Guest Editorial

Special Issue on Biologically-Inspired Information Fusion

Design, implementation and effective deployment of artificial cognitive systems is an exciting area that is rapidly developing into a multi-disciplinary subject with the potential for significant impact on science, engineering and society in general. Since we are in a very real sense trying to mimic the desirable behavior of humans and (perhaps) other animals, particularly with respect to their adaptability and robustness, there is considerable interest in understanding how knowledge of natural systems may help us to apply biological strategies to artificial systems. At the same time, drawing on a computational metaphor for perception and cognition, developing new computational and algorithmic techniques might allow us to understand natural systems better. Of particular interest to this journal are new approaches to building adaptive information fusion systems. Can knowledge of biological multisensory processing help develop robust fusion schemes? Can we use biological or behavioral models to help us understand how and why multisensory integration occurs in animals and humans?

These ideas in part are borne out of the recent movement to bring together the life and physical sciences to promote cross-dissemination of ideas so as to kick-start new avenues of research (perhaps a reaffirmation of existing approaches). An example of this movement was the UK Government's Foresight Cognitive Systems Project in 2002-2003, which attempted to set priorities in this area (summarized in [3]), focusing on four grand challenges: memories for life, localization in animals and artificial systems; the role of rhythmic activity in the brain; and neurocomputational approaches to speech and language. One simple message from these is that both neuro- and computational scientists have something to gain from working together, whether that is new tools to model biology and to test hypotheses not so easily tested in vivo, or knowledge of biological processing that can inform new computational paradigms.

In natural systems, the integration of sensory information has an effect prior to birth and remains important throughout development (see the review in [1]). Here then, through a better understanding of the structures and processes involved in this natural adaptive integration, we may be able to construct a truly artificial multisensory processing system. The hope is that psychological and physiological knowledge of multisensory processing, and particularly the low-level influence that different modalities have on one another, can be used to build upon existing theoretical work on computational mechanisms to design and implement systems that can fuse together different information sources.

In August 2006, a Workshop was held on Biologically-Inspired Information Fusion at the University of Surrey, UK, with the aim of bringing together researchers from the different disciplines interested in natural and artificial multi-sensory processing. The location was very appropriate, considering that this university was where McGurk and MacDonald first studied the remarkable effects on speech perception ('lip-reading') of setting audio and visual cues in opposition [2]. The Workshop focused on how we can improve our understanding of sensory fusion within the context of computational systems that can learn to integrate information. Here, biologists, psychologists, computer scientists and robotics engineers were brought together to see what could be gained from cross-dissemination, not only in terms of learning about current research, but also to set priorities for future work. Particular emphasis for the future was laid on:

1. Sensory fusion, disorder and clinical application: How can we develop machine aids in the form of implants or prosthetics to overcome or reduce the effects of disorders?
2. Exploiting effective biological processes for sensory integration: What biological processes can be exploited for improved performance by computer systems?
3. Developing a common language for inter-disciplinary communication and collaboration.

In this Special Issue, based on extended versions of papers presented at the Workshop, we provide examples of how work towards these priorities is already underway. By its very nature, this work is cross-disciplinary. As such, we present six articles, two based on psychology and four on computer science. Of these, we range from a state-of-the-art review of audiovisual integration for speech perception, through the application of mathematical principles to improve our understanding in psychophysics, to the description of biologically-inspired algorithms for fusion.

The Special Issue starts with "Assessing the role of attention in the audiovisual integration of speech". Here, Navarra et al. consider if an attentional process has a role in the audiovisual understanding of speech. For example, in a film dubbed into a second language, does attention help filter out the lip movements of speech in the original versus the dubbed language? If such a process does influence speech recognition, then computationally this could help