Ekspedisi Saintifik Lata Jarum 2009

Views from the physicists

The physicists Mrs. Tina Rezaie Matin, MSc., and Prof. Ille C. Gebeshuber from the Institute of Microengineering and Nanoelectronics (IMEN) at UKM were participating in the Scientific Expedition Lata Jarum 2009, applying the Biomimicry Innovation Method (BIM) in the rainforest. BIM has four key elements: *Identify Function:* The challenges posed by engineers/natural scientists/architects and/or designers are distilled to their functional essence. *Biologize the Question:* In the next step, these functions are translated into biological questions such as "How does nature manage lubrication?" or "How does nature manage joining rigid parts in relative motion?" The basic question is "What would nature do here?" *Find Nature's Best Practices:* Scientific databases as well as e.g. scientific expeditions to the rainforest with its high species variety are used to obtain a compendium of how plants, animals and ecosystems solve the specific challenge. *Generate Process/Product Ideas:* From the best practices, ideas for products and processes are generated.

The project in Lata Jarum was to find Nature's best practices concerning current issues in nanotechnology, exemplified by

- colours that are based on nanostructures (rather than pigments),
- attachment and defense structures,
- reinforcement structures,
- reflectors of night active spiders.

The fern *Selaginella willdenowii* (Figure 1) has iridescent blue colors that change with the viewing angle. As reported by Professor Lee, a former researcher at the University of Malaya, a nanostructured thin layer system is the reason for these colors[1]. Inspired by this natural photoprotection system, photoprotective coatings for emerging microelectromechanical systems (MEMS) shall be developed at IMEN.

Figure 1. The fern Selaginella willdenowii, a masterpiece of nanostructures in Nature, and very interesting for emerging micro- and nanotechnology.

[1] Lee D.W. and Lowry J.B. *Physical basis and ecological significance of iridescence in blue plants.* Nature 254 (1975) 50-51.

Some leaves have highly regular holes (Figure 2). As mentioned on an expedition to Sabah in July 2009 from Jimmy Omar, head of the Educational Programme and Tour Coordinator at Danum Valley Field Centre, the holes are made by animals who eat part of the plant while it is still very young and rolled up. This is a fabulous example to teach students that sometimes you have to leave your twodimensional way of thinking when you want to understand the whole.

Figure 2. The regular holes in this plant are caused by animals who feed on them when the leaves are still rolled up.

Rattan (Figure 3) has elaborate mechanical attachment and defence structures: hooks and spikes on various levels of hierarchy – even on the leaves. Recurring principles of biology are correlation of form and function, modularity and incremental change, genetic basis, competition and selection, hierarchy and multi-functionality[2]. Various plants have developed such mechanical protection systems (see e.g., Figure 4).

Figure 3. Rattan has different spikes in the stem, the branches and the small leaves. These spikes serve as defence mechanism against herbivores.

[2] Fratzl P. and Weinkamer R. *Nature's hierarchical materials*. Progr. Mat. Sci. 52 (8) (2007) 1263-1334; Vincent J.F.V. *Deconstructing the design of a biological material*. J. Theor. Biol. 236 (2005) 73-78.

Some general principles that can be applied by engineers who are not at all involved in biology have been distilled[3]. These basic principles comprise *integration instead of additive construction*, *optimization of the whole instead of maximization of a single component feature*, *multi-functionality instead of mono-functionality*, *energy efficiency* and *development via trial-and-error processes*. Systematic technology transfer from biology to engineering thereby becomes generally accessible, even for the engineer who is not at all involved in biology.

Figure 4. Little spikes on the leaves serve as mechanical protection.

Climbing palms such as the highly specialised rattan palms in the southeast Asian rainforests evolved leaves armed with hooks and grapnels for climbing (Figures 3-5). In many plants the branches are constructed to optimize bending and torsion in relation to the deployment of recurved hooks. Hooks increase in strength toward the base of attachment organs and always fail before the axis in strength tests. Hook size and strength differ between species and are related to body size and ecological preference. Larger species produce larger hooks, but smaller climbing palms of the understory deploy fine sharp hooks that are effective on small diameter supports as well as large branches and trunks (Figures 3-5).

