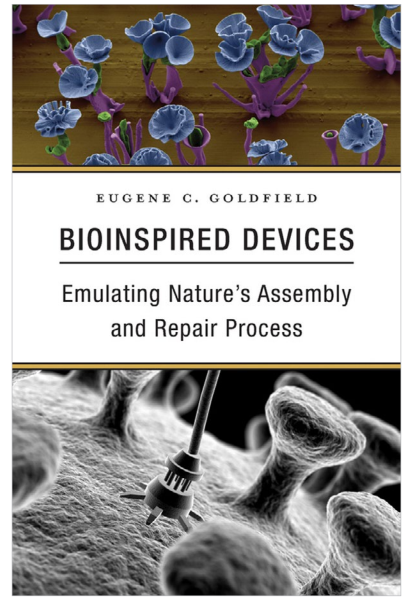
Biological plagiarism: emulating nature without due credit



Bioinspired Devices: Emulating nature's assembly and repair process
Eugene C. Goldfield
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The title of this handsomely produced book suggests an overview of the many engineering advances made possible by the burgeoning field of bioinspiration, aka biomimetics. The author's credentials are not in doubt. Eugene Goldfield is Associate Professor of Psychology in Psychiatry at Boston Children's Hospital, Harvard Medical School. He is also on the faculty of the Wyss Institute for Biologically Inspired Engineering at Harvard University, and this book inevitably highlights work being done there, as well as by a plethora of other researchers globally; for example, Goldfield has done much work on wearable robots for young children (p. 33). Unsurprisingly, *Bioinspired Devices* receives praise from his peers—it certainly promises much. Throughout the book, copious use is made of tables and figures (some in full colour), copied or compiled from the academic literature.

Unfortunately, it is a rather tedious tome, distended by the author's laborious, jargon-heavy reportage of facts from a vast array of well over 1,300 academic papers (pp. 377–443). Often there is little discussion or application. Goldfield has the knack of concentrating on the minutiae of such studies in an obtuse, almost inaccessible manner! Moreover, he seems to assume that his readers will need little assistance in grasping the technical vocabulary of multiple fields of medicine, molecular biology, neuroscience, computer science, engineering, and much more. I doubt there is a polymath alive who could honestly access all of this material without resorting to a large amount of cross-referencing and additional reading. This is a shame.

Additionally, while chapters five and six (pp. 149–233) plumb the depths of cutting-edge neuroscience research (passed over in this review due to space constraints), it is disappointing that the material is not connected there and then to the book's theme: bioinspiration. Chapter seven, "How nature remodels and repairs neural circuits", does advance the discussion, but it is similarly tough going: one sentence (pp. 197–198) runs for 87 words, not including a further 34 words, abbreviations, and dates in parentheses! Not until the last chapter (from p. 338) is there a really focussed treatment of bioinspired devices themselves, although the author does use chapter four (pp. 111–146) to outline *how* bioinspiration engineers are emulating biology in building their own devices. These negatives aside, this is an intriguing book with respect to the origins debate.

Homage to evolution

Of 10 chapter titles, half of them personify nature as an intelligent, forward-thinking, creative agency. In fact, such 'secular-god-substitute' language so peppers Goldfield's terse, academic writing that I quickly decided to record the instances. The following statements (or close equivalents) evidence sheer evolutionary faith: "nature builds" (27 times), "nature uses" (5 times), "nature remodels" (4), "nature harnesses" (3 times), "nature leverages" (twice), "nature achieves", "nature invents", "nature has conserved", and "nature has discovered". We also read of "nature's solutions" (8 times) or "evolutionary solutions" (p. 235), and that things are "corrected by nature" (p. 30), plus other personifications that I pass over here. Never is the slightest justification given for these non–evidence-based assertions, which does not befit a serious academic text.

In these and other ways the author is careful to affirm his belief in the creative, innovative power of evolution. For instance, excitatory inputs of mouse motor neurones arose through "the evolutionary organization of the rhythm generating circuit, necessary for the emergence of bilateral appendages" (p. 172). And certain regions of the cerebral cortex represent, he says, "a significant evolutionary advance" (p. 182). Discussion of how this occurred is restricted to bland suggestions: what "may have been", "may have", "may not be" (p. 207).

Hallmarks of nature worth emulating

Goldfield argues that we can think of the sensory organs of humans and

Image: Kostas Karakasiliotis, Biorobotics Laboratory, EPFL

Figure 1. *Salamanda robotica*, a waterproof salamander robot designed both to swim and to walk on land. It has eight motors to perform spine undulations and extra motors to power each leg (discussed in Goldfield, pp. 242–246).

various other organisms as smart instruments. Indeed, but, holding to "our evolutionary heritage in animals" (p. 46), he also says these "have evolved through tinkering" (p. 8). Bioinspired research with that premise obviously contrasts with an *a priori* acceptance of originally perfect biological designs which were corrupted subsequently (Genesis 1:31; 3:17–19). People like Goldfield are not consciously "thinking God's thoughts after Him" but are 'thinking Darwin's thoughts after him'.[1] Nevertheless, theirs is a laudable aim, to try to integrate the human body with complex artificial systems in order to repair congenital defects, ameliorate the impact of sensorimotor damage (e.g. due to strokes), to create improved prosthetics for those paralysed by life-changing injuries, and much more.

