Biomimetics and related topics

4th meeting of the “multilatérale des 4 moteurs pour L’Europe”

IESF, Lyon, 06/29/2017

Summary

This brief talk is devoted to new trends in sciences and technologies, as regards to biomimetics or bio-inspiration.

In fact, the reference to living beings for technological developments becomes more and more frequent. For example, the last Friday it was discussed during the program of the broadcast station France Inter "La Tête au Carré". During this program, a special issue of the magazine "La Vie" dedicated to these subjects has been presented.

The first question before to investigate such topics is to guess their novelty or not, and mainly their relevance. “Is there something new under the sun, is there something fresh in the kingdom of science? And mainly: Is it promising”

In your folder, you have at your disposal a set of illustrations made in the perspective of a “powerpoint” presentation. It was not easy to do that this evening so I proposed to give you a printed form. In fact, it may be more beneficial for you, because rather to follow a presentation, with usual difficulties, during which the speaker speaks too fast and shows quickly a succession of slides. Then and now you have documents at your disposal, thus time to look at them and… possibility to avoid a rapid oblivion.

What about novelty?

For instance, the comparison between the spider web and the nets of hunters and fishermen may lead us to believe that our distant ancestors were inspired by the formers to conceive the latters. But, on the other hand, the manufacturing techniques differ singularly. Obviously, we don’t mimic a spider to make a net, except in blockbusters devoted to “Spiderman”.

Many other tools and techniques have possibly similar origins. But the traces of these discoveries have been lost, because the prehistoric scientists didn’t published their results, did not patent their discoveries. It was not yet the time for!

On the other hand, we have writings and drawings coming from artists and engineers of the past. The best known being Leonardo da Vinci and his projects of flying machines based on the observation of bird flight.

We can find other examples, I like one of them, that is to say the discovery of perspective drawing by Piero della Francesca around 1450, from the study of binocular vision found in a book written four centuries before by an Arabic scientist named Alhacen. It leads to an amazing question: although sculptures representing very nicely, for example humans, animals and many other objects, was very older, why the 3D illusion on paintings, enabled by the invention of perspective, appears only during the 15th century?

But nowadays, as the prefix "bio" is bankable, we can ask the question: Are "BIOmimetics" and other similar words recovering a real significance or a fashion of the day or just empty buzzwords?

Novelty certainly not, but amplification and rationalisation

For us, engineers and scientists, one of the most efficient way leading to decide about the interest of such innovations or not, and to the opportunity to invest them, is to examine the context (5 points):

First on the more recent history of the domain, to say after the second war, then we can cite important events: invention of cybernetics (1947) which led to science of automatic control, of bionics (1958), of artificial intelligence at the end of 60's, and so on…

Second to look at the literature, for instance I explored the data base of the famous scientific journal *Nature,* so we observe an exponential growth of publications which refer to biomimetics and bioinspired. More over Nature propose a definition of biomimetics. (6)

Third, an epistemological argument, this definition is precisely a first step, but we can find others ones.

Forth, theoretical argument linked to the biological evolution, which led to "natural" efficient materials, compounds, structures and mechanisms and the Darwinian process itself, a kind of "*natural serendipity*" were chance plays an important role as in "serendipity" itself.

And fifth, to propose actual typical examples and new ideas such as the development of eco-inspiration.

In fact this kind of approach was familiar to some scientists. For instance, when I was in charge of the direction of scientific research programmes at the CNRS, I used early this practice in order to know if it would be relevant to sensitize the scientific community to new trends appearing in the literature or just from more or less precise ideas of researchers gathered here and there. Practically, I introduced early the concepts we discuss today, about 10 years ago in the framework of the Amazon Programme of the CNRS.

Conclusion

In conclusion, "biomimetics" and related words name promising sectors of activities, especially because life sciences and related scientific and technological domains are developing fastly, in opposite to an opinion shared at the beginning on the century by many scientists and analysts who believed that the growth of research and applications will had soon to slow down in these domains. For example, someone thought that the sequencing of human genome, a kind of Holly Grail, would mark the end of the Quest. A little more then a decade after, it is not the case and probably for a long time. Particularly biomimetics and bioinspiration are topics of the future and we can now advice to give an attention to them, as for other topics in biological sciences or related to them. Moreover, this is a nice way of biodiversity valorisation.

