http://dx.doi.org/10.14236/ewic/HCI2018.86

Bio-Inspired Human-Computer-Interaction

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Bio-inspiration, the use of principles derived from biological system to the construction of artefacts, has been successfully applied in many areas of engineering. Here I argue that Human-Computer-Interaction can greatly benefit from applying principles found in different areas of biology. While HCI system, in general, can learn from biology, the recent trend of moving away from conventional user interfaces to a more naturalistic interaction makes bio-inspiration timely. To support the case, the paper maps four domains of HCI to areas of biological sciences and gives examples of works that applied the underlying principles.

Bio-inspired HCI, Naturalistic interface, Virtual human, Neurocomputation. Ethology

1. INTRODUCTION

The concept of bio-inspiration has been successfully applied to tackle a wide range of engineering challenges from self-cleaning materials to mine-detection robots (Badia, Bernardet, Guanella, Pyk, & Verschure, 2007). In this paper, I would like to put forward the argument that HCI has a lot to learn from biological systems.

2. METHODOLOGY

Two aspects make up the methodology of bio-inspired engineering: The specific process of building artefacts and the mapping of areas of biological sciences to domains of system construction.

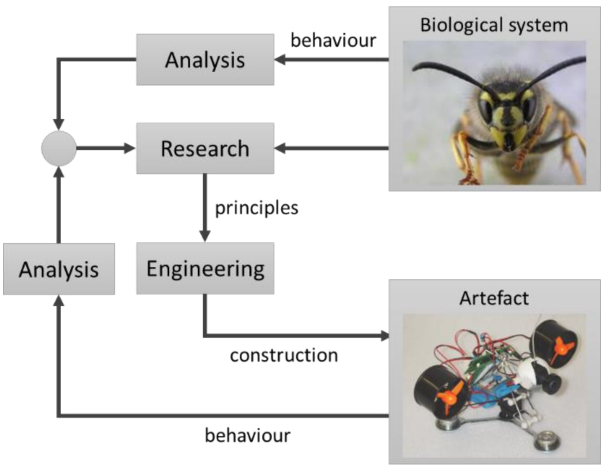

***Figure 1**: Illustration of the methodology of bio-inspired engineering.*

1.1 The process

Bio-inspired engineering begins by finding a suitable model system, i.e. a natural system that excels at the task we are interested in solving. After this initial stage, we enter a cyclic process of extracting principles form the natural system, applying them to the construction of the artefact, and comparing the behaviour of the artefact with the behaviour of the model system (Figure 1). These steps are iterated until the artefact achieves initial functional goal.

Note that a close interaction between engineering and natural sciences is one of the key aspects of the methodology of the bio-inspired engineering.

1.2 Mapping levels

Figure 2 shows how domains relevant to human-computer-interaction can be mapped to areas of biological sciences.

While bio-inspiration can be pursued independently in these four domains, the full power of the concept

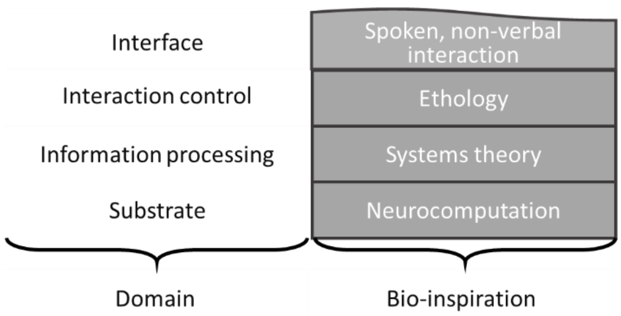

***Figure 2:** HCI domains and bio-inspiration*

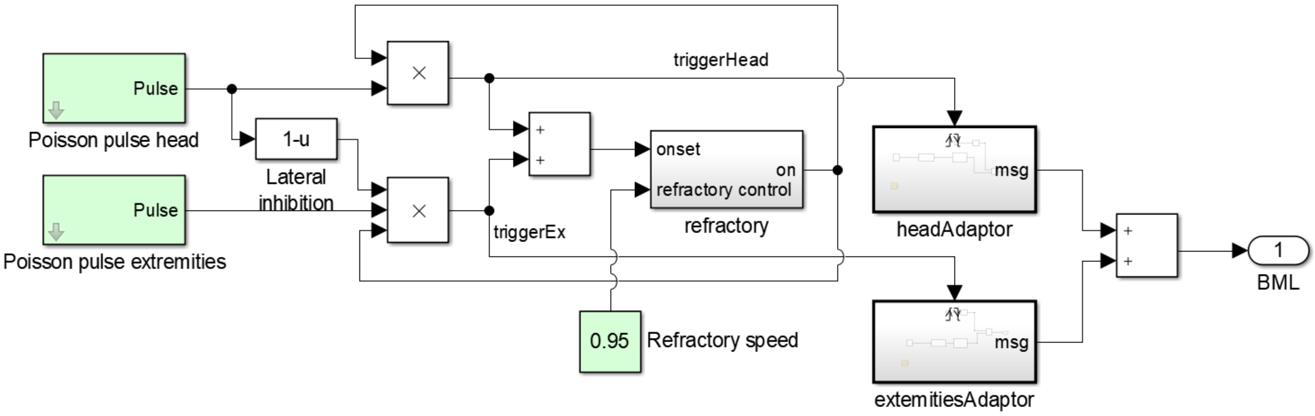

Figure 3: *Example of a systems theory-based control system for the behaviour of a virtual human* (Bernardet, Chollet, DiPaola, & Scherer, 2016)

will be achieved when all are adopted in an interlocked approach where the domains support each other. Pursued conjointly or independently, what stands at the heart of the bio-inspired approach, is the aim of understanding the underlying biological principles; if we do not understand the principles, we put ourselves at risk of producing shallow, dysfunctional copies of the biological systems. The danger of such an “unprincipled” approach is nicely illustrated by Rodney Brooks’ tale of building an aeroplane from inappropriate materials because of the lack of understanding the principles underlying flying vehicles (Brooks, 1991).

