated chirp signal. Further¬more, variable symbol durations are employed to eliminate cyclostationary features that might otherwise be exploited by an enemy to detect the existence of the hidden information.

What are the key takeaways from your conference talk? How would you summarize your presentation?

The key takeaway of my talk is that biomimicry, or bio-inspired design, has a wide range of applicable areas formerly not fully explored. My presentation was about designing a novel electromagnetic waveform to serve multiple purposes simultaneously: the waveform carries high security communication while serving as a radar waveform at the same time. This is probably not a traditional biomimicry field, but our design is indeed inspired by bird chirps and whale songs, and how nature does not separate many of the functions we engineers define in our design.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hope that my talk and our recent work in bio-inspired joint RF waveform design would open the gate to a rich research area of biomimicry which is kind of uncharted territory. Most of the existing work in the RF signal processing community did not think that there is much to learn from or be inspired by nature. I am confident that my research will continue on this path and through collaboration with biologists and other engineers we can further design and develop bio-inspired signal processing algorithms and

Blossoms and Oriental White-eye | Photo: TC Photography, 2013 | Flickr cc

systems. I hope that many of my colleagues will also at least try this new approach and see if it can generate some interesting results or ideas.

What stood out at this conference and what did you learn?

It came as a surprise to me that so many people with such diversified backgrounds are interested in biomimicry. I did learn a lot in different people's approach in solving the challenges they faced in different disciplines.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Quite a few. An old colleague and friend of mine, Professor Haibo Dong of University of Virginia (who had worked at Wright State University before he joined University of Virginia), also gave a talk on his research on bio-inspired flapping-wing unmanned aerial vehicles and other cool stuff. The conference gave us a chance to reconnect and discuss our common interest and collaborations. We are already in the process of working on joint research proposals and projects.

Any action items after this conference? Things you will do, would like to do?

I plan to visit my collaborator Professor Zhijin Wu of Brown University to continue our discussion on computational biology and bio-inspired computing.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

I believe that we are just scratching the surface of what can possibly be done in bio-inspired design. Many fields are already pretty mature in their bio-inspired design such as new materials and new mechanical designs inspired by nature. But in my opinion many other engineering fields can also benefit from biomimicry and bio-inspired design.

What do you see as the biggest challenges?

The biggest challenges are complexity and scalability. There have been many successful stories of biomimicry and bio-inspired design in various aspects of systems, but most of them only take inspiration from nature to solving a small subset of problems, or on a small scale. It is not totally clear if we can take biomimicry and bio-inspired design to the next level and apply them to a large, complex system. Similarly, it is not entirely certain if some of the successful design in the small scale system can be applied and be equally successful when it is scaled up to a larger system. This is an interesting philosophical question, because nature itself actually indicates that complexity and scalability are not problematic at all: nature uses the same design principles in complex systems with significant different scales. But what human beings have been able to learn from nature does not seem to be applicable to complex systems and large scale systems yet. I think these are the biggest challenges, but I am also confident that the answers to these challenges also remain in biomimicry and learning from nature.

What areas should we be focusing on to advance the field of bio-inspired design?

I believe that most of the engineering fields can benefit from biomimicry and bio-inspired design. I personally have been striving to use bio-inspired design in signal processing and computing. Recent advances in deep learning neural network and its application in artificial intelligence and machine learning is a perfect example. These recently developed neural networks are inspired by nature and human brain, but not copied from nature. Researchers have shown that some of these neural networks and algorithms can perform extremely well on tasks formerly thought only human can do: playing the ancient oriental game of Go, for example.

How have you developed your interest in bio-inspired design?

My sister, Dr. Zhijin Wu, is a professor of biostatistics of Brown University. She has been trained in both biology and statistics with degrees from Johns Hopkins University, University of Southern California, and Peking University. We have been collaborating on different areas such as statistical communication and signal processing. A few years back, I invited her to give us a talk on her research of DNA sequencing at Wright State University and Air Force Research Laboratory. In the audience were some of my colleagues conducting research on radio frequency signal processing for radar, communication and navigation systems. Discussions after the talk led to further brainstorming of whether biomimicry and bio-inspired design can be applied to electromagnetic waveform design to enhance performance and security. The collaboration has been quite successful, with one recently graduated Ph.D. and a few publications.

What is your best definition of what we do?

My definition of biomimicry or bio-inspired design is pretty loose. As long as we take inspiration from nature, it is bio-inspired design. Such a design may not be strictly following a certain mechanism in a living organism, but it gives us a hint of what nature would do.

By what criteria should we judge the work?

From the engineering standpoint, it is easy to judge the work: the bio-inspired design should perform better in terms of some predetermined metrics. However, in my opinion, even if sometimes the bio-inspired design does not offer a clear advantage over conventional design, it may still have significant value. Therefore, the work cannot simply be judged from the engineering side. If the new approach provides some insight into the problem, that is a great success. If the new approach provides some feedback to biologist in understanding how nature developed the inspiration itself, that is a greater success. One major obstacle in convincing people to conduct research in biomimicry and bio-inspired design, is that the bio system is so big and so complex that we cannot expect to have a full understanding of the mechanism and generalize them into a bunch of equations. Therefore, even a little progress in helping the understanding of the complex bio system, is a giant step.

Small Bird | Photo: flash nerd, 2010 | Flickr cc

What are you working on right now?

I am working on the "learning" aspect of cognitive RF systems. We have a three phase model in cognitive radio and cognitive RF systems, namely sense, learn and adapt. The cognitive node senses its environment, learns from the past experience, and then adapts its waveforms and other features according to the environment. The cognitive RF system, naturally, is a bio-inspired system. And the "sense, learn, adapt" model is also clearly bio-inspired. We have done lots of work in the past in both the "sensing" phase and the "adapting" phase, but not much on the "learning" aspect. I am working on with my colleagues on how to take advantage of recent progresses in artificial intelligence community to advance the "learning" aspect of cognitive RF systems so that it can perform better in complex environments. Our work has received strong interest and support from the Space Communication group of NASA Glenn, and the Sensors Directorate of AFRL. Recently, we have received an Ohio Federal Research Network (OFRN) project entitled "Intelligent Channel Sensing Based Secure Cross Layer Cognitive Networking for Resilient Space Communication". I am leading this project with four other professors from Wright State University, University of Toledo, Ohio University, and two industrial partners to come up with a better system more resilient to dynamic and complex environment.

How did you get started in bio-inspired design?

Both of my parents are medical doctors and professors in a medical school. My only other sibling is also a biologist with degrees in biochemistry, molecular biology and biostatistics. I am an outlier of my family to pursue a different career path. But biology and the mystery of life have always fascinated me. I have always been trying to seek similarities between what I do and the biology field. For example, when I teach information theory and coding theory to my graduate students, I always use the example of DNA where four nitrogen-containing nucleobases — cytosine (C), guanine (G), adenine (A), and thymine (T) are used to encode the secret of life. That is a code from nature.

Which work/image have you seen recently that really excited you?

Google's Alphago recently defeated one of the best Go players in the world. This really excited me because many people including myself have been under the impression that although computers can easily beat humans in chess, they would never beat humans in Go because Go is such a complex game that only humans can master it. Now we know that computers can master Go too. What else can they not do?

What is your favorite bio-inspired work of all time?

There might be some debate on whether this is really a bio-inspired work, but my favorite bio-inspired work is the invention of radar. The principle of radar is the same as echo-location in bats, where bats emit squeaks and by receiving the echoes they can locate objects around them.

What is the last book you enjoyed?

Out of Control: the New Biology of Machines, Social Systems and the Economic World by Kevin Kelly

Who do you admire? Why...

Albert Einstein. The reason is obvious. Who doesn't admire him? In my opinion he is not only the greatest scientist ever, but the greatest philosopher too. Without him, we would still have the special theory of relativity. But most science historians agree that without him we probably would not have the general theory of relativity today. Recently, scientists announced that they had made the first observation of gravitational waves, which was predicted by Albert Einstein in 1916. This is just another vivid example of his imminence and why he is admired by so many people, including me.

What's your favorite motto or quotation?

Naturally, my favorite quotation is from Albert Einstein: *God may be sophisticated, but he's not malicious.* Another quote from him: *Nature shows us only the tail of the lion. But there is no doubt in my mind that the lion belongs with it even if he cannot reveal himself to the eye all at once because of his huge dimension. We see him only the way a louse sitting upon him would.*

I believe that these two quotes from Einstein also gave us inspiration to work on bio-inspired design and not get frustrated by the apparent lack of success or full understanding of what has been actually done. We may not fully understand the world, but there is hope that we are approaching that goal through our everyday work.

What is your idea of perfect happiness?

Perfect happiness does not exist on its own. It only comes from harmony between an individual and his environment, especially the people surrounding him.

If not in your current profession, who/what would you be?

Like I said earlier, I chose a different career path from my family. If not in my current profession, I would probably be in the biology and medical field, and probably still conducting research on biomimicry, only from the other side of the aisle. ×

Blossoms and Oriental White-eye | Photo: TC Photography, 2013 | Flickr cc

Top of the world

Photo: Axel Rouvin, 2006 | Flickr cc

Materials and Structures II

Rajah Brooke's Birdwing (*Trogonoptera brookiana*)

Photo: That Bee, 2008 | Flickr cc

Interview

Lyndsey McMillon-Brown

special issue | **People:** Interview | **Author:** Lyndsey McMillon-Brown

Lyndsey McMillon-Brown earned her B.S. in Mechanical and Manufacturing Engineering from Miami University (Ohio) in 2013, she then completed her M.S. in Chemical Engineering at Yale University in 2015 and is now continuing towards a PhD at Yale with a research focus on alternative materials and nano-patterns for enhanced light trapping in solar cells. Since 2011, Lyndsey has been a co-op for NASA Glenn Research Center conducting solar cell research. Her research at Yale and NASA has yielded two peer-reviewed publications. Lyndsey has always been passionate about increasing the involvement of minorities and girls in STEM professions. She makes strides towards this goal by serving as a NASA Student Ambassador, which allows her to visit schools to inspire students to pursue STEM. She has co-founded The Yale League of Black Scientists, a graduate student group which places a special emphasis on working to increase the participation of traditionally underrepresented groups in STEM. Lyndsey is also a co-founder of the Society of Women Engineers Graduate Chapter at Yale. Additionally, Lyndsey serves as an advisor to undergraduate student researchers all in an effort to inspire underrepresented students in STEM.