[3] Nachtigall W. *Vorbild Natur: Bionik-Design für funktionelles Gestalten*. Springer, Berlin (1997)

Figure 5. Spikes and hooks increase in strength toward the base of attachment organs and always fail before the axis in mechanical strength tests.

On the expedition to the Danum Valley in Sabah, on the night tracks, we saw multicoloured reflections that turned out to come from the eyes and legs of night active spiders. Although the eyes are just some hundreds of micrometers in size, reflections can be seen from 20 meters away, and more. Doing research on spider's eyes in the middle of the night seemed strange to our rangers: they never saw what we saw (since the light reflects back to the headlight of the researchers, the guides simply did not see the reflections!), the rangers were always amazed how we could successfully locate the spiders even during rain (which is actually easy to do, since raindrop reflections are white, whereas spider eye reflections are coloured). From the reflections in their eyes, we located the spiders, made a photograph (Figures 6 and 7), and were measuring the maximum distance to the spider where we still could see the reflections.

In 2009, Gebeshuber and co-workers from UKM proposed a novel way to describe the complexity of biological and engineering approaches depending on the number of different base materials is proposed: Either many materials are used (*material* dominates) or few materials (*form* dominates) or just one material (*structure* dominates). They state that the complexity of the approach (in biology as well as in engineering) increases with decreasing number of base materials and propose that biomimetics, i.e., technology transfer from biology to engineering, is especially promising in the development of micro-electro-mechanical systems (MEMS) because of the material constraints in both fields[4].

[4] Gebeshuber I.C., Stachelberger H., Ganji B.A., Fu D.C., Yunas J. and Majlis B.Y. *Exploring the innovational potential of biomimetics for novel 3D MEMS*. Adv. Mat. Res. 74 (2009) 265-268.

Figure 6. Night active spiders that were located by the strong, colourful reflections of the light of our headlights in their eyes.

Figure 7. Our investigations of the reflective properties of the eyes of this night active spider showed that with our headlights only ONE of the eyes appeared to be reflective at each point in time. This indicates highly directional reflectivity properties of the eyes.

Structure and function as well as structure and material are closely related in natural systems. Historically interested readers might also want to read Haeckel´s book "Art forms in nature"[5] and D'Arcy Thompson´s book "On Growth and Form"[6], especially chapters V on biomineralized structures and VIII on form and mechanical efficiency. Investigations on the cause of the excellent properties of natural materials lead to investigations of intrinsic material properties. Many of the structures in Nature are of amazing beauty (Figures 8 and 9). The fungus on the tree trunk as shown in Figure 8 exemplifies in a beautiful way the transition from the simple to the complex, as it occurs, e.g., in Nature, in the tree of knowledge, and in scientific endeavours[7].

Figure 8. Structures in Nature: lichen on rock.

In an ongoing research project, Ille Gebeshuber and co-workers from the University of Applied Arts, Vienna investigate architecture defined by natural patterns. Living Nature is continuously changing in a process of adaptation and thereby adjusts to a complex, changing environment; utilisation of these highly optimised solutions promise innovations that are smarter and more efficient than traditional ones. Static and dynamic natural patterns are investigated and the results shall be implemented as design strategies via a transfer process. The main goal of this research is the investigation of aesthetic and functional interpretations for a novel type of architecture.

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[5] Haeckel E. *Kunstformen der Natur.* (Art forms in nature). Leipzig and Vienna: Biobliographisches Institut (1899(.

[6] Thompson D'A. *On growth and form.* Cambridge University Press, Cambridge, England (1917).

[7] Gebeshuber I.C. and Majlis B.Y. *New ways of scientific publishing and accessing human knowledge inspired by transdisciplinary approaches.* Tribology - Surfaces, Materials and Interfaces 4(3) (2010) 143-151.

Figure 9. Structures in Nature: tree trunk, cut banana leaf and fungus growing on three trunk.

