## Biomimetics as a source for human innovation

# Using nature's inventions

Nature is full of inventions that work and last. Biomimetics try to imitate and use nature's inventions. Some of the commercial implementations of biomimetics can be seen in toys. But the ultimate challenge to these efforts is the development of humanlike robots that appear and behave like living humans.

Von Yoseph Bar-Cohen

Nature capabilities are far superior in many areas over human made capabilities and adapting many of its features and characteristics can significantly improve our technology (Bar-Cohen 2005). For example, biological materials such as leather and wool are much better than the materials we use for clothing (Carlson et al. 2005). Moreover, the spider constructs an amazing web made of silk material that, for a given weight, it is five times stronger than steel.

Humans have learned a lot from nature and the results helped surviving generations and continue to secure a sustainable future. Through evolution, nature has continually „experimented" with various solutions to its challenges and has improved the successful ones. Specifically, it uses principles of physics, chemistry, mechanics, materials science, and many other fields that we recognize as science and engineering. The process has also involved scaling from nano and macro to the macro and mega. Surviving organisms that nature creates are not necessarily optimal for the organism performance since all that is needed is to survive long enough to reproduce.

## Biology as a model

Adapting inventions from nature can involve copying the complete appearance and function of specific creatures as in toy stores where they are increasingly becoming filled with simplistic imitations in the form of electro-mechanized toys such as dogs that walk and bark. The design and function of diver fins were copied from the legs of water creatures like the seal and frogs. In contrast, even though flying was inspired by birds, insects and dispersed seeds, human were unable to fly by simply copying nature's concepts. It required mastery of aerodynamics, physics, materials science, engineering as well as other principles before flying became feasible. However, once human made flying machines became feasible, improvements in aircraft technology led to capabilities that far exceed any creature that lives on earth.

The body is an incredible chemical laboratory that processes materials that are acquired from the surrounding to produce energy, construction materials, multifunctional structures and waste (Carlson et al. 2005; Nemat-Nasser et al. 2005). Some of the fascinating capabilities of natural materials include self replication, multifunctionality, self-healing, and reconfigurability. Biological materials are made inside the organisms' body without the harsh conditions (e.g., heat, pressure or vacuum) that are used for the processing of human made materials. Also, biological materials produce minimum waste; the materials are biodegradable; and are recycled by nature. Mimicking nature offers the potential of superior materials for daily use as well as for constructing improved prosthetics. Learning from nature how to make new materials and effectively processing them can make our choices greater and improve our ability to recyclable waste to better protect our environment. Also, animals can build amazing robust structures that support the required function over the duration that it is needed. Often, as in the case of the spider's web, the size of a structure can be significantly larger than the species that builds it. Even plants offer engineering inspiration, where the Velcro was invented mimicking seeds adherence to animals' fur.

Biomimetics have an important role in making user friendly instruments and operating instructions. For example, it is very clear which is a male or female connector, and also what does saw teeth means. Other terms derived from biology with their usage clearly understood includes the heart to suggest the center, the head as the beginning, and the brain to describe a computing system. Such terms are also used in organizations to describe various parts including head, branch, and others. The use of the terms intelligent or smart suggests the emulation of biological capabilities with a certain degree of feedback and decision making. In the world of computers and software many biological terms are commonly used to describe aspects of technology including virus, worm, infection, quarantine, replicate, and hibernate to name just a few.

Some of nature's capabilities can inspire new mechanisms, devices and robots. Examples may include the woodpecker's ability to impact wood while suppressing the effect from damaging its brain. Another inspiring capability is the ability of numerous creatures to operate with multiple mobility options including flying, digging, swimming, walking, hopping, running, climbing, crawling. Increasingly, biologically inspired capabilities are becoming practical including collision avoidance using whiskers or sonar, controlled camouflage, and materials with self-healing. One of the challenging capabilities will be to create miniature devices that can fly with enormous maneuverability like a dragonfly or the hummingbird; adhere to smooth and rough walls like a gecko; adapt to the texture, patterns, and shape of the surrounding environment like a chameleon, or also reconfigure its body to travel thru very narrow tubes like an octopus; process complex 3D images in real time; recycle mobility power for highly efficient operation and locomotion; self-replicate; self-grow using resources from the surrounding; chemically generate and store energy; and many other capabilities for which biology offers an inspiriting capabilities for science and engineering. While many aspects of biology are still beyond our understanding, significant progress has been made.

## Emerging humanlike robots

Robots are increasingly finding applications in our daily life, and the development of humanlike robots is becoming the ultimate challenge to this technology (Bar-Cohen, 2005 and 2008). At the rate that these robots are developed one may envision the emergence of robots as our future appliance or even artificial companion. Some of the leading countries at which humanlike robots are being developed include Japan and Korea.