What are the key takeaways from your conference talk? How would you summarize your presentation?

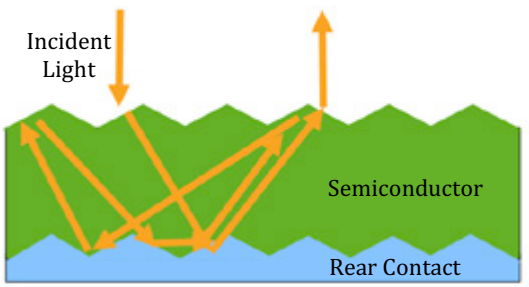
The primary research take-away is that through the incorporation of diatom frustules we've developed a low cost, low temperature method to enhance the absorption and thus efficiency of solution-processable polymer solar cells. This is exciting because it allows less expensive material to be used without sacrificing device performance.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

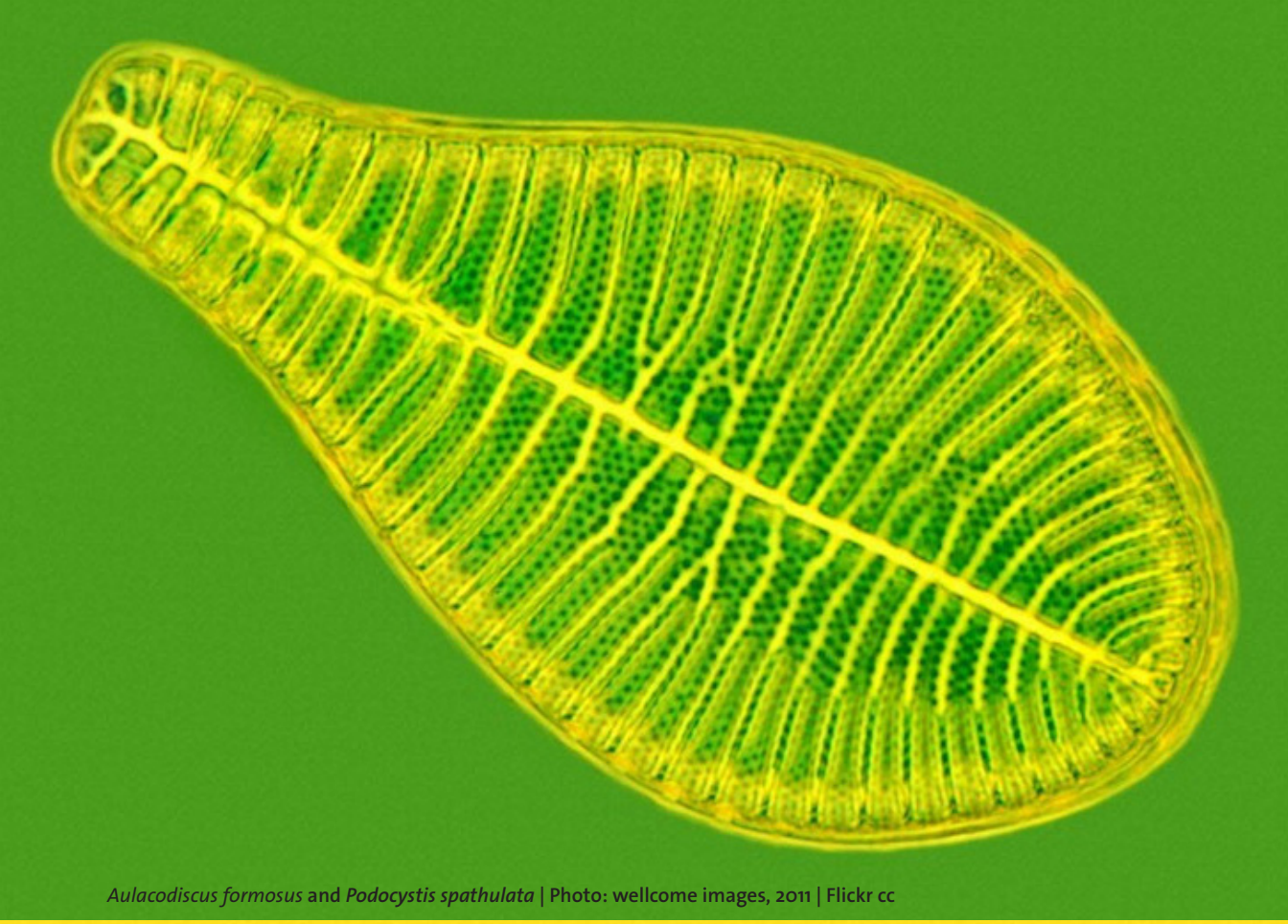
I hope my conference talk reinforced the idea that solar cells are becoming increasingly feasible for large-scale commercial integration, as costs approach fossil fuel energy costs. Also, I hope my talk will inspire people across fields to take a close look at diatom algae, as they have tremendous capabilities and have proven to work well in a diverse array of applications. I think the diatom is truly a natural champion. Ideally, my talk will help promote the utility of the diatoms across the STEM disciplines, while also inspiring those in various solar and energy fields to consider bio-inspired additives.

What stood out at this conference and what did you learn?

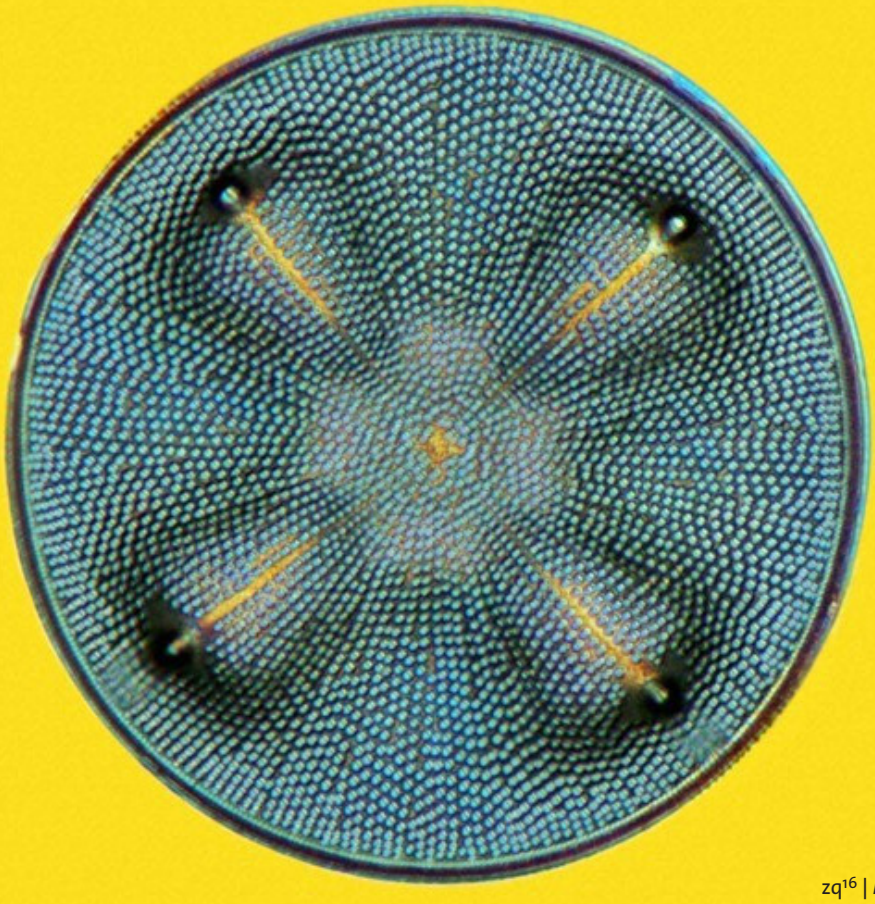
I learned so much from the swarm talks. This research is fairly new to me, and I was fascinated



A solar cell's performance can be enhanced if light travels a longer optical path, and thus spends more time within the photoactive layer generating electrical current before escaping the solar cell. The integration of bio-inspired nano-patterns and designs into solar cells facilitate light trapping within the photoactive layer, thereby enhancing the solar cell's absorption and power conversion efficiency | Image courtesy of Lyndsey McMillon-Brown



Aulacodiscus formosus and *Podocystis spathulata* | Photo: wellcome images, 2011 | Flickr cc



to learn that natural swarm behaviors can be used to solve applied science and engineering problems.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

I was fortunate to meet Professor Kenneth Sandhage because I have read so much of his work on diatoms. It was an honor to meet him and be able to discuss his work in person!

Any action items after this conference? Things you will do, would like to do?

I would like to stay connected to, and follow, the research of those who were in attendance at the conference. It was refreshing and eye-opening to see the work of colleagues in other fields. I think there is much we can learn from each other, and I hope to capitalize on that.

Diatom frustule

Photo: wellcome images, 2012 | Flickr cc

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

Bio-inspired design is a growing field that is gaining steam from individuals who realize the value and benefit of this approach to innovation. Researchers across STEM disciplines are having success with this method and they are calling attention to a new way to solve the world's challenges. As more attention is called to biomimetic practices, I believe that researchers will realize the versatility and breadth to which bio-inspired design can be applied. Tharalelo Mokgokong is an excellent example of the endless possibilities of bio-inspired design. He implemented an ant colony inspired transport system into the South African Postal Service. As a result, 50% fewer mail trucks are delivering packages faster with no loss of labor. The remaining 50% of drivers were retrained to aid internally. These types of successes will continue to serve as a launch pad for researchers in a variety of fields to consider technical advancements by implementing bio-inspired design.

What do you see as the biggest challenges?

One serious challenge is integrating bio-inspired design into the curricula of K-12 and post-secondary education programs. By introducing the concepts of biomimicry much earlier in the edu-

cation system, future scientists and engineers will be better prepared to implement and expand upon these skills in their research careers.

What areas should we be focusing on to advance the field of bio-inspired design?

The fields of energy harvesting and sustainability can benefit immensely from bio-inspired design. From whale-inspired wind turbine design to termite-inspired sustainable buildings, we've seen that nature has masterfully honed in on optimal solutions to many of the challenges we face. I suspect the challenges of increasing surface area of electrodes in batteries, and increasing the light absorption of solar cells can be addressed through bio-inspired design and innovation from STEM professionals.