The various hallmarks of (divine) design may not be recognized as such, so that naturalistic biomimeticists like Goldfield may justifiably be accused of what I call biological plagiarism. Nevertheless, he obviously recognizes the rich pickings to be had from detailed study of the natural world. Much can be learnt from considering the fundamental characteristics of living organisms (pp. 15–31). For a start, the complex systems of various organisms are wonderfully *robust*. Also, the ways in which an animal's anatomy and nervous system integrates with the environment (including "reciprocal and dynamical … coupling") are remarkable. Looking to the future, bioengineers anticipate the seamless integration between man-made devices and the body's organs and systems. For example, such aids would then be fully *embodied*, much as a discarded shell becomes an extension of a hermit crab's body. This would be true whether these devices were placed inside the body (e.g. a computer-aided muscular actuator) or worn like a piece of clothing.

More complex organisms are *anticipatory*, especially those with significant brain function, something that advanced robotics research seeks to emulate. In future, devices will be increasingly *smart*, better inspired by the ingenuity of animals in their apparently mundane tasks, such as searching for life-sustaining food and water. Scientists are working hard to copy the *self-repairing* ability of biomaterials like bone. And, at a deeper level, by studying the novel properties arising in self-organizing, complex biological systems (so called *emergence*), scientists are seeking to better treat people with various psychopathologies and brain diseases. These features and more are worth emulating.

A wellspring of ideas

Goldfield's vision for bioengineering is founded upon *how* and *what* "nature builds, controls, and manufactures" (p. 31), the subject matter of chapters two and three respectively. Along the way (and this is a feature of this book as a whole), he showcases many of the advanced scientific techniques being employed to advance our understanding of diverse biological fields, such as: morphogenesis,[2] tensegrity (tensional integrity),[3] embryogenesis, cellular networks, epigenetics,[4] breathing, and swallowing. The point is these are all rich sources of bioinspiration, albeit that the details of this research are not developed until much later in the book.

Biomaterials galore are a treasure trove in this field: structural ones like plant cellulose, chitin, and collagen (in various animals); rigid ones (like wood, coral, and tooth enamel); tensile ones like spider silk; pliable ones like resilin (the tendons in insect wings); and composite ones like animal cartilage, bone, and the gel of jellyfish. Of course, many biomaterials possess more than one of these properties.[5] And the ways in which these biomaterials are constructed into such items as turtle shells, crustacean appendages, or squid eyes are enormously enlightening for scientists. Sadly, whatever the marvel under consideration, the god of naturalism gets the credit; for example,

> "… nature's materials achieve the seemingly contradictory requirements of being sufficiently stiff to support a load yet tough enough to resist crack propagation, by the self-assembly of *composite* materials into hierarchical structures with interfaces" (pp. 74–75).

At a higher level, the biological smart instruments mentioned earlier are ripe for scrutiny: the stride generator of a crab, the odometers of ants and bees, the sun-compass of migrating birds and butterflies, and the altitude controllers of humble flies (p. 89) are all fascinating and inspiring. Well might biomimetics experts both envy and try to emulate the exquisite mechanosensory perception of even the lowliest creatures. An outstanding example is the bizarre-but-brilliant nasal organ of the star-nosed mole, with its twenty-two nasal rays and "25,000 epidermal touch domes (papillae) called Eimer's organs, innervated by more than 100,000 myelinated fibers" (p. 92). Such is the precision of this organ that it operates more like the retina of visual systems, a sort of 'tactile eye'—smart indeed![6]

Even tiny *Drosophila* (the well-known genus of fruit flies) can navigate and fly to habitable oases across many kilometres of open desert. How? By making use of a "repertoire of instruments common in many insect species", such as "a sky compass to read the polarization of the sky", not to mention an "optical flow detector, and odor plume tracker"—and all of the fruit fly's super-miniaturized smart instruments are integrated together (p. 94).

From the smallest to the largest scales, bioinspiration scientists are also learning a great deal about mechanotransduction, for example, studying hearing mechanisms, hydrostatic skeletons (such as in *Octopus vulgaris*), and 'nature's pumps'. We might not be surprised to learn that the tongues of marvellous nectar-sipping hummingbirds are actually elastic micropumps. But how many people who watch a dog thirstily lapping up water appreciate that they are witnessing a complex hydrostatic pump in action (p. 101)? At every level, the sheer wealth of species available for study constitutes an inexhaustible wellspring of research leads.