Alain Pavé

Professeur émérite à l'Université Claude Bernard - Lyon 1
Membre de l'Académie des technologies,
Correspondant de l'Académie d'agriculture
Laboratoire de Biométrie et de Biologie Évolutive
UMR CNRS/INRIA 5558
Université Claude Bernard Lyon 1
+33 (0)679442814
alain.pave@univ-lyon1.fr
www.alain-pave.fr

NATIONAL ACADEMY OF TECHNOLOGIES OF FRANCE

4th meeting of the "*Multilatérale des 4 moteurs pour L'Europe*",
IESF, Lyon, June 29, 2017

Biomimetics and related topics



When life becomes a source of new technologies

New concepts… but an old history

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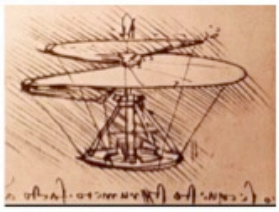
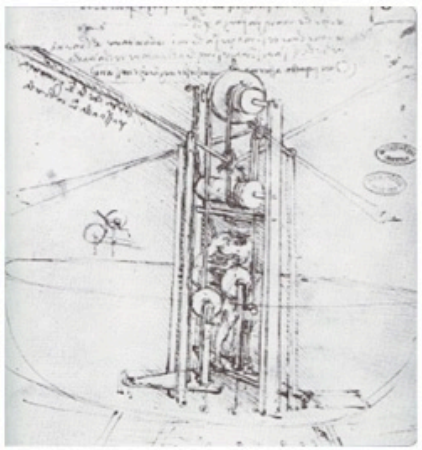
Simple ideas
But often difficult to apply





Flying machines
(Leonardo da Vinci, codex, 1485)

Air fluxes around moving wings of mosquitoes
Nature, 6 April 2017

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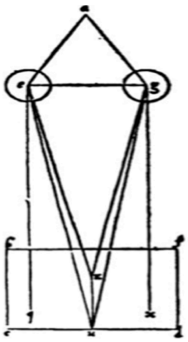
POUR UN PROGRÈS RAISONNÉ, CHOISI ET PARTAGÉ

When the study of life inspire the artist : discovery of perspective

Mercy (1445-1460)

Binocular vision



Alhacen
965-1040

The baptism of Christ (1448-1450)

Piero della Francesca (~ 1412-1492)

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Biomimetics, bio-inspired technologies: are they relevant to define scientific and technological domains ?

1. Practical, empirical arguments
2. Use of these new words in the litterature ("the use makes law": "customary law"):
3. Theoretical arguments
4. Epistemological arguments
5. Examples

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1. Recent history: empirical arguments

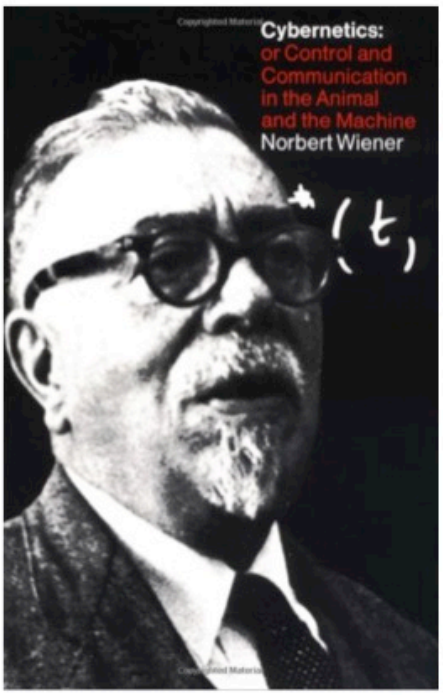
- Cybernetics (Norbert Wiener, 1948), from results of physiology (internal regulations)
  - Theory of automatic control
- Bionics (Jack E. Steele, 1958) : sensors, computers
  - Biology and electronics
- Systemic : general theory of systems (Ludwig von Bertalanffy, 1968) from organism paradigm
- Artificial intelligence and **robotics** (~1980)

2000's

- Bio-inspired Informatics (e.g. Genetic alg.)
- Bio-inspired Technologies(e.g. production of energy)
- Bio-inspired Material
- Bio-inspired Chemistry (e.g. design of pharmaceutics)

...