How have you developed your interest in bio-inspired design?

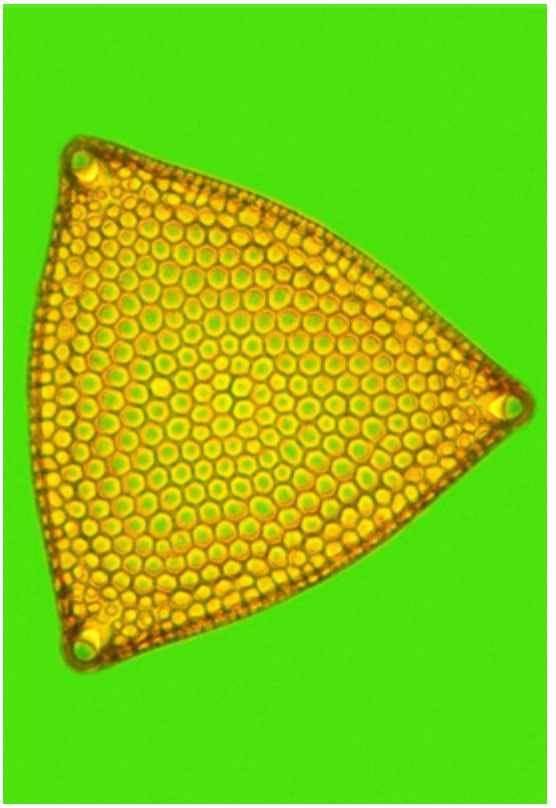
During my time as an undergraduate engineering major at Miami University in Ohio, Professor Osama Ettouney often reminded us that nature has already solved many of our problems and we just need to search for the solution. That philosophy of first observing nature before beginning to develop solutions stuck with me. Fortunately, that is not a far leap for my research field in solar cells and energy collection since nature already utlilizes countless designs and structures to harvest solar energy.

What is your best definition of what we do?

I think our work is dual thrust. We use bio-inspiration as a means to solve the problems that we face in our own research, and we also work to spread the word of bio-mimicry and bio-inspiration with the aims of broadening the field.

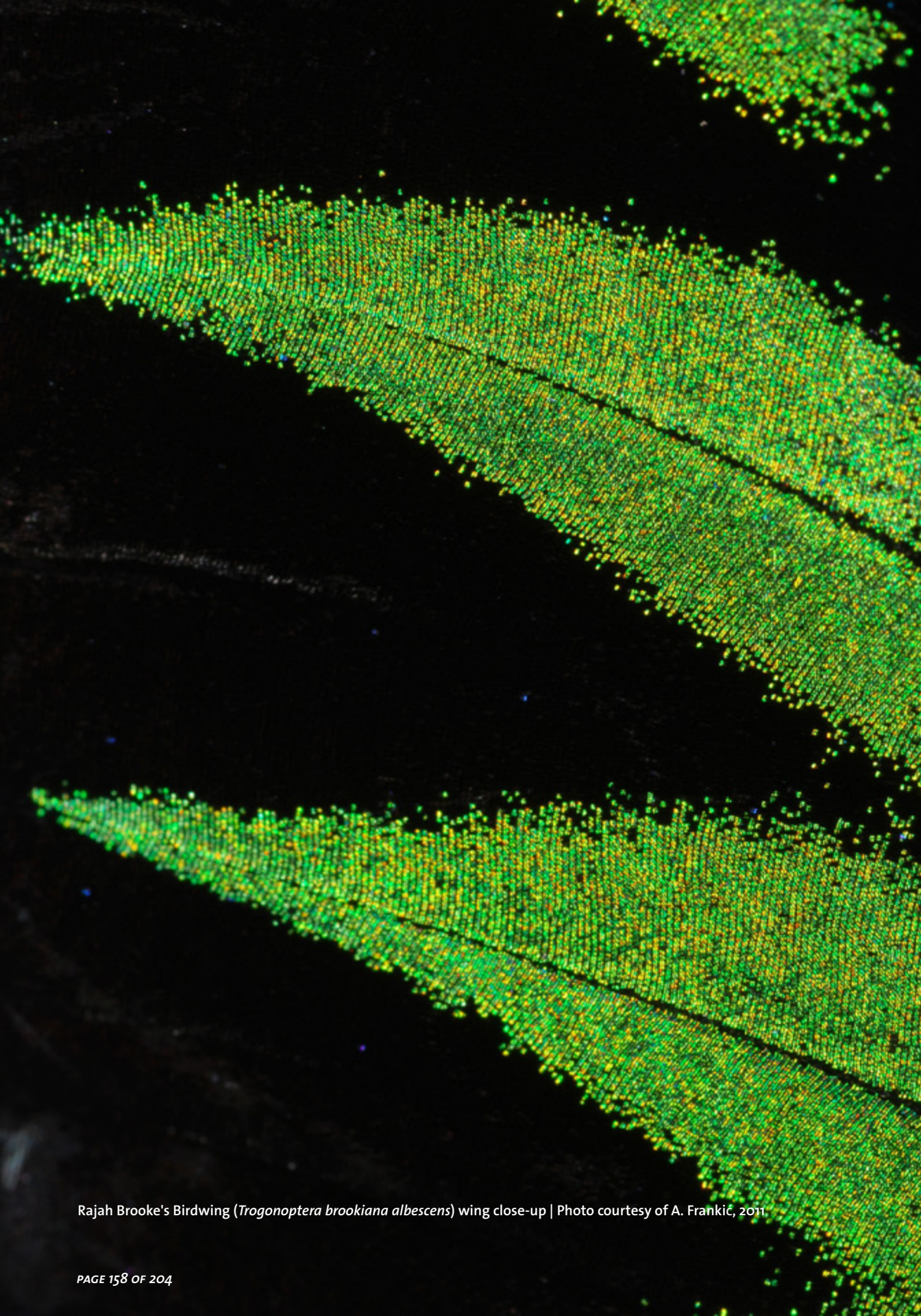
By what criteria should we judge the work?

We should judge this work by the ability to solve a problem in the most effectual, energy efficient and cost effective manner. I think we would do



Diatom frustule

Photo: wellcome images, 2012 | Flickr cc



Rajah Brooke's Birdwing (*Trogonoptera brookiana albescens*) wing close-up | Photo courtesy of A. Frankić, 2011

a disservice to people interested in exploring the field if we judged new contributions solely by how closely they mimicked nature. For some problems, our engineers and scientists might develop great solutions in-lab, while for others a better solution may be pre-existing in nature. I find it imperative that we encourage bio-inspiration in any of its forms to avoid quelling innovation by establishing barriers for those entering the field.

What are you working on right now?

I'm continuing work on bio-inspired patterns as light traps for solar cells. Fortunately, I am able to follow my heart, and interesting creatures as I make this journey towards my dissertation.

How did you get started in bio-inspired design?

I was trained at my undergraduate institution (Miami University, OH) to always look to nature as we aim to solve engineering design problems. That philosophy coupled with my innate awe of natural phenomena created a smooth transition into studying patterns in nature as a means to enhance the light absorption of solar cells.

Which work/image have you seen recently that really excited you?

I recently saw a paper in *Science* about the enhanced optical reflection and radiative heat dissipation in Saharan silver ants. These ants have developed hairs with a metallic appearance, which dissipate heat to maintain an operable body temperature amid the 70C desert surface temperatures. It's an amazing feat to manipulate light in such a way! Plus, the ants just look so cool with this metallic surface finish. I think these creatures are spectacular and I'd like to do some work with them in the future.

What is your favorite bio-inspired work of all time?

My favorite bio-inspired work is the research of Zhiwu Han and many others on the tropical butterfly *Trogonoptera brookiana*. They revealed that the vibrant colors in the butterfly's wings are not a result of pigmentation, but instead of light manipulation performed by the nanostructure of the scales within the wing. This discovery enabled and inspired works of many individuals regarding these wing scales and the manipulation of light.

What is the last book you enjoyed?

I'm currently reading the *Time Traveler's Almanac* – it's a compilation of fantastic time travel stories. This book is expanding the limits of my imagination, as I was surprised to find that many time travel stories regularly ask existential questions about the meaning of life, and what it might be like to live forever. It's exciting to consider how our behaviors would change if we were not constrained by time.

Who do you admire? Why...

I very much admire Katherine Johnson, an African American physicist, space scientist and mathematician who made fundamental contri-

butions to the early NASA missions by determining the trajectories, launch windows, and emergency return paths for many flights. She made the flight of the first American in space possible. I admire her intellect, and perseverance. She was the first woman, and first of three students to desegregate the graduate school at West Virginia University. However, I also respect how difficult her work must have been as a woman and African American working in STEM throughout the Civil Rights Movement. She had to be mentally strong to endure such turbulent sociopoliti-

Katherine Johnson sits at her desk with a globe, or "Celestial Training Device." | Photo: NASA

cal times, while also being an intellectual powerhouse. I aspire to make world changing science contributions like Katherine Johnson, and I also aspire to motivate young women scientists similarly to how Katherine inspired me.

What's your favorite motto or quotation?

"The person who gets the farthest is generally the one who is willing to do and dare. The sure-thing boat never gets far from shore." – Dale Carnegie

What is your idea of perfect happiness?