In Japan, besides economical factors and potentials, the rush to make humanlike robots is motivated by the major depopulation problem that is resulting from their record low birthrate and from their having the longest lifespan of any group of people on Earth. For this country that has the second-largest economy in the world, great concerns have arisen regarding the future need for employees to staff factory floors and other low-paying jobs that require low-level skills and that may be dirty, dangerous, and physically demanding. Robots that appear as lifelike humans are emerging rapidly in Japan, and they are being made to look like and to operate as receptionists, night watchmen, hospital workers, guides, pets, and more. Humanlike robots are currently being used to provide medical therapy to elderly. Besides helping to reduce stress and depression among the elderly, robots can provide them as much support and assistance as possible.

Numerous humanlike robots have already been reported and the development of many others is rapidly underway (1). For example, under the lead of Hiroshi Kobayashi, scientists at Tokyo University of Science made a cyber-receptionist female-like robot, called Saya, that behaves with an attitude and a temper (2). This robot is equipped with voice-recognition technology, allowing it to make 700 verbal responses as well as various facial expressions, including joy, despair, surprise, and rage.

## The armwrestling challenge

One of the biomimetic materials that have gained a lot of attention in recent years is the electroactive polymers (Bar-Cohen, 2004). Their functional similarity to biological muscles gained them the name artificial muscles. These materials are still in development stages and the expectations still far exceed the current capability.

In an effort to promote worldwide development of these materials and potentially lead to the realization of their potential, the author posed in 1999 an armwrestling challenge (3). A graphic rendering of this challenge is illustrated in Figure 1. In posing this challenge, the author sought to see a robotic arm activated with electroactive polymers (EAP) win against a human in a wrestling match. The first arm-wrestling contest of EAP driven robotic arms and a human, a 17-year old female high school student, was held on March 7, 2005 as part of the EAP-in-Action Session of the SPIE's EAPAD Conference. Three robotic arms participated in the contest and the girl won against all these ➜

**Figure 1:** Grand challenge for the development of EAP actuated robotics.

Source: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

**Figure 2:** An EAP driven arm made by students from Virginia Tech and the human opponent, 17-year old student.

Source: Own

arms (a photo of one of the wrestling sessions is shown in Figure 2). After this contest, the format was changed and on February 27, 2006, rather than wrestling with a human opponent, the arms performance was measured and compared to the student's data. Again, the student won and quantitatively was at two orders of magnitude superior speed and strength.

In a future conference, once advances in developing such arms reach sufficiently high level that exceed the student data that was recorded in 2006, a professional wrestler will be invited for the next human/machine wrestling match.

## Outlook

Through evolution nature introduced highly effective inventions. Humans have always made efforts to imitate nature and we are increasingly reaching levels of advancement where it becomes significantly easier to mimic biological methods, processes and systems. Benefits from the study of biomimetics can be seen in many applications, including stronger fiber, multifunctional materials, improved drugs, materials with self-healing, superior robots, and many others. Nature offers a model for addressing our needs. We can learn manufacturing techniques from animals and plants including the use of sunlight and simple compounds to produce with no pollution, biodegradable fibers, ceramics, polymers, and various chemicals.

Technologies that allow developing biologically inspired systems and, in particularly, humanlike robots are increasingly emerging. Making such robots that are actuated by artificial muscles and controlled by artificial intelligence would allow engineering concepts that are now considered science fiction. As the technology progresses, it is more realistic to expect that biomimetic robots will become commonplace in our future environment. Moreover, it will become increasingly difficult to distinguish them from organic humanlike robots. The author's armwrestling challenge having a match between EAP-actuated robots and a human opponent highlights the potential of this technology. Progress towards winning this armwrestling challenge will lead to exciting new generations of robots and capabilities in many areas.

### Annotations

(1) http://www.androidworld.com/prod01.htm
(2) http://www.washingtonpost.com/wp-dyn/articles/A25394-2005Mar10.html
(3) http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

### Literature


Bar-Cohen, Y. (Ed.): Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges. In: SPIE Press Washington, Vol. PM136, March 2004, pp. 1-765.

Bar-Cohen, Y. (Ed.): Biomimetics - Biologically Inspired Technologies. CRC Press, Boca Raton, FL, USA. ISBN 0849331633, November 2005. pp. 1-527.

Bar-Cohen, Y. / Hanson, D.: Humanlike Robots. Currently in preparation.

Carlson J. / Ghaey, S. / Moran, S. / Tran, C. A. / Kaplan, D. L.: Biological Materials in Engineering Mechanisms. In: Bar-Cohen, Y. (Ed.): Biomimetics - Biologically Inspired Technologies. CRC Press, Boca Raton, FL, USA, 2005. pp. 365-380.

Nemat-Nasser, S. / Plaisted, T. / Starr, A. / Vakil-Amirkhizi, A. : Multifunctional Materials. In: Bar-Cohen, Y. (Ed.): Biomimetics - Biologically Inspired Technologies. CRC Press, Boca Raton, FL, USA, 2005. pp. 309-340.



**AUTOR + KONTAKT**

***Dr. Yoseph Bar-Cohen*** is Senior Research Scientist and Group Supervisor at the Jet Propulsion Laboratory (JPL).

Jet Propulsion Lab, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, USA. Tel.: +1 818 3542610, E-Mail: yosi@jpl.nasa.gov, Internet: http://ndeaa.jpl.nasa.gov