Figure 2. Wearable prosthetic limbs are of enormous benefit to individuals. Integrating these with a person's nervous system, enabling conscious movement, is no longer science fiction, but there is still a long way to go.

Exciting developments

Until now, I have referred to bioinspiration scientists, bioengineers, and biomimeticists. In fact, these umbrella terms represent the collaborative efforts of biologists, medical scientists, clinicians, engineers, robotics experts, computer scientists, and more. Goldfield relates many examples of intriguing achievements that have come about through such fruitful partnerships.

There are many bioinspired adaptive materials: self-healing ones, slippery liquid-infused porous surfaces (SLIPS), and helically assembling bristles with adhesive and particle-trapping properties (pp. 115–121). Some groups are constructing organ-on-chip microfluidic devices that can model tissue or organ physiology (pp. 121–122). Muscle–tendon units, "a marvel of nature's engineering", are being emulated in order to better mimic their motor function and their spring-like, braking, stabilizing and energy-storing capabilities (pp. 123–126). Further fields of investigation are soft sensors, actuators, 'programmable matter', soft robots, water-jumping robots, robobees and octobots (pp. 127–146).

Medically, there is exciting cutting-edge work; for example, modelling the regenerative powers of animals after amputations and spinal injuries, or studying birdsong to better understand the production of human speech (pp. 245–265). We cannot showcase here the numerous examples of bioinspired designs to which Goldfield draws attention. However, the intelligent layperson is better served by far more accessible books on the subject.[7]

Science fiction or fantasy?

After further discussion of the ways in which biomimetics experts seek to emulate biological responses to congenital abnormality, pathology, and injury (which includes a brief treatment of rehabilitation robots and virtual reality; pp. 317–321), Goldfield concludes the book with his vision for how best to emulate nature in bioinspired technologies. As already mentioned, 'nature' is his secular substitute for the Creator. Even so, what principles can be gleaned by biomimeticists, whether they choose to credit the omniscience of God or do not (biological plagiarists)? Goldfield lists the following (pp. 373–374):

1. *Self-assembly*—at all scales, this is a feature worth emulating.
2. *Consortia*—try to build biological–synthetic devices from a consortium of interchangeable parts.
3. *Decentralized control*—use components which, hopefully, will collectively self-assemble into complex architectures.
4. *Flexibility with stability*—build devices from redundant components that, later on, can be quickly dismantled and reassembled for a different function.
5. *Emergent behaviour*—aim to have components, the individual specialized functions of which collectively exhibit complex emergent behaviour.

While Goldfield's *Bioinspired Devices* exposes the reader to many interesting attempts to follow these principles, the artificial instruments and interventions are exceptionally modest when compared to 'nature'. For example, there have been striking strides forward in facial recognition and socially assistive robots, but the construction of a robot that could empathetically respond to injury or disease (let alone anticipate problems) remains science fiction. In spite of the impressive advances in computation, artificial intelligence, and robotics, real-world biology is still orders of magnitude more sophisticated.

References

1. Johannes Kepler (1571–1630) is usually credited with saying: "I was merely thinking God's thoughts after him. Since we astronomers are priests of the highest God in regard to the book of nature, it benefits us to be thoughtful, not of the glory of our minds, but rather, above all else, of the glory of God."
2. The changing shape of an organism, morphogenesis, is affected by such things as mitosis (cell division), apoptosis (programmed cell death), cell shape alterations, cell movements, and cell interactions.
3. Tensegrity studies the way in which cell or tissue shape alters through the balance of forces of compression and tension. Tensegrity might help associate individual cell behaviour with collective cellular organization as tissue (p. 44).
4. See Amber, A., Epigenetics—an epic challenge to evolution, creation.com/epigenetics-challenges-neo-darwinism, 21 April 2015.
5. An example is abalone shell, a material that can absorb heavy impacts and resist crack propagation. See Sarfati, J., Amazing abalone armour, *Creation* **30**(1):44–45, December 2007; creation.com/amazing-abalone-armour. Also: Tuinstra, L., Uncuttable: Designs in nature inspire new super material, creation.com/uncuttable, 15 October 2020.
6. See: Weston, P. and Wieland, C., The mole, *Creation* **25**(2):46–50, March 2003; creation.com/the-mole#organ. Especially note the in-depth box about this mole's 'tactile fovea', in the online version of the article: Sarfati, J., Superb sense organ sheds light on alleged eye imperfection.
7. Two notable ones are: Burgess, S. and Statham, D., *Inspiration from Creation: How engineers are copying God's designs*, Creation Book Publishers, Atlanta, GA, 2018; Sarfati, J., *By Design: Evidence for nature's Intelligent Designer—the God of the Bible*, Creation Book Publishers, Atlanta, GA, 2008.