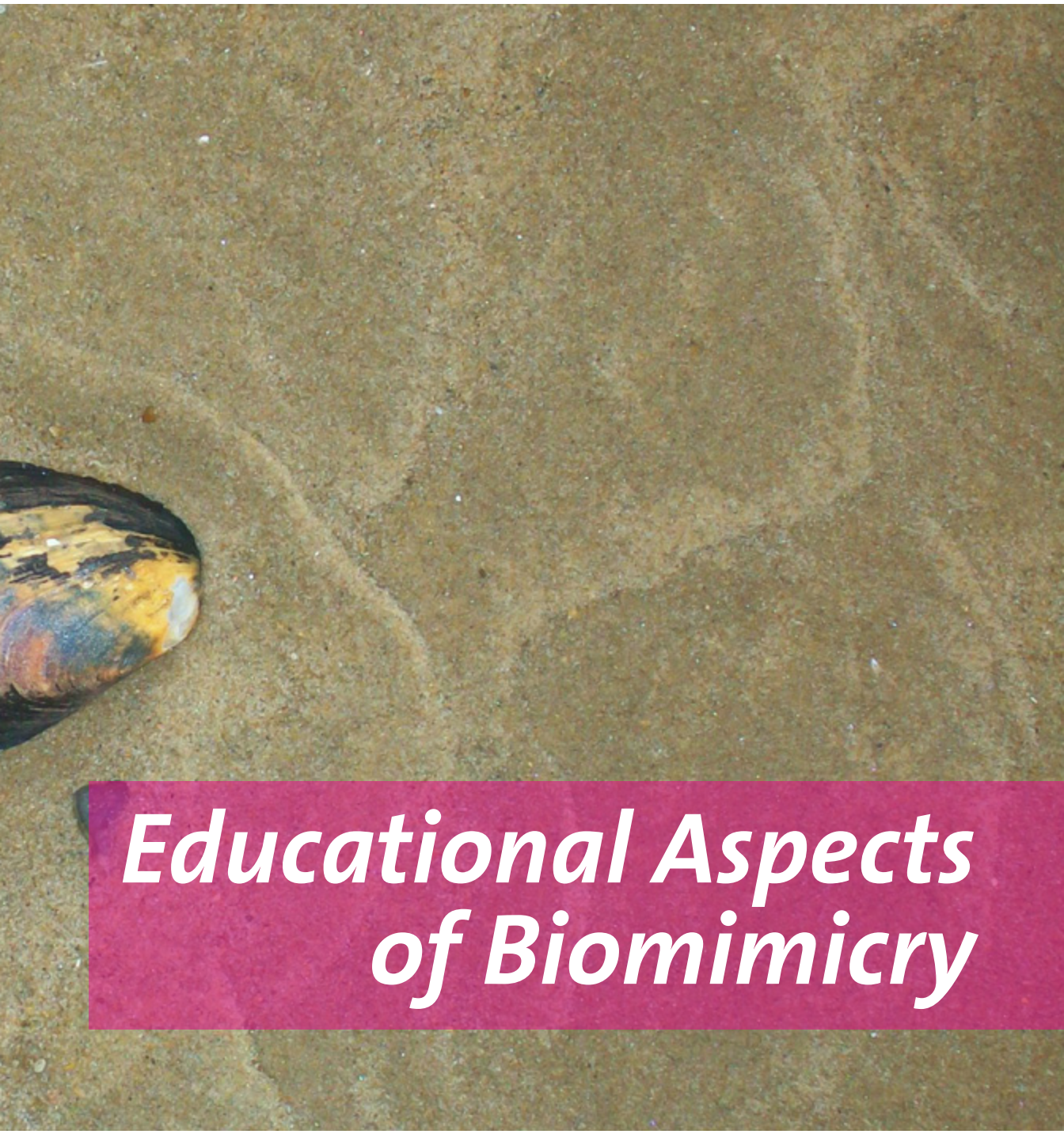
My idea of perfect happiness would be to live in a world free from bias and systemic practices that exploit or hinder the advancement (or survival) of historically marginalized peoples. A world free from racism, xenophobia, sexism, homophobia and other oppressive practices is a world for which I dream. In that perfect world I'd personally like the freedom to explore science that interests me, free from external pressures like journal impact factors. I would also like ample quality time with family and some spare time for golf.

If not in your current profession, who/what would you be?

I would be a politician or lawyer and I would work on developing policies that enable alternative energy practices and the advancement of science. I believe my work has the ability to reduce our carbon footprint, reduce the cost of solar energy, create jobs, and improve the quality of life for generations to come. I'm a firm believer that we should cherish the earth and aim to leave future generations with a home rich in renewable resources and diverse in species. As policy can thwart or enable a movement, I would love to see increased legislation aimed at advancing the field of alterative energy. I believe that policy can thwart or enable a movement. I sincerely believe in the work that I do, so I would love to see legal infrastructure to advance the field. ×

Mussel

Photo: Andy Gant, 2009 | Flickr cc



Educational Aspects of Biomimicry

Shells Inner Harbor - Wellfleet, MA

Photo: Brian Birke, 2012 | Flickr cc

Interview
Anamarija Frankić

special issue **People:** Interview

Author: Anamarija Frankić

Dr. Anamarija Frankić is a founding director of the Green Harbors Project®, and the Biomimicry LivingLabs®, a research faculty at UMass Boston and University of Zadar, Croatia. She is a Biomimicry, Fulbright and Sea Grant Knauss Fellow, in 2014 she founded the Biomimicry New England. Her educational background in biology, ecology, limnology and marine science, guided her interdisciplinary restoration research and management work in coastal, marine and fresh water ecosystems, nationally and internationally. Her work is about integrating human services with ecological services and functions in our built environments to support resiliency and sustainability. She initiated and established the 'livinglabs' for applied science education and research where students, local communities and businesses are able to 'learn and teach by doing' biomimicry, applying nature's wisdom for resilient today and tomorrow; her premise is that 'the environment sets the limits for sustainable development'.

What are the key takeaways from your conference talk? How would you summarize your presentation?

(Practical and interdisciplinary) Education through concrete research project that applies solution(s) to local community needs in addressing environmental issues. That is what the main goal is for the Green Harbors Project and Biomimicry LivingLabs: teaching and learning by doing applied science projects in urban harbors.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

Presenting the successful examples such as Biomimicry LivingLabs as expos for sustainable technologies that solve local issues - actually empowers communities, experts, students and most of all academia and science;

What stood out at this conference and what did you learn?

This was a very well organized, focused, comprehensive meeting that brought together scientists, academia, students snd industry, providing successful examples as well as needs for future efforts in Biomimicry.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

The NASA Biomimicry initiative opens and provides new venues for innovative science, technology, and education which is very much needed in our tipping times of environmental and social issues and concerns. I met interesting experts from various fields of industry and research, and the best part was to meet many students and hear from them.

Any action items after this conference? Things you will do, would like to do?

I would like to collaborate with Dr. Shyam and his team specifically in addressing community and civic participation in our Biomimicry projects. It is important to translate science and technol-

Oyster spats (baby oysters) on a clam shell, Wellfleet Harbor | Photo courtesy of A. Frankić

Oyster reef and salt marsh before and after | Photo courtesy of A. Frankić, 2016

ogy to our every day needs in solving problems and improving sustainable and resilient today and tomorrow.

What are your impressions of the current state of biomimicry/bio-inspired design?

We are at the tipping point - the 'anthropocene' era when we need to massively embrace the bio-inspired designs and strategies in every aspect of our lives; we cannot miss this opportunity given the dire straits caused by our behavior in the last few hundred years.

What do you see as the biggest challenges?

How to change our industry, and wasteful behavior that has been instilled in us through education and everyday lifestyle that everyone else wants to imitate globally; how crazy is that? We have been leading ourselves into a disaster, the change is happening too slow, so biomimicry education needs to be available for free.

How have you developed your interest in biomimicry/bio-inspired design?

I was born with it like everyone else, we just lose the connection through various lifestyles. As a biologist and marine scientist, I also tried various ways in science and technology to search how to solve environmental problems. My education took me from biology, limnology, marine science, environmental management and policy, and the same year I finished my doctoral degree the biomimicry book came out. And that was it, the cycle and search was almost done, as I started to practice what I believed in and what I knew the best.

What is your best definition of what we do?

We are learning, teaching and doing what nature has been doing for millions of years. It is hard to catch up and remind ourselves that we are part of the same nature and that we can learn much faster if we can just let go of the forms that we inherited and that have nothing to do with resiliency. We need to be adaptive in order to be healthy, wealthy and sustainable – and that is what nature thrives for every single moment. And that is what we are trying to do by doing biomimicry.

By what criteria should we judge the work?

I think that we have been doing a great job by evolving the biomimicry life's principles. It is hard to fulfill all of them and have a holistic approach in everything humans do and produce, which is the main reason for compromises. So, criteria should be principles from nature that are also human principles – and that should be the main set of criteria to guide our work (judging is the word I don't really like to use, how about 'assess', or 'evaluate').

What are you working on right now?

It is a work in progress, almost organically grown, as I was learning form nature how to best help it heal. In coastal urban systems, where we accept them to be polluted and degraded, I have been working on restoration projects, through

Oyster reef restoration site | Photo courtesy of A. Frankić, 2011

LivingLabs as part of the Green Harbors Project. My focus is on one amazing species – the oyster – that told me that it cannot function just by itself, it needs a reef, where many oysters build these amazing structures and homes for hundreds of other species. I learned that oyster reefs also like to have salt marshes nearby and they support each other sharing food and water; they support each other's resiliency by working together. There is another part of the coastal story – eelgrass beds (or subaquatic vegetation) that depend on both salt marsh and oyster reefs. Although we recognize that these habitats coexist in coastal areas, we tend to address them separately. To regenerate degraded coastal areas, we need to change how we see and do both science and management.

How did you get started in biomimicry/bio-inspired design?

I think I answered this question, but as I came to Boston area (2006), I realized that even with the best possible restorations we don't have space to bring back lost habitats, so my interest shifted to how can we build human structures that can biomimic oyster reefs and salt marshes, and whole watersheds. How can human structures support human services and ecological services at the same time and space? With my students, I started designing 'green piers' and harborwalks, ripraps, etc., and that was when I proposed the LivingLabs program for teaching and learning by doing biomimicry; where we can showcase existing and new applied sciences and technology designs and solutions – it is time to get outside the academic labs and closets ☺.

Which work/image have you seen recently that really excited you?

Floating islands that inspired me to do green piers, so we can combine human and ecological services and functions.

What is your favorite biomimetic work of all time?

There are so many, but the ones that are capturing the wisdom of a green cell are the best – although not done yet but biomimicking the most effective way to use sun energy and produce food is something I wondered about even as a kid; my mom said that I wanted to have a green hair so I would not have to come home for supper – and continue to play outside and produce my own food like green plants do ☺.

Not bad for an eight year old; which is the main reason I've been teaching young kids as they do get it, while most of my colleagues still don't.

What is the last book you enjoyed?

There are so many, as I always read several books at once: *One square inch of silence* by Gordon Hempton, and *Always, Rachel* (letters of Rachel Carson, who has been and is my inspiration).

Who do you admire? Why...

Women, when you read biographies of Maria Sklodowska Curie, Marguerite Yoursenar and Rachel Carson, it just blows your mind how brave and strong they were at the times that there was no support for women in science and art.