Question : which is the proper word, biomimetics, bioinspired, bionics, . ?



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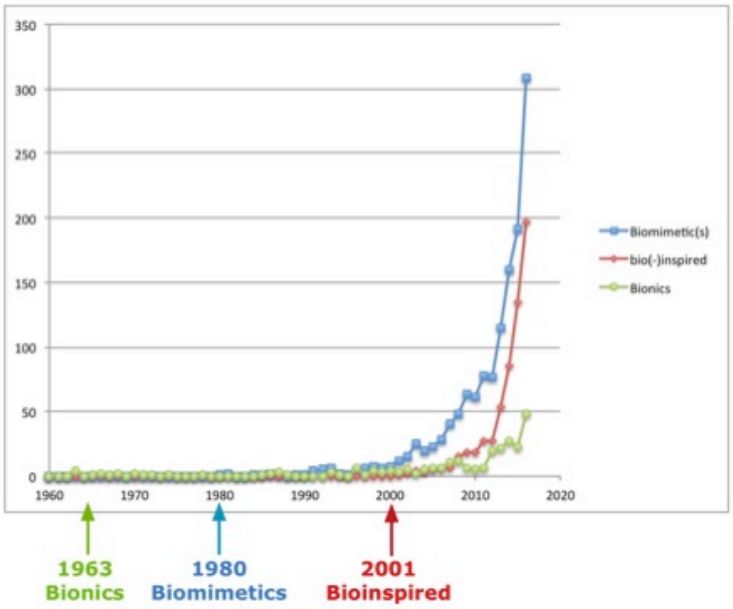
2. Customary argument : occurrences of biomimetics and similar words in literature



Nature Data base

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3. Theoretical arguments : What about life and technologies?

- Living systems (organisms, populations, communities, … biosphere) result from about 4 billion years of biological evolution, which led to a great diversity of "adapted" structures, materials, compounds, …
- Many "solutions" has been "found" allowing survival, reproduction, development in a complex and changing environment, largely *unpredictable*
- It proceeds from « Trial and error » scheme, principally stochastic, what we call Darwinian evolution :
  - Reproduction - variations
  - Selection
  - And genetic drift
- Some of these solutions can be sources of progresses
- The life exhibits a set of natural technologies, … "*natural serendipity*"

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4. Epistemological arguments

- **Definition (*Nature*): Biomimetics** is an interdisciplinary field in which principles from engineering, chemistry and biology are applied to the synthesis of materials, synthetic systems or machines that have functions that mimic biological processes. Biomaterials are any natural or synthetic material that interacts with any part of a biological system. Biomimetic designs could be used in regenerative medicine, tissue engineering and drug delivery.
- In such an interdisciplinary context, to lead to efficient developments, the field has to be well defined and organised
- Categorisation and relationships between categories
  - For instance, biomimetics and bio-inspired: Are they distinct or are they synonymous, or still are they partially recovering ?
  - Transpositions between categories: what is common between bio-inspired algorithms, and bio-inspired materials?

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5. Examples

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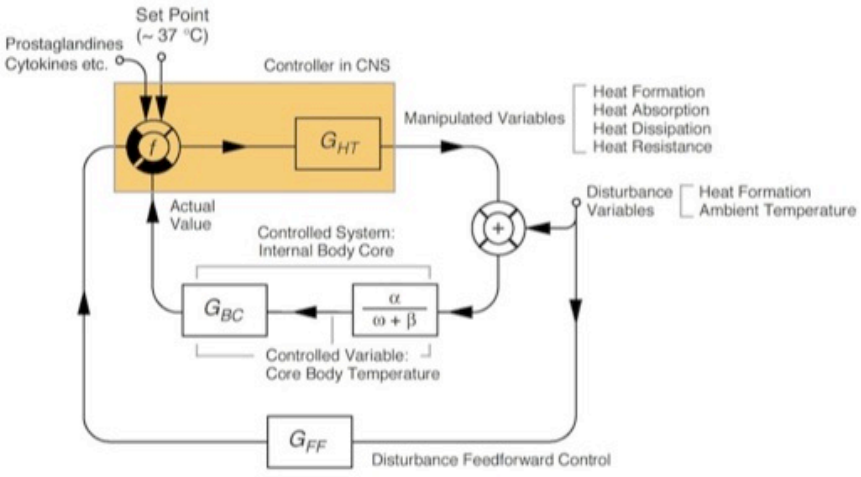
Cybernetics

