biology letters

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Biol. Lett. 2010 **6**, 431-433 first published online 14 April 2010
doi: 10.1098/rsbl.2010.0270

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Animal behaviour

Biol. Lett. (2010) **6**, 431–433
doi:10.1098/rsbl.2010.0270
Published online 14 April 2010

Meeting report

Social insects inspire human design

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The international conference 'Social Biomimicry: Insect Societies and Human Design', hosted by Arizona State University, USA, 18–20 February 2010, explored how the collective behaviour and nest architecture of social insects can inspire innovative and effective solutions to human design challenges. It brought together biologists, designers, engineers, computer scientists, architects and businesspeople, with the dual aims of enriching biology and advancing biomimetic design.

Keywords: biomimetics; biomimicry; nest architecture; social insects; swarm intelligence

1. INTRODUCTION

Humans have long looked to nature for practical inspiration; after observing paper wasps, Réaumur (1719) suggested that people, too, could make paper from wood fibre, without cotton or linen rags. However, the formal use of biology as a design tool, known as biomimicry or biomimetics (Benyus 1997; Vincent *et al.* 2006), is a recent and rapidly accelerating enterprise in academia (Hesselberg 2007) and industry (Bonser 2006). Biomimicry approaches the biological world as a catalogue of successful designs, honed by natural selection, that can be imitated or translated to solve human problems. The conference 'Social Biomimicry: Insect Societies and Human Design', hosted by Arizona State University, USA, 18–20 February 2010, explored how social insects can serve as models for biomimetic design, and asked what general lessons can be learned about biomimicry.

Social insects (ants, bees, wasps, termites, etc.) are uniquely qualified to inform human design. They have evolved tightly integrated societies with up to millions of members, and have solved many problems inherent to social organization (Wilson 1971). Individual social insect workers exhibit relatively simple behaviours, but collectively, colonies can perform complex functions such as routing traffic, allocating labour and resources and building nests that provide physical and social services. Unlike most human operations, social insects accomplish such feats without a supervisor or centralized control; instead, colony-level patterns self-organize, or emerge, from local interactions that elicit positive and negative feedback responses (Camazine *et al.* 2001). These interactions are often mediated by stigmergy, a form of indirect communication through modification of the environment. Self-organization and stigmergy motivate the field of swarm intelligence, which designs algorithms for the solution of optimization and distributed control problems (Bonabeau *et al.* 1999).

The realization of social-insect-inspired design, and biomimicry more broadly, requires communication and collaboration across disciplinary and professional boundaries. 'Social Biomimicry' provided a forum for exchange between biologists, designers, engineers, computer scientists, architects and businesspeople.

2. PROBLEMS AND SOLUTIONS

Presentation symposia highlighted problems shared by social insect colonies and human-engineered systems, and considered applications of social-insect-inspired design. Task allocation is central to the organization of work, from insect colonies to human factories. Jennifer Fewell (Arizona State University) explained how, in groups of insects and possibly humans, division of labour can self-organize when individuals vary in their thresholds for responding to task-specific stimuli. This simple mechanism can generate high levels of task specialization while allowing flexibility to respond to changes in demand. Related models have been applied to distributed control problems such as robot coordination (Krieger *et al.* 2000) and flow shop scheduling (Cicirello & Smith 2004). Craig Tovey (Georgia Institute of Technology) argued that biomimetic task allocation is most effective when the biology matches the design challenge at hand. For example, a honeybee colony's allocation of foragers among flower patches is an appropriate model for managing an Internet hosting centre because the two problems are analogous: both colonies and hosting centres must maximize resource (nectar or revenue) influx from multiple sources in a variable and unpredictable environment (Nakrani & Tovey 2007). In general, swarm intelligence solutions are better suited to dynamic problems than to static ones, which do not present the difficulties faced by social insect colonies.

