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Guest Editorial: Biologically Inspired Design

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Natural processes have led to the development of a plethora of biological systems that carry out a multitude of tasks in a highly resource-effective manner within a variety of environments and constraints. Many of these tasks, environments and constraints are similar to those relevant to engineering design. Therefore, biological systems offer a rich, potential source of inspiration for novel engineering designs.

There is ample anecdotal evidence of biological systems being used as inspiration for engineering. In the last few decades, research into developing biomimetic systems, which requires a detailed understanding of biological phenomena with the goal of technologies that mimic such phenomena, have been steadily increased. Notable attempts including the development of bullet-proof jackets by mimicking spider-webs, robots that mimic various forms of natural movement such as those by fishes, leeches and earthworms, and materials that mimic various properties of natural materials.

Biologically-inspired designs have traditionally been an outcome of individual interest, accidental exposure, or systematic study. However, better understanding the process of biologically inspired design and supporting this process in a systematic manner to enable more effective and efficient biologically inspired engineering design is only beginning to gain momentum as an emerging area of active research and exploration. This special issue aims to provide a state of the art collection of research outcomes in this area.

For this issue, while papers with AI content were solicited, we broadened the scope to also include papers that provided knowledge and associated methodology for biologically-inspired design. Suggested topics included, but were not limited to:

- Models, techniques, or systems, both human-centred and computational, for (supporting) biologically inspired design (including biomimetics/biomimicry/bionics);
- Models of reasoning for biologically inspired design;
- Studies of reasoning for biologically inspired design.

The special issue contains five papers.

The first paper, *Biological First Principles for Design Competence*, by Andy Dong, focuses on the biological origin of design competence. This paper interprets the concept of biologically inspired design as the understanding of design competence from biological evidence. The paper reviews biological evidence from as diverse areas as evolution, genetics, and ethology, from the perspective of design research to propose that design competence is the product of an evolutionary history during which five key competences in biological evolution developed: conception unbounded by sensory perception, symbolic manipulation at a level of secondary representation, theory of mind,curiosity, and mental time travel. Based on these five competences, the paper

concludes by discussing how computation may provide a useful way to understanding the origins and evolution of design competence.

The second paper, *On the Analogical Roots of Biologically Inspired Design*, by Swaroop S. Vattam, Michael E. Helms, and Ashok K. Goel, takes biologically inspired design as an approach to design that espouses the adaptation of functions and mechanisms in biological sciences to solve engineering design problems, and argues that while biologically inspired design is inherently analogical in nature, current understanding of its analogical basis is relatively limited. The paper presents an observational study of a series of biologically inspired design sessions, in terms of *Why, What, How,* and *When* questions of analogy, which the authors argue would contribute toward developing a content theory of creative analogies in the context of biologically inspired design.

The paper, A Methodology for Supporting 'Transfer' in Biomimetic Design, by Julian Sartori, Ujjwal Pal and Amaresh Chakrabarti, focuses on three issues: based on an analysis of various models espoused in biomimetics literature, it develops a generic model of the biomimetic design process; based on analysis of twenty actual biomimetic design cases, it identifies a generic set levels of abstraction at which biomimetic transfer takes place; and it presents a validated set of guidelines to encourage greater ideation fluency in the biomimetic design process.

The paper, *A Natural-Language Approach to Biomimetic Design*, by L.H. Shu, summarizes various aspects of identifying and applying biological analogies in engineering design using a natural-language approach. In this approach, biological knowledge in natural-language format, e.g., books, papers, etc., are searched for instances of keywords describing the engineering problem. Strategies for facilitating this search as well as how descriptions of biological phenomena are used in problem solving are summarized and demonstrated with several application case studies.

The paper, Function-Based, Biologically-Inspired Concept Generation, by Jacquelyn K. S. Nagel, Robert L. Nagel, Robert B. Stone, and Daniel A. McAdams, presents a method for functionally representing biological systems through systematic design techniques, to support conceptualization of biologically-inspired engineering designs. Functional representation and abstraction techniques are utilized to translate biological systems into an engineering context, to make biological system information accessible to engineering designers with varying biological knowledge. Two approaches to concept generation are discussed: (1) using biological models to discover corresponding engineering components to mimic the biological system; and (2) using a repository of engineering and biological information to discover which biological components inspire functional solutions to fulfil engineering requirements.

Together, the papers present a variety of perspectives. The paper by Dong focuses on the biological roots of design competence, and argues design competence as an evolutionary trait. Taking the DRM framework of Blessing and Chakrabarti (Blessing and Chakrabarti, 2009), research focused on design can be categorised into descriptive (i.e., *as is*) or prescriptive (i.e., *as should be*) studies. Taking this view, the first two papers are

specifically focused on providing a descriptive view of biologically inspired design, while the last two papers focus primarily on alternative prescriptive views of how to support ideation in biologically inspired design. The paper by Sartori et al. focuses on both: first identifying an overall biomimetic process and the levels of abstraction at which 'transfer' takes place (descriptive views), and then providing guidelines for supporting the biomimetic process (prescriptions).

Further, both the descriptive and prescriptive approaches nicely contrast or complement one another. While Vattam et al. use observational studies of designers to develop an overall biologically inspired design process, Sartori et al. develop a generalised model based on a number of biomimetic design processes from the literature. While various categories of transfer are identified by Vattam et al., various levels of abstraction of transfer are identified by Sartori et al.

Together three approaches to supporting biologically inspired design are promulgated in the papers. Sartori et al. provide guidelines for the overall biomimetic design process, in particular focusing on the step of 'transfer'. The work of Shu and that of Nagel et al. provide two contrasting approaches to identify analogous biological phenomena. While the work of Shu focuses on natural-language based approaches to search for relevant analogies in existing literature, Nagel et al. focus on structuring information extracted from literature before searching on them for analogues. Both have their merits: the former requires undertaking neither the structuring effort nor the substantial effort of populating a database based on this structure. Instead, effort is invested in identifying appropriate search strategies for locating meaningful information from a plethora of existing knowledge in the natural-language format; the latter requires investing substantial effort into pre-structuring information, as well as the entry of a meaningful quantity of information in that structure, for the downstream benefits of easier and more focused search. Both can be potentially biased, in how information is structured searched, or how search results are presented.

Several future directions of research have been suggested in the papers. Overall, we see enormous scope for new research to be carried out in this area, in terms of developing better and more detailed understanding of the processes of biologically inspired design, as well as potential alternative approaches to supporting these processes.