Subsequently I will outline and give examples of how the areas of biological sciences can be mapped and used specifically for the construction of HCI systems.

3. INTERFACES

Predictably, user interfaces as we know them – graphical and text-based, with keyboard, mouse, or touch-input – are losing importance; rather, interaction with computers will become more naturalistic and similar to the way we interact with animals and humans. One of the drivers of this development is the observation that interactions with animals are a uniquely rich, engaging, and gratifying (Beetz, Uvnäs-Moberg, Julius, & Kotrschal, 2012).

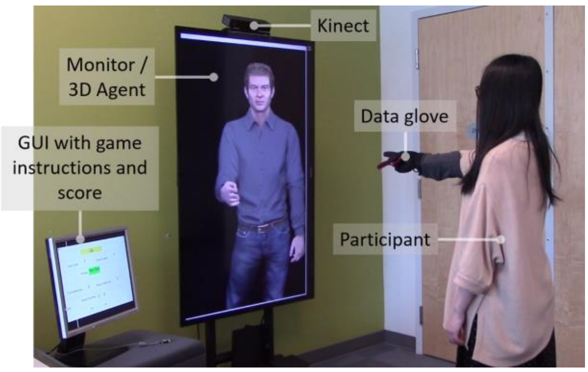

Figure 4: *A user interacting with a virtual human* (Saberi, Bernardet, & Dipaola, 2015).

While computers will receive their input from spoken language, nonverbal behaviour and other affective computing techniques (Picard, 1999), they will produce output in the form of computer-generated virtual humans and other creatures. In this interaction, non-verbal communication will be as important as symbolic, speech-based information exchange.

An example of a system where the interaction between the human and the computer is primarily based on non-verbal behaviour is our work with real-time interactive virtual humans (Saberi et al., 2015).

4. INTERACTION CONTROL

Ethology, the study of animal behaviour and its underlying mechanisms provides a wealth of mechanisms that are of interest to the construction of HCI systems. These mechanisms include self-awareness, action selection and motive management, reflexive behaviour, learning through classical and operant conditioning, and self-organisation.

I will illustrate this methodology using two of my recent works. In (Bernardet, Aleixandri, & Verschure, 2017) we investigated how non-verbal interaction controlled by a balance between predictability and probability leads to an attribution of agency to an interactive space. With the aim of building virtual humans that can convey the impression a distinct personality, we developed a non-verbal behaviour control system that is grounded in current psychological empirical finding and theory (Saberi, Bernardet, & DiPaola, 2014). The approach differs from others' in that we propose an aetiological hypothesis about personality, rather than building a system that merely replicates the phenomenon.

5. INFORMATION PROCESSING AND SUBSTRATE

Artificial neural network-based machine learning methods are undoubtedly the most prominent use of biologically inspired technology (LeCun, Bengio, & Hinton, 2015). The progress in this domain supports capabilities of vital importance to HCI such as natural-language processing (both speech-to-text as well as text-to-speech), image analysis, and behaviour classification. Impressive as the progress is, I foresee that the exploitation of a deeper understanding of biological principles, e.g. the role of brain oscillations (Fell & Axmacher, 2011), will be the key to harnessing the full power of neurocomputational systems, that potentially have super-Turing powers (Cabessa & Siegelmann, 2014).

The approach of applying neuromorphic – brain-inspired – design principles to the construction of a large-scale human-machine interaction artefact is exemplifies by the interactive space named "Ada". This inside-out robot space was developed for the Swiss national exhibition in 2002 and was experienced by more than 500,000 visitors over a period of 5 months (Eng et al., 2003).

Figure 5: *View of the "Ada the intelligent space" exhibition. The interactive inside-out robot applied brain-inspired, neuromorphic principles to the construction of a human-machine system.*

However, the information processing does not necessarily have to be using a neurocomputational approach. Following the argument that cybernetics is the universal method for the biological sciences, this approach is equally well suited to building systems that implement principles found in biological systems.

The endogenous and exogenous reflexive behaviour system for virtual humans presented in (Bernardet et al., 2016) illustrates the application of both, neurocomputational and control-theoretical principles to building interactive artefacts.

6. CONCLUSION

Interaction with computers still does now feel as effortless and natural as the interaction humans; in this paper, I argue for a bio-inspired approach to the design and development of human-computer-interaction systems that complements more traditional engineering methodologies. Importantly, the approach is based on the understanding of the principles underlying biological systems. The full potential of this approach will come into force as traditional user-interfaces are increasingly replaced by more naturalistic interaction methods.

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