Nest-site selection is a leading model for studies of collective decision-making by social insects, and has potential for diverse biomimetic applications. When a colony fissions or its nest is damaged, it must search for and choose among new nest sites and then migrate. Consensus is built through a distributed, voting-like process: scouts independently discover, assess the quality of and recruit nest-mates to candidate sites, and the colony only commits to the best site once a quorum has been reached (Franks *et al.* 2002). Nigel Franks (University of Bristol) compared the collective decision-making strategies of house-hunting ants (genus *Temnothorax*) with those employed by Internet search engines, and Martin Middendorf (University of Leipzig) explained how nest-site selection can inspire algorithms for organic computing systems featuring autonomous, reconfigurable helper components. Once a honeybee colony decides on a new home, the swarm lifts off and flies up to several kilometres to the chosen nest site, even though the majority of colony members do not know its location. Kevin Passino and Kevin Schultz (Ohio State University) presented research on the mechanisms underlying

Received 19 March 2010
Accepted 24 March 2010

swarm guidance and cohesion, and how they can be applied to distributed agreement problems in engineering, such as control of energy-efficient ‘smart lighting’ systems.

The nests of social insects, like human buildings, must accommodate and organize their inhabitants. Walter Tschinkel (Florida State University) speculated that nest architecture is shaped by natural selection to provide vital services including shelter, defence, organization of work, facilitation of movement and communication, ventilation, and microclimate control, but he conceded that because the study of ant nests has been mostly descriptive, biomimicry of nest function is probably premature. Ilaria Mazzoleni (Southern California Institute of Architecture) emphasized the adaptation of social insect nests to environmental conditions, and suggested that architects can apply similar principles to design buildings that are congruous with local climate and responsive to seasonal changes. The giant mounds built by African termites are monuments of insect architecture that have inspired passive cooling systems in human buildings. However, Scott Turner (State University of New York) discovered that *Macrotermes michaelseni* mounds do not regulate nest temperature in the way previously imagined; he presented a new model for how termite mounds promote gas exchange in a process analogous to the function of a lung. Turner and engineer Rupert Soar are developing termite-inspired building materials that capture turbulent winds to manage the internal climate of buildings (Turner & Soar 2008).

The coordinated behaviour of social insects can also inspire biomimetic control strategies for groups of robots, designed for jobs ranging from toxic waste clean-up to space exploration. Insect colonies are robust, scalable and function without centralized control, direct communication or *a priori* information about the environment—all desirable features in multirobot systems. Collaborators Stephen Pratt (Arizona State University), Spring Berman, and Vijay Kumar (University of Pennsylvania) described their use of group prey retrieval by the ant *Aphaenogaster cockerelli* as a model for cooperative manipulation and transport by robots. When a forager ant discovers a prey item that is too large to retrieve alone, it recruits assistance from a team of workers that lifts and carries the item back to the nest over obstacle-laden terrain. The researchers are investigating the individual actions and communication pathways that make group retrieval efficient in ants, and translating them into algorithms for controlling robot teams.

The keynote address was delivered by Eric Bonabeau (Icosystem Corporation), who uses swarm intelligence to design forecasting and optimization tools for businesses. He suggested that the general methodology of self-organization can be more instructive than specific biomimetic algorithms, and stressed two critical challenges: the ‘inverse problem’ of defining individual behaviours and interactions to shape emergence, and the exploration of a wider range of possible solutions than can be anticipated.

3. WORKING GROUPS

Working groups probed fundamental issues underlying biomimicry of social insects and other systems.

(a) *Social insects as models for biomimetic design*

Two approaches to biomimicry were distinguished. One is strict mimicry—imitating a biological model that closely corresponds to a particular design challenge. Biomimetic solutions based on deep analogies with social insects are rare, perhaps because colony-level traits, like those of organisms, are not optimized by design, but are selected in aggregate and shaped by different ecological and evolutionary constraints. An alternative and more common approach is to seek general inspiration from biological principles, without detailed similarity between model and mimic. Computer scientists and engineers have, with varying degrees of fidelity and success, applied principles of social insect organization to problems that are insufficiently solved by conventional methods. Architects also incorporate design ideas loosely inspired by biological function, rather than pursuing mimicry of form. The appropriate mode of knowledge transfer from biology to design depends on the specificity of the biomimetic solution; a popular article, lecture or documentary may be enough to inspire, whereas closer mimicry requires more formal collaboration.