The relation between structure and function in Nature is beautifully exemplified by structural colours. There are two types of colours: chemical colours and physical colours. In chemical colours, coloured pigments are the source of the colour. The material itself determines which colour we can see. Physical colours, on the other hand, are generated by the structure of the material. The structures interact with the light, and the colours are generated via various physical phenomena such as interference or diffraction. For this to be effective, the structures have to be on the range of the wavelength of the light, which means that in the visible range, structures of several nanometers are needed. In our Lata Jarum expedition, we came across natural structural colour samples in insects, fruits and leaves (Figure 10). The reflection on the fly is very metallic and angle-dependent, and this is due to the helical pitch of the liquid crystals. Iridescent beetles, butterflies, certain sea organisms and many birds derive their unique colours from the interaction of light with physical structures on their external surfaces. Understanding how these structures give rise to the stunning colours we see in nature could benefit the quest for miniature optical devices and photonics. There are still colours in Nature where investigations have yet to carried out to determine of the colouration comes from structures or pigments (Figure 11).

Figure 10. Structural colours in insects, fruits and leaves.

Figure 11. The hairs of this leaf are soft and have different colour depending on their location: close to the attachment of the leaf, the hairs are pink; on the leaf itself, they are transparent. It still remains to be investigated if this effect stems from structural coloration.

Some butterflies have patterns on their wings that look like huge eyes, and predators mistake the small animal for a way larger animal, preventing the butterfly to be eaten. The caterpillar shown in Figure 12 takes another ‘strategy’: its two ends look like heads, and it has fake eyes and antennae.

Figure 12. This caterpillar has a chance of 50% to survive if some other animal wants to bite its head off, if the caterpillar’s rear end is mistaken for the head.

Various plants in the tropics exhibit nyctinastic movements: these are plant movements in response to the daily cycle of light and dark (Figure 13). Examples of plants that demonstrate these movements include honeylocust trees, silk trees and bean plants. The prayer plant gets its name from the fact that its leaf blades are vertical at night, resembling praying hands. During the day, however, the leaf blades are positioned horizontally. Carolus Linnaeus planted a "flower clock" made of different species of plants with nyctinastic movements. The movements of each plant species occurred at a specific time of day when the light was right for the plant (http://en.wikipedia.org/wiki/Linnaeus'_flower_clock). On the basis of extensive but indirect evidence, Darwin proposed that an important function of daily leaf movements is to minimize radiative heat loss to the night sky and thereby protect the leaves from nocturnal chilling, an interpretation which has currently fallen into disrepute[8].

Figure 13. A tropical plant exhibiting nyctinastic movement: the leaves are actively moved together in the night.

Flowers attract animals in different ways. Some flowers are brightly coloured, and smell wonderful (Figure 14, left), whereas some others, such as *Rafflesia* (Figure 14, right), smell and look like rotten flesh; both attract insects such as flies and beetles that pollinate them. We had the great chance to encounter *Rafflesia* in full bloom in Lata Jarum! *Rafflesia* is a genus of parasitic flowering plants. It was discovered in the Indonesian rain forest by an Indonesian guide working for Dr. Joseph Arnold in 1818, and named after Sir Thomas Stamford Raffles, the leader of the expedition. It contains approximately 27 species, all found in southeastern Asia, on the Malay Peninsula, Borneo, Sumatra, and the Philippines. The plant has no stems, leaves or true roots. It is an endoparasite of vines, spreading its root-like haustoria inside the tissue of the vine. The only part of the plant that can be seen outside the host vine is the five-petaled flower. In some species, such as *Rafflesia arnoldii*, the flower may be over 100 centimetres (39 in) in diameter, and weigh up to 10 kilograms (22 lb). The flowers look and smell like rotting flesh, hence its local names which translate to "corpse flower" or "meat flower". The vile smell that the flower gives off attracts insects such as flies and carrion beetles, which transport pollen from male to female flowers. Little is known about seed dispersal. However, tree shrews and other forest mammals apparently eat the fruits and disperse the seeds. Rafflesia is an official state flower of the Malaysian state Sabah.

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8 Enright J.T. *Sleep movements of leaves: In defense of Darwin's interpretation*. Oecologia 54(2) (1982) 253-259.

Figure 14. Beautiful flowers. The one on the left smells like perfume, the one on the right (Rafflesia sp.) smells and looks like rotten flesh. Both attract flies and beetles that pollinate it.

It was a wonderful trip, full of joy, lovely people (Figure 15) and new experiences! Thank you, Prof. Jumaat!

Figure 15. Some of the participants of the Lata Jarum 2009 expedition, preparing to go back to the camp after visiting Rafflesia in full bloom.

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