Women were invisible in those fields until today and they still made a difference, by following their passion and wisdom (Mrs. Curie had to pretend to be a man in order to study physics at Sorbonne, and she is the only human being that received two Nobel prices for two different science fields: physics and chemistry). It is unfortunate that today we still don't teach and learn about everyday women that made it possible for us (me) to do what I love the most.

What's your favorite motto or quotation?

> We have a beautiful mother,
> Her green lap
> Immense
> Her brown embrace
> Eternal
> Her blue body
> Everything we know | Alice Walker

What is your idea of perfect happiness?

To be here and now in nature, preferably near the ocean and listen with love and appreciation, and dance ☺.

If not a scientist/designer/educator, who/what would you be?

An artist – but I can still be that through biomimicry as it brings, arts and sciences together in harmony (STEAM). ×

Reprinted in part from ZQ Issue 6

Wellfleet Harbor

Photo: NASA's Marshall Space Flight Center, 2010

Wikimedia Commons

Nature Triangulated: Mantis

Artwork courtesy of Derek Miller

Interview

Peter Niewiarowski

Dr. Peter Niewiarowski (https://www.uakron.edu/biology/faculty-staff/detail.dot?identity=1201909), Professor of Integrated Biosciences (IB) and Biology at the University of Akron (UA), is a Biomimicry Research and Innovation Center (BRIC) Principal Investigator. His appointments include Post-Doctoral Researcher, Savannah River Ecology Lab, University of Georgia, 1993-1995; UA Professor since 1995; and, Interim Director, UA Integrated Bioscience PhD Program, 2009-2012. His research includes projects in amphibian population biology, life history evolution and physiological ecology of lizards and gecko ecology and evolution, especially as it relates to adhesion. Gecko adhesion research, in collaboration with the lab of Ali Dhinojwala, a UA polymer scientist and BRIC principal investigator, is the main focus of his current work, including biomimetic applications.

Peter teaches introductory and advanced levels within UA's Biology and IB programs. He developed courses including Advanced Ecology, Herpetology, Principles of Biology, Vertebrate Zoology, Tropical Vertebrate Biology, Communicating in Integrated Bioscience, Research in Integrated Bioscience, Theory and Foundations of Biomimicry, and Biomimicry Design.

Peter holds a BS in Biology, Marlboro College, Marlboro VT, 1984, and a PhD in Ecology and Evolutionary Biology, University of Pennsylvania, Philadelphia PA, 1992.

What are the key takeaways from your conference talk? How would you summarize your presentation?

The key takeaways for me were:

There is a persistent diversity of interest and passion in and around the idea of biomimicry.

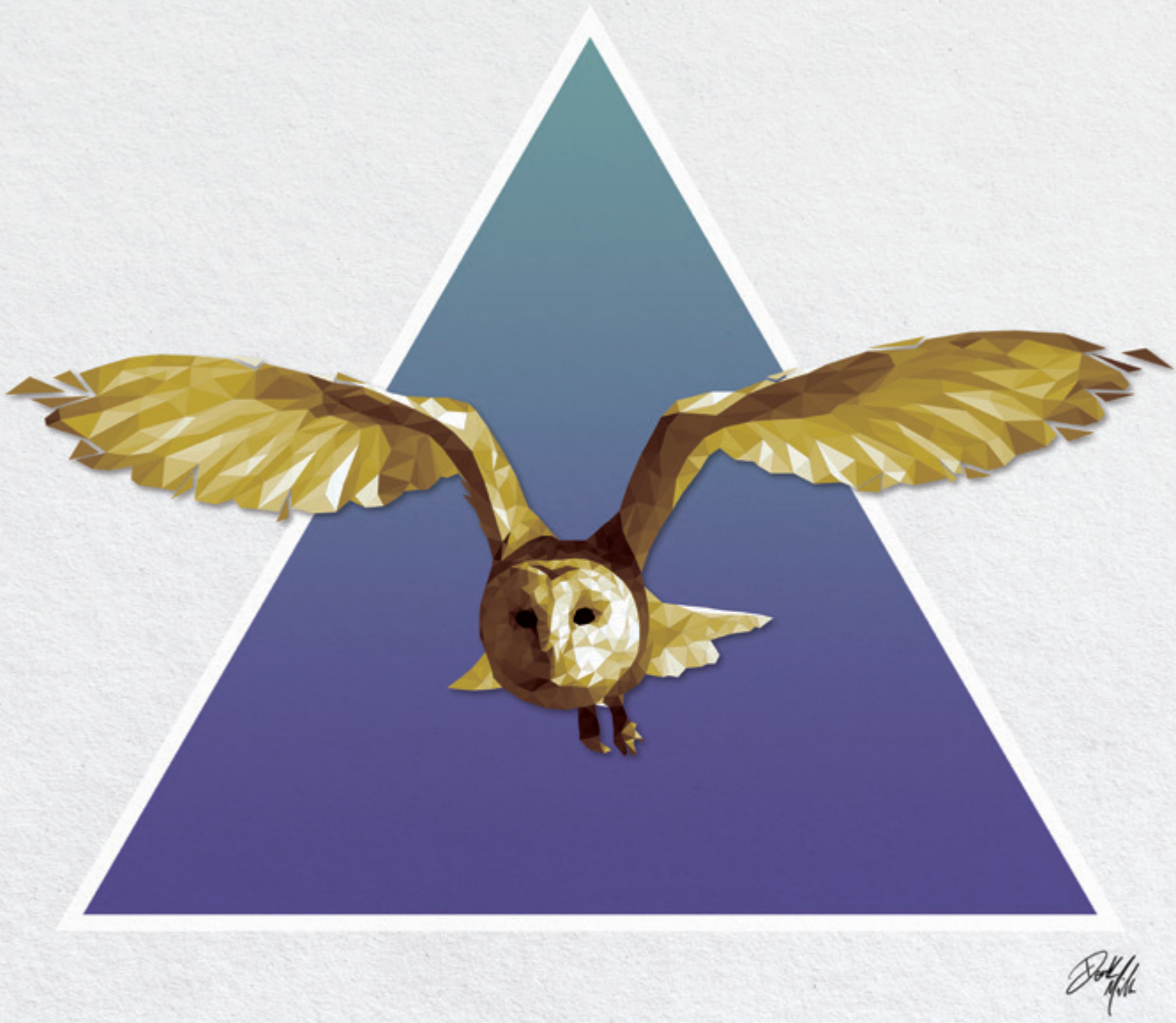
No matter the particular field of expertise, conference participants (students of biomimicry) seem engaged by an awe, fascination or respect for the way solutions to challenges have emerged from living systems.

A reminder that imagination and passion are full partners with knowledge and skills in problem solving and technology.

My presentation was mainly about the need to be true to an idea of interdisciplinarity in the practice of biomimicry, and to remind people that biomimicry does not belong, nor emerge from within any one discipline. This makes practice hard because of the way that we have been educating and training ourselves for 'expertise' over the last century+. The other main point is that if we practice biomimicry and do not seek or value 'surprise' then we will likely miss out on the full power of the paradigm. Biomimicry requires patience, humility, confidence, collaboration and a healthy appreciation of the value of failure and success.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

Just to help remind people that the practice of biomimicry is probably less about the how much anyone one of us "knows" and more about how much we can learn together to transform our world at the smallest and largest scales. Biomimicry practice must be inclusive.



Nature Triangulated: Owl | Artwork courtesy of Derek Miller

What stood out at this conference and what did you learn?

The history of biomimicry thinking at NASA and the way powerful ideas emerge and re emerge when they are synthetic or integrative.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

Our (UA Biomimicry Research and Innovation Center) strengthened ties to NASA Glenn and the great people who have championed biomimicry there in the past and those that are picking up that work today. We also made some great contacts with students and organizations that are interested in collaborating in research and education in biomimicry.

Any action items after this conference? Things you will do, would like to do?

Try to stay better connected to more people involved in biomimicry research and education globally.

What are your impressions of the current state of biomimicry/bio-inspired design?

In my view, it is in a very exciting, generative phase. There is no shortage of activities and initiatives, formal and informal, academic and non-academic, which are popping up globally. Many are connected or are getting connected through dynamic knowledge and social networks that amplify potential impacts beyond local frames. I am daily struck by the intellectual and creative dissonance that emerges from so many diverse and widely distributed efforts in both the application and process of biomimicry. The dissonance is driven by enormous messiness, which is disconcerting to many people, but which is also a fundamental source of surprise and success. For a biologist, it is like going to a new place for the first time ... the excitement around the unknown and of discovery is visceral. It is great to be a part of this time in the development of the ideas and application of biomimicry.

What do you see as the biggest challenges?

I think the biggest challenges include finding ways to connect, sustain and deepen the diverse groups developing biomimicry across the globe. From my vantage point, I think we need more work across disciplinary lines in academic settings, and this will require courage, experiments and patience. There are many programs where two disciplines are brought together, like biomechanics and bioinformatics. Much rarer are platforms where the cultures, methods, and perspectives of 3 or 4 fields can be brought to bear collaboratively on problem definition, discovery, design and the application of biomimicry. In my view, expanding what is possible with biomimicry will require such exploration, integration and synthesis. Similarly, we should look for new ways to create paths that cross and become well-worn between academia, business and communities. Universities can lead both of these kinds of changes, but it is not work that universities are necessarily used to. Our collective here in northeast Ohio was built by partners that cross many of the lines noted above and we

Nature Triangulated: Deer | Artwork courtesy of Derek Miller

find the work difficult yet rewarding. Biomimicry as a practice would benefit from more experiments crossing these boundaries.

How did the University of Akron Biomimicry Training Platform get started?

Doug Paige (Associate Professor of Industrial Design at the Cleveland Institute of Art, https://www.cia.edu/faculty-and-staff/douglas-paige/) and I started collaborating in 2010 on combining biology and design as part of the University of Akron's Integrated Biosciences PhD program. Holly Harlan, founder of the Cleveland Entrepreneurs for Sustainability (E4S) network, encouraged us to attend a Biomimicry 3.8 Educators Workshop in San Francisco. When challenged to set ourselves a Big Hairy Audacious Goal, we decided to launch a sustainable PhD platform around biomimicry and collaboration that cuts across fields and programs. It was an idea that would have gone exactly nowhere without the collaboration of Tom Tyrell and Don Knechtges, two entrepreneurs who created Great Lakes Biomimicry (GLBio, https://glbiomimicry.org/), an organization focused on using biomimicry for regional economic development. GLBio connected us to industry, making the funding for biomimicry fellowships possible. The virtual Biomimicry Research and Innovation Center (BRIC, https://www.uakron.edu/bric/) was launched in 2012 and recognized as a key initiative of the University of Akron's Achieving Distinction Strategic Investment Program (http://www.uakron.edu/provost/achieving-distinction/2012-recipients.dot). BRIC's success in winning university support depended on our corporate connections and economic development focus through collaboration with GLBio. Moreover, the focus of GLBio was to define a large scale sustainable platform for regional economic development through biomimicry. That vision was and continues to be a force driving biomimicry well beyond academic boundaries.