Thermoregulation in homeothermic organisms and temperature regulation of technological systems

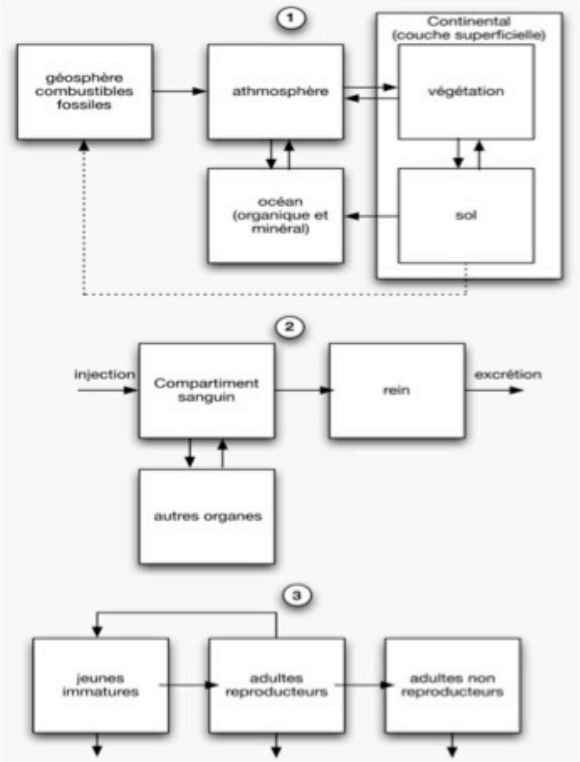


Compartmental systems

Biogeochemistry
(Climate researches)

Physiology/Medicine

Population biology



Bio(-)inspired informatics

- Use of the expression "electronic brain », but it has become obsolete
- Artificial Intelligence (1980's)
- Neuronal networks (1980's)
- Evolutionist algorithms
- Cellular automata

} Random kernel (Monte-Carlo)

- Cooperative systems (e.g. multi-agents systems)
- …

Materials

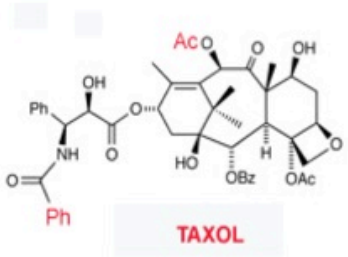
The most cited domain in the litterature

Lotus flower: hydrophobic surface

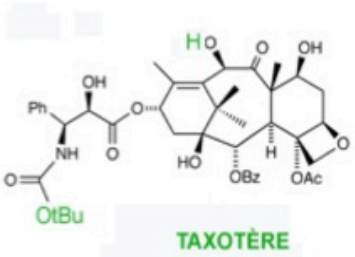
The foot of the Geko: adhesive surface

Chemistry and pharmaceutics

- Search and identification of active compounds, and… transformation of them (activity *vs* toxicity)



TAXOL



TAXOTÈRE

Energy

- Hydrogen production directly from solar energy : « artificial » leafs (bio-inspiration) biomimetic devices and/or processes (photosynthesis),
- Cf.:
  - Marc Fontecave (Collège de France, Paris)
  - Vincent Areto (CEA, Grenoble)
  - Daniel Nocera (MIT/Harvard, Boston, Mass.)

La feuille artificielle en action.

Artificial leaf: Si et catalyst (Co, Ni and Mo)

http://www.sciencemag.org/content/334/6056/645.abstract

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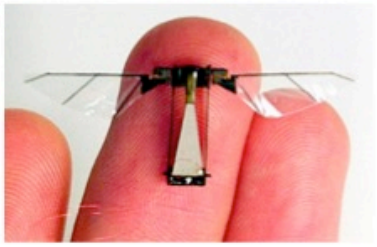
Bio-inspired drones

- Insects (DGA)

Modèle cinématique de thorax avec ailes battantes



Robert Wood, Harvard Univ.