Biologists and designers in the group offered different perspectives on biomimicry. Biologists cautioned that our understanding of how insect societies actually work is limited, and that more basic biology is needed before novel features can be mimicked. Designers, however, emphasized that biological hypotheses, even those not yet tested, can direct them towards solution spaces that might otherwise not be realized. Ultimately, designers seek solutions that work, regardless of whether they are inspired by or hold true to biology. Biologists, on the other hand, prefer that biomimetic solutions accurately reflect their living models, so that new insights into biology may be revealed.

(b) *Bridging biology and design*

Biomimicry calls for exchange of information and ideas between fields that may not have established channels for cross-communication. Departmental organization, grant requirements and conference themes were identified as factors that influence the initiation of collaborations. Jeanette Yen (Georgia Institute of Technology) noted that incorporating biologists, engineers and architects into the Center for Biologically Inspired Design promoted biomimicry research at Georgia Institute of Technology. Some grants are available only to co-investigators from different disciplines, thus encouraging researchers to search for collaborators outside of their field. For example, the Multidisciplinary University Research Initiative from the Office of Naval Research prompted the aforementioned collaboration between Vijay Kumar (robotics engineer) and Stephen Pratt (biologist). Finally, conferences organized around central questions that apply to multiple disciplines can connect researchers who do not ordinarily interact.

Training students to engage in biomimicry necessitates interdisciplinary programmes that bring biologists into the design studio, and bring designers into the biology classroom. In both cases, it is important to allow students time to learn the language of the unfamiliar discipline, and to ensure that students from all disciplines are involved in the entire problem-solving process. InnovationSpace, a product development programme at Arizona State University, has recently partnered with the Biomimicry Institute to further integrate biomimicry into its curriculum.

(c) *Implementing social biomimicry in human organizations*

Innovations inspired by social insects can prescribe approaches to solving complex problems that differ fundamentally from approaches that are intuitive and comfortable for humans. Therefore, human organizations may be reluctant to adopt social-insect-inspired strategies, even when such practices are more effective than those already in use. A group including social insect biologists, a corporate manager, entrepreneurs, an organizational developer and social scientists discussed the challenges of implementing social biomimicry in human organizations.

The participants agreed that human organizations, particularly businesses, should embrace good solutions inspired by social insects. However, they cautioned against focusing on biological inspiration at the time of implementation. Most people have little or no training in biology, and scientific language can be intimidating or off-putting. More importantly, the innovation should be judged on its effectiveness as a solution to a human problem, rather than being perceived as better because of its 'natural' origin.

4. PERSPECTIVES

Biomimicry can generate innovative, economical and sustainable designs that serve society; we assert that the biology-design exchange can also benefit biology. Collaborations with designers can supply perspectives, tools and technologies that aid the primary investigations of biologists (e.g. video tracking and simulation modelling in animal behaviour). Moreover, biomimicry presents an opportunity for basic, curiosity-driven biology to have broader impacts, and it may lead biologists to pursue new avenues of research that are compelling on their own and can stimulate design. The conference identified a number of open questions in social insect biology that are pertinent to design, including how task and resource allocation decisions affect colony performance; how colony structure and efficiency scale with colony size; and how spatial distributions and constraints influence social organization. Architects, computer scientists and engineers in attendance expressed an eagerness to visit biology laboratories and field sites, to help find answers.

Because discoveries of biomimetic solutions often involve an element of serendipity, future directions are difficult to predict. However, in order to realize the full potential of biomimicry, whether it is transformative or transient, young people must be trained to think and communicate at the interface between biology and design. One of the most promising aspects of the conference was its educational impact—it was proposed and organized entirely by graduate students; more than 30 students and postdocs from various disciplines presented posters and contributed to working groups; and the conference-sponsored 'Social Insect Science EXPO!' engaged local children with interactive research exhibits, perhaps inspiring future biologists and designers.

More information is available at http://sols.asu.edu/frontiers/2010. We thank all conference participants for their insights and encouragement, and Jennifer Fewell and Stephen Pratt for reviewing the manuscript. Support was provided by Frontiers in Life Sciences and the Graduate and Professional Student Association, Arizona State University, and by National Science Foundation award no. 0964277.

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