What are the unique features of Biomimicry Training Platform?

Although other institutions support PhD fellowships, they are typically associated with a single professor or grant initiative. The Biomimicry Training Platform is a research area of the University of Akron's Integrated Biosciences (IB, http://www.uakron.edu/ib/) interdisciplinary PhD program that draws students from a wide range of colleges, such as Arts and Sciences, Engineering, Polymer Science, School of Nursing, Arts and Sciences, Engineering, and Fine Arts. The platform started with three biomimicry Fellows in the fall of 2012 (http://bioinspired.sinet.ca/content/uakron-phd-training-biomimicry-peter-h-niewiarowski) and has since grown to 15 Biomimicry Fellows (https://www.uakron.edu/bric/fellowships/). In the same time, IB has grown to 50 PhD students in five research areas.

We admit students with a Bachelor's or Master's degree from any program. The current Fellows have backgrounds not only in biology but also arts, industrial design, engineering, mathematics, and computer science. They are supported by BRIC that draws faculty members from all colleges. BRIC is a fluid and dynamic organization – although focused on biomimicry, the members continue to work closely with colleagues in their individual faculties. Additional partners include the Cleveland Institute of Art, GLBio, and the

professional design firms Balance Inc. (http://www.balanceinc.com/) and Nottingham Spirk (http://nottinghamspirk.com/).

Lastly, Biomimicry Fellows are embedded in industry or schools, supported by five-year industry or foundation stipends of about $130K arranged by BRIC and GLBio. Fellows funded by industry usually work with the company's R&D department, providing training in biomimicry as a tool, exploring specific initiatives, developing intellectual property, and in some cases working on new products and services. Six of the current Fellows are funded by foundations such as the Cleveland Zoological Society, Avon Lake Regional Waters and the Nord Family Foundation – they work with non-profits or help K-12 schools to develop curricula that broaden the STEM (Science, Technology, Engineering and Math) experience to include new approaches to innovation.

What factors helped the initiative be successful?

It is still too early to assess success, given the relative youth of the initiative compared to established PhD programs. We were fortunate to have strong support from U/Akron leadership from the beginning of the project. The partnership among U/Akron faculty, the Cleveland Institute of Art, GLBio and industry has been essential in building a collaborative that actively engages and nurtures networks.

U/Akron brought academics who understand the challenges of developing PhD programs as well as existing research connections with industry R&D departments. The Cleveland Institute of Art provides a focus on arts and design that complements the U/Akron capabilities. GLBio was started by two entrepreneurs who had a long history in running both small startups and large companies. GLBio had built extensive networks of regional corporate leaders interested in economic development, innovation and sustainability – invaluable in identifying suitable targets for the initial proof of concept. The full impact of BRIC, especially beyond the boundaries of the University, cannot be appreciated outside of its deep collaboration with GLBio. Industry partners such as Partner Hannifin, Sherwin Williams, GOJO Industries, Lubrizol, Bendix, Goodyear, Kimberly-Clark, and Nottingham Spirk help ground the Fellows' research.

Lastly, BRIC has been able to build a critical mass of local expertise that also has global reach. In spite of the importance of digital communications, face-to-face interactions are still essential for effective interdisciplinary collaboration.

What insights have you developed since founding BRIC?

Interdisciplinary collaboration sounds easy but requires considerable and constant effort if it is going to be repeatable and scalable. Like any complex system, it involves building a network that enables information flows, interactions and creating new capacity.

All parties need to feel that they are getting value from the interaction. BRIC allows industry personnel to learn biomimicry concepts, explore how they can incorporate biomimicry at different scales into different departments, and experiment on specific projects. The value for Fellows tends to be more diverse. Some want to make an impact beyond building knowledge in their field

or are attracted by the creative aspects of making ideas real. Others see collaboration as a way to identify gaps in current knowledge, increasing the breadth and depth of their understanding. The process of developing practical applications by creating and then testing models is consistent with how academics work.

Lastly, biomimicry is more than knowledge transfer – often the knowledge is either not available or hard to apply. Success frequently involves negotiating a common understanding across fields. Soft skills in social interaction and confidence combined with humility are as important as specific expertise – key relationships are tested regularly. It is crucial to create a 'space' that encompasses the important knowledge fields and ideally enhances all of them.

What results have you seen so far?

The first cohort of three Fellows (Daphne Fecheyr-Lippens, Bor-Kai Hsiung, and Emily Kennedy) are now in their fourth year. All have vastly different backgrounds but are deeply committed to biomimicry. They are truly the heroes and pioneers, dealing with the enormous challenges of dealing with the cultures of a university graduate program and industry R&D. They take great pride in how the initiative has grown around them. They have shown the value of taking ownership and being empowered to drive change by engaging in the real world.

Industry results depend heavily on company leadership, expectations and dynamics. Emily Kennedy has worked with multiple R&D departments at GOJO (https://www.gojo.com/) to improve sustainability, reduce carbon footprint and develop new ways of delivering products, leading to the filing of six patents. I expect that six or so Fellows will be delivering similar results over the next few years.

What opportunities do you see in the future?

Opportunities: really, imagination is the only limit. Most exciting, in my opinion, are opportunities for diverse partnerships to drive formal R&D of methods for the field of biomimicry, and for getting biomimicry thinking into school curriculums at early ages.

What is your favorite interdisciplinary work of all time?

A book: *On Growth and Form* by D'Arcy W. Thompson. Cliché, I know.

What is the last book you enjoyed?

The systems view of life: A unifying vision by Fritjof Capra

Whom do you admire? Why...

People that pursue their dreams with passion, but never at the expense of others. Because that's a big part of what improves our world.

If you could choose another profession or role, who/what would you be?

Never even think about that; seems like a distraction to consider it.

What is your idea of perfect happiness?

It seems like an odd question. What I can say is I would be happier if I had a little more time for play, family and friends and a little more money to travel to faraway places I have yet to see. ×

Reprinted in part from ZQ Issue 16

Nature Triangulated: Tortoise | Artwork courtesy of Derek Miller

Horseshoe crab

Photo: sneakerdog, 2006 | Flickr cc

Special Events

Peter Cottontail?

Photo: sixpackshack, 2008 | Flickr cc

Interview

Rebecca Eagle-Malone

special issue **People:** Interview **Author:** Rebecca Eagle-Malone

Rebecca, mother of 3 children, explored both urban and rural landscapes in Stark and Carroll Counties while growing up. After graduation, she eventually spent time living in Oklahoma, Virginia, and Connecticut. In every location, she found interesting natural features unique to that particular region. From all these adventures blossomed an intrigue of ecosystems and how each one sustains itself on local and available resources—each component working for survival , yet interworking as a whole to serve the ecosystem as a whole. Upon returning to Ohio in 2010, Rebecca took that intrigue to The University of Akron to complete a degree in Biology. Finding a love of plants and trees, specifically, developed out of a seasonal job (or two!) with Cleveland Metroparks Natural Resource's Plant Community Assessment Program. She believes that plants and soil hold many properties that have often been overlooked to solve problems we are currently facing on the planet and intends to do as much as she can to bring about an awareness of botany biomimicry. Currently, she is sponsored by Cleveland Metroparks Zoo as an educator of biomimicry within the Conservation Science Education Department.

What are the key takeaways from your conference talk? How would you summarize your presentation?

As the evening reception presenter, my intent was to get my guests excited about biomimicry. I wanted to inspire them via an up close opportunity to see and feel our Animal Ambassadors (Cleveland Metroparks Zoo).

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

It is my hope that I have opened a door to begin looking at nature through the biomimicry lens. First by asking, "What makes this organism unique?" Then, thinking, "How/Why does it do this?" Finally, implementing, "Could this work for this problem we're having?" I expect they will never look at the world around them in the same way again.

What stood out at this conference and what did you learn?

The most significant point of the conference is this: Working together, instead of independently, can save us a vast amount of time and seriously allow us to blast off in terms of development. It is very interesting how much/how little all of us know about others' disciplines. Some things that are common sense to others are foreign concepts to the rest of us, and vice versa. I will use the bird call cryptology as an example. Ornithologists have known certain aspects bird communication for many, many years. However, maybe they lack the knowledge of mathematics and computer science to transpose the bird call into a means of undetectable communication. Maybe they have that knowledge, but they don't realize the need for undetectable communication. Do you see where I'm going with this? We all could really benefit from collaboration.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

A few of us are interested in furthering the knowledge of biomimicry education. Particularly in non-traditional venues. I certainly welcome anyone interested in collaboration!

Any action items after this conference? Things you will do, would like to do?

Although I've been planning this for about a year, I see now just how much we need to develop biomimicry education (curriculum) for public school settings. We are also working on getting a paper published.

What are your impressions of the current state of bio-inspired design? What is working well for the current state of bio-inspired design?

The coolest thing about bio-inspired design, for me, is seeing people get so excited about it! I lead a class for Miami University here at Cleveland Metroparks Zoo in biomimicry. The class is composed mostly of educators. As part of their course requirements, they create a design or a lesson plan. They love it! Some are inhibited: "I can't draw!" "I don't have a creative bone in my body!" Once they see some of the nature-inspired creations already out there and learn the design process, they're hooked. The encompassing benefit is this: these educators are taking biomimicry back to their institutions to further the message.

Armadillo

Photo: Nathan Rupert, 2014 | Flickr cc

Spiral fern | Photo: terrabellastudios, 2008 | Flickr cc

What do you see as the biggest challenges?

Trying to create nature-inspired design as a group of one is the biggest challenge. I really believe that if we plan to work as a team of biologists, artists, mathematicians, computer scientists, psychologists, chemists, architects, etc. we can have the next boom in development.

What areas should we be focusing on to advance the field of bio-inspired design?