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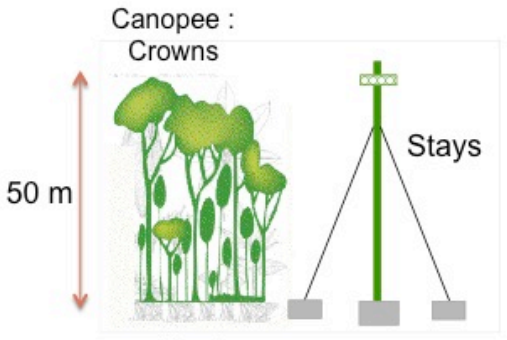
Bio-inspired mechanics

- Why a tree resists to wind ? Inspiration for new vertical structures such as masts for boats

Typical tree in the amazon forest

Copas metal pylon



(Canopee observatory permanent access system – CNRS & Ulm Univ + Körber Fundation)
Nouragues CNRS forest research station (Frtench Guyana) CNRS

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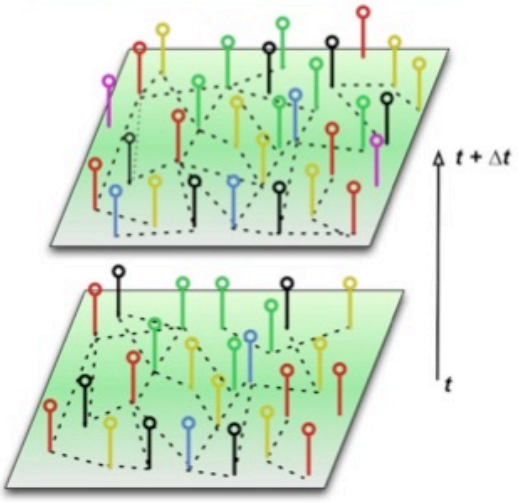
Eco-inspiration ?

A natural forest is more or less a chaotic system changing with time but maintaining its chaotic structure => resilience

A self-disorganised ecosystem?
And not a super organism !



AP, 2007, 2011, …

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Is *randomness* usefull ?

- Chance is necessary to biological evolution
- Optimization algorithms
- Management of multispecies forests on the model of natural forests
- Agro-ecology
- Management (Abrahamson & Freedman : « A drop of disorder = a lot of benefits » or "A Perfect Mess: The Hidden Benefits Of Disorder")
- Aviation Tracking and Missile Avoidance Strategy (on bat model of hunting or on gazelle behaviour faced to cheetah)…

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Conclusion

- Interest in creating new concepts and categories and new words:
  - Grouping different practices (=>invariants)
  - Knowledge organisation
  - Innovations
  - …
- Another argument for studying and preserving biodiversity? Maybe the main…

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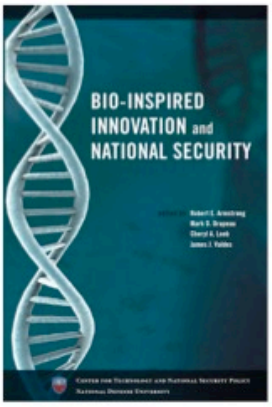
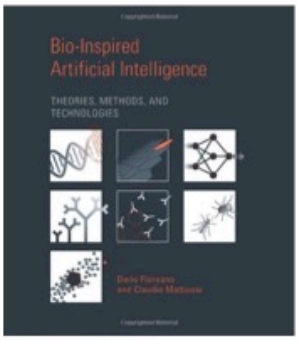
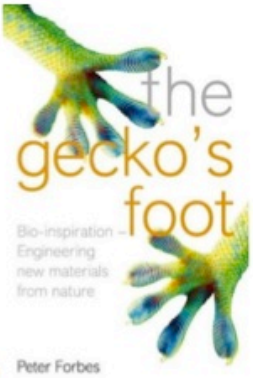
Some books







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Thank you for your attention