Collaboration! Group/Team Work! Knowing who to ask what questions.

How have you developed your interest in bio-inspired design?

I develop my interest in biomimicry by actively being in nature. For example, I garden. Being active in my garden and flowerbeds offer up-close moments for me to physically see and touch my plants, insects, soil, rocks, etc. These moments inspire questions: Why is the plant doing this? How is it doing this? Could we use these abilities for something? How would it look?

What is your best definition of what we do?

I see nature doing cool things, and I figure out how to solve human problems with those things.

By what criteria should we judge the work?

We should judge our work on how it preforms. Is it better than what is currently out there? Does it use less energy? Is it less expensive? Does it produce less waste at the end of its useful life? Is less waste created in the development? Will people buy it? Implementing as many Life's Principles as possible should be our guide.

What are you working on right now?

I am currently an educator at Cleveland Metroparks Zoo. We are leading the way in biomimicry education! Among the many ways we educate others about biomimicry, we also offer a degree program (Masters of Arts in Biology and Masters of Arts in Teaching Biological Sciences) through Miami University of Ohio and Project Dragonfly. Within the electives, we offer a class on Biomimicry (Ecophysiology). We just finished our semester, and the feedback has been great. The students (educators of various types) are very excited to spread the word about bio-inspired design!

How did you get started in bio-inspired design?

My first run-in with biomimicry was in 2012. Janine Benyus spoke at our campus (The University of Akron), along with the "new" fellows at the very beginning of the Biomimicry PhD program. I was awestruck, but I didn't ever imagine it was something "I" could do. I still enrolled in the program, but it wasn't until our first Design Challenge class that I really fell in love and "jumped on the bandwagon!"

Which work/image have you seen recently that really excited you?

Any microscopic view, SEM or lower magnification, of a plant is always exciting! If you've never seen one, put it on your bucket list!

What is your favorite bio-inspired work of all time?

This is so hard to decide! I'll say mosquito proboscis-inspired medical needles. The proboscis is 30x smaller than a typical 30G medical needle. A 30G needle is actually smaller than the typical sizes used for blood draws and vaccination injections! Imagine an injection that is more than 30x smaller than what is currently used!

What is the last book you enjoyed?

The last book I enjoyed... *The Time Traveler's Wife* by Audrey Niffenegger. I'm more of a daily newspaper, monthly magazine kind of gal.

Who do you admire?

Why...My grandma, my dad, and my mom! They taught me everything I know: love your family, support each other, be kind, and work hard. My grandma and my dad taught me about plants, animals, and the natural world from the very beginning of my existence. My mom taught me independence, organization, and etiquette (though I still fall short of her expectations in this realm, I'm sure! It's hard to be a botanist with clean fingernails!) Without my cheerleaders, I'd be nothing.

What's your favorite motto or quotation?

"Save the World!" (Which is what I plan to do. See me if you're interested in collaborating!)

What is your idea of perfect happiness?

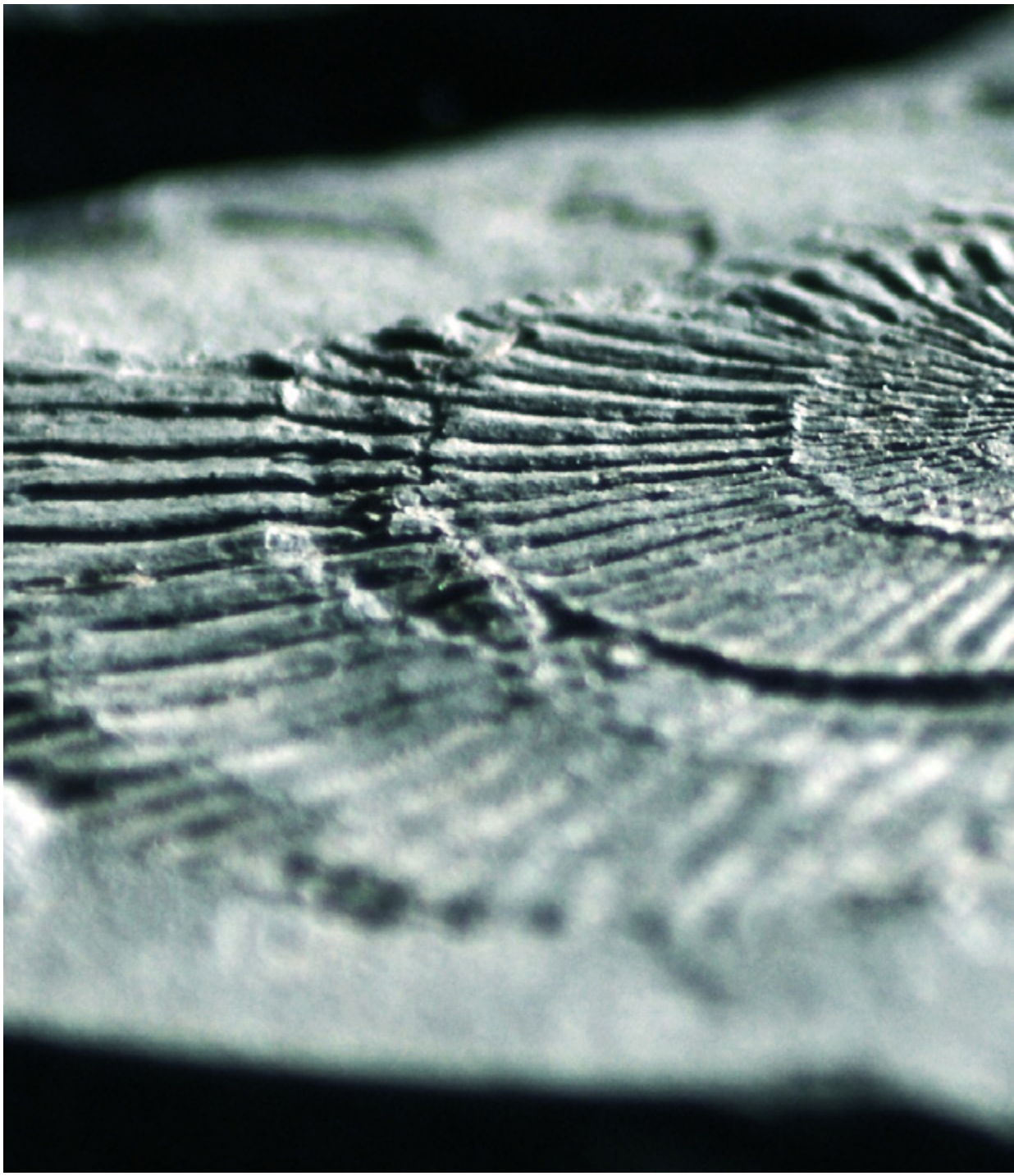
Nothing would create my perfect happiness more than my children achieving perfect happiness in their lives.

If not in your current profession, who/what would you be?

I'm not sure there is a job description for this, but I'd be "The One Who Saves the World!" ×

Armadillo

Photo: Mark Dumont, 2015 | Flickr cc



Fossil

Photo: Hellebardius, 2013 | Flickr cc

Interview
Stephen Howe

Stephen is beginning his second year in the Biomimicry PhD fellowship at the University of Akron. He received his Bachelors of Science in Biology focusing on ecology evolution and natural history from Westmont College in Santa Barbara California. As an avid swimmer and scuba diver, his love of water was naturally paired with an affinity for fish, cetaceans, and other aquatic organisms. He has also harbored a passion for dinosaurs since his youth, including their surviving descendants, birds. His research focuses on aspects of flight and swimming kinematics and he hopes to apply it towards improving autonomous and remotely operated swimming and flying vehicles.

What are the key takeaways from your conference talk? How would you summarize your presentation?

My presentation aimed to bring down the notion that fossils are failures, and not worthy to be included in our study of biomimicry. I explain how evolution and extinction work and how that should affect the way we view extinction in regards to biomimicry. I finish up by exploring paleontology, highlighting the different tools we can use to study fossils, and how we can apply those findings to biomimicry.

What impact do you hope/expect/intend your conference talk to have on your profession and/or others? How will it advance the field?

I hoped that my talk encouraged people to consider the history of life in its entirety when doing biomimicry. By considering the evolutionary context of the natural models we mimic I believe we will better understand those models and be better equipped to apply those models correctly and effectively.

What stood out at this conference and what did you learn?

I tend to be drawn towards the big charismatic animals. I was impressed by the talks that explored the smaller side of biology especially the two diatom talks.

Any circumstantial benefits? New collaborations? Interesting discussions during the breaks?

As a grad student I appreciated the feedback I got after my presentation. I picked up a few leads for projects I might be interested in pursuing, and had the chance to talk to many of the people whose work I found particularly interesting.

Any action items after this conference? Things you will do, would like to do?

I would like to continue exploring the topic of paleobiomimicry, specifically developing our capacity to use museum collections, such as the one at the Cleveland Museum of Natural History, as knowledge banks for bio-inspired design.

What are your impressions of the current state of bio-inspired design?

I believe we are on the precipice of making a distinct impact in the world of design and science.

Sunshineboy | Photo: Saparevo, 2009 | Flickr cc

Recognition of the field is going up but I would argue the average person's understanding of the field is still low.

What is working well for the current state of bio-inspired design?

I think the establishment of both the University of Akron's Biomimicry PhD and Arizona State University's Biomimicry Masters program are important steps towards a lasting presence of bio-inspired design.

What do you see as the biggest challenges?

Communication and dissemination. As bio-inspired design sits at the intersection of many fields, effectively communicating between experts is difficult. Beyond that communicating what bio-inspired design is to the public is difficult. We have to be diligent on developing the image of bio-inspired design. When I talk to people now, they are most likely to associate what I do with the medical field. While bio-inspired design has helped advance medicine, it is so much more than that and we need to be careful of our field being confined to just one box.

What areas should we be focusing on to advance the field of bio-inspired design?

Translating existing research into useable design principles. The thing about biomimicry is most of the research has already been done for us. Since the first biologists began working we have amassed a huge body of knowledge on how natural systems function. But now we are faced with the colossal task of picking through that mountain of research, to digest it and make it accessible to those who want to apply it to their work.

How have you developed your interest in bio-inspired design?

1. Consume media: books, news articles, and online video are all great ways to keep up to date on what people are doing all over the world, but they serve to inspire new directions of thinking. Which leads me to

2. Consume nature: I've been finding that I spend too much time at my desk in the lab trying to think about what I know about the natural world instead of going out into it to let it show me what it knows. This doesn't have to be a grand adventure into some pristine national park either. Looking out the window at a bird, or stopping in a fish shop can be enough to spark a design inspiration.

What is your best definition of what we do?

To me, bio-inspired design is applied convergent evolution. Convergence is the phenomenon where two or more evolutionary lineages separately arrive at similar biological solutions to problems. Convergent systems are responding to similar selective environments. When we do biomimicry we skip millions of generations of independent selection and borrow the design principles directly, understanding that the reason the principle works in our system is because we are beholden to the same physical and chemical laws as natural systems.

By what criteria should we judge the work?

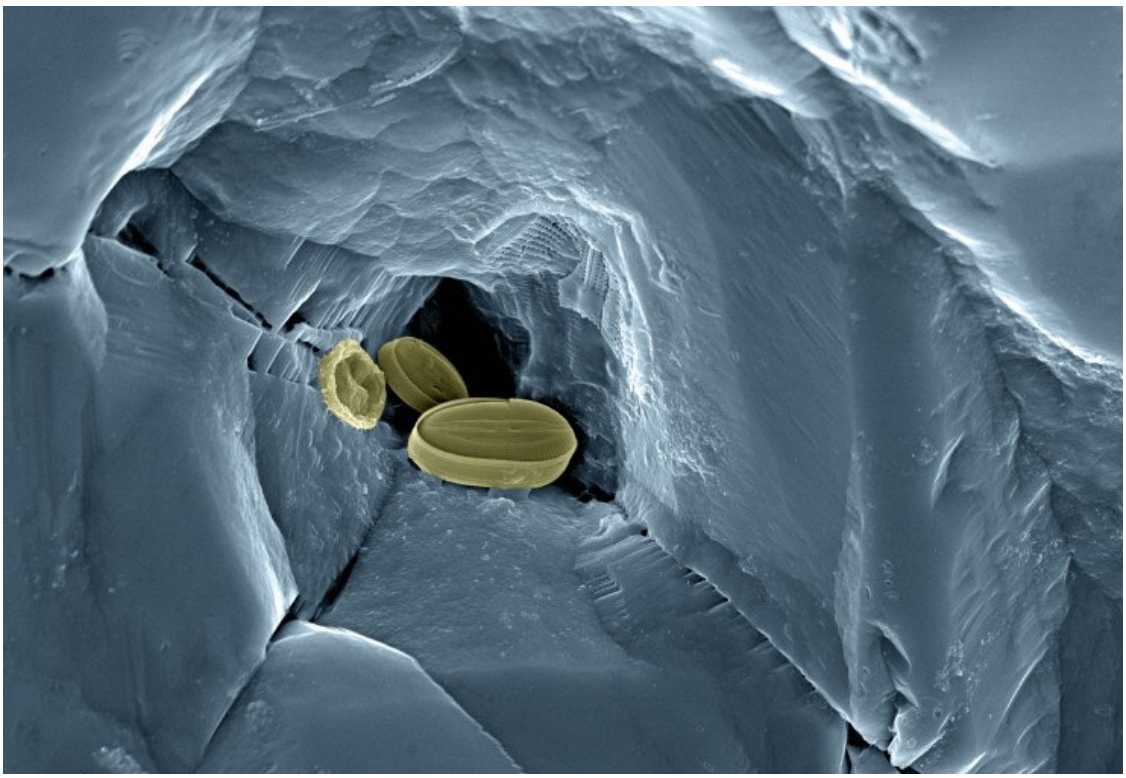
The minimum criteria for a successful bio-inspired design is to meet the needs of the system. And in many cases even that is not enough to entice people away from established technologies. A successful bio-inspired design either exceeds industry standards by a wide margin, or invokes one or many auxiliary benefits that make the technology worth adopting even if it only meets the existing standard.

What are you working on right now?

I am currently developing my dissertation proposal. I intend to focus on fluid dynamics, either sky or sea, and my dissertation work will likely spill over into robotics.

How did you get started in bio-inspired design?

I unwittingly stumbled into bio-Inspired design in high school. I am a hydromaniac (as opposed to pyromaniac) and thus was interested in how we could keep scuba divers underwater longer. I drew up a schematic for a SCUBA apparatus that



Diatoms hidden inside a grain of sand, SEM

Photo: Wellcome images, 2015 | Flickr cc

Hornbill | Photo: Matthew Kenwrick, 2011 | Flickr cc

was inspired by fish gills, the circulatory system, and the human lung. While I didn't get to see the idea through, I still would tinker with designing things that took inspiration from the natural world. Towards the end of my undergrad I came across Jay Harman's book *The Shark's Paintbrush* and was taken with the subject. I found the university of Akron's biomimicry PhD program and the rest is history.

Which work/image have you seen recently that really excited you?

Pleurobot, the salamander robot, excites me most. This bio-inspired robot was recently unveiled by Auke Ijspeert in his December TED talk, and it represents the potential for bio-inspired design to advance research. Anyone who has to work with live animals knows how difficult it can be sometimes. But if we can make machines that mimic these systems closely enough we can gather a better understanding of how the system exists in nature.

What is your favorite bio-inspired work of all time?

Whale Power, being into all things water as I am this seems natural. It was also the first "official" bio-inspired design I was exposed to.

What is the last book you enjoyed?

Jurassic Park, I hadn't actually read the book till about this time last year. Better late than never.

Who do you admire? Why...

My Grandpa, George Howe, is largely the reason I am a scientist today. He instilled in me, and helped cultivate a curiosity for the natural world. Being a botanist he was always one to stop and smell the roses, or the buckeyes, or the *Quercus agrifolia* (the California Live Oak).

What's your favorite motto or quotation?

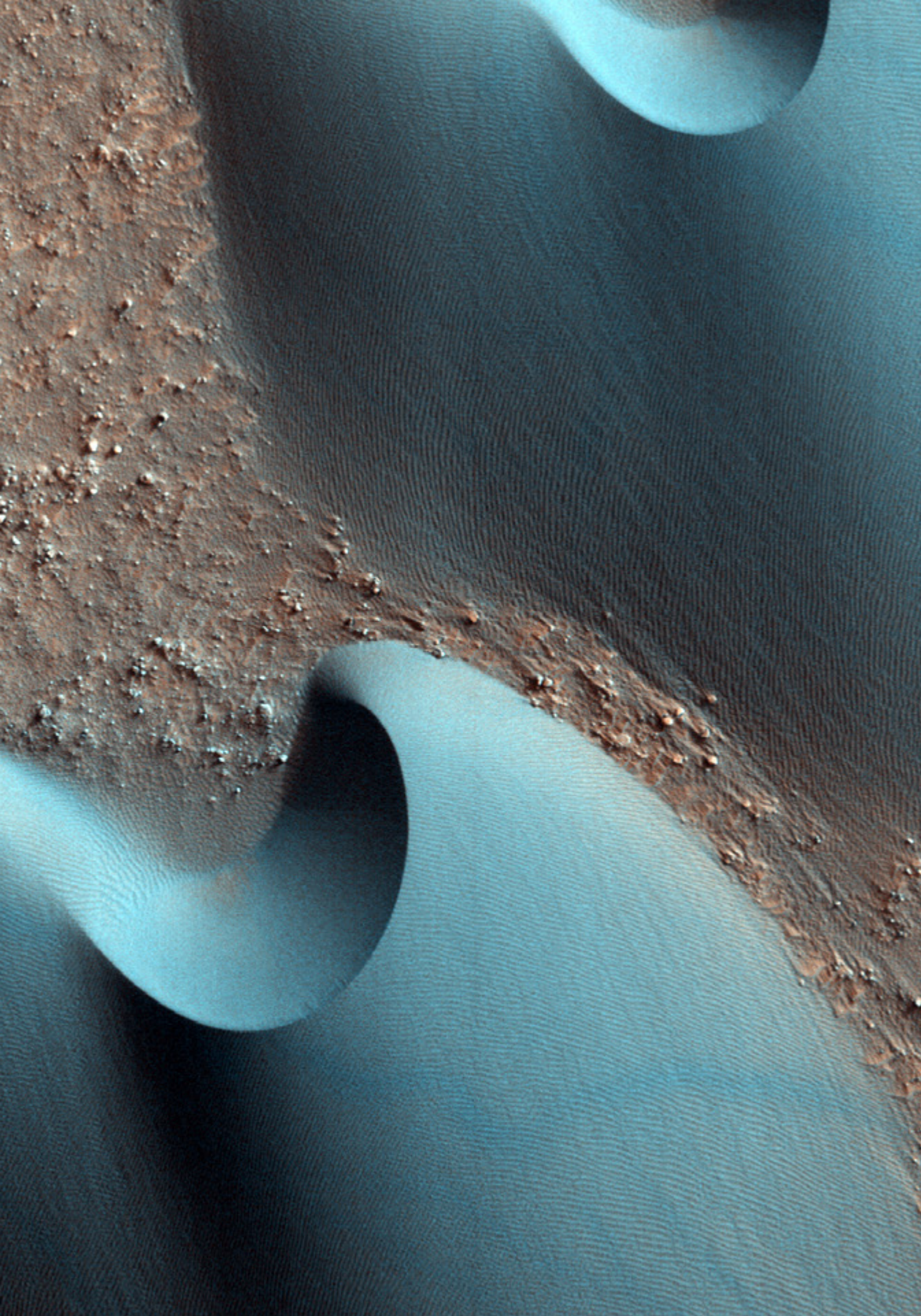
"Shoot for the moon, and if you miss you'll land in the treetops; Shoot for the treetops and you'll smack your face on the trunk." I think this quote comes in a number of iterations but this is the version I heard as a child.

What is your idea of perfect happiness?

Happiness is like a cat in that it is elusive, comes and goes as it pleases, and does not submit to your whim. You can be doing something you traditionally love and not be happy. Joy on the other hand is a fruit you cultivate in your life and is evident even when you are faced with adverse circumstances. Happiness is a state of mind joy is an attitude. I do not expect to always be happy but I can hope to always be joyful.

If not in your current profession, who/what would you be?

I like working with my hands, I would probably be a sculptor of some sort, whether that's clay, wood, stone, Lego, surfboards, I'm not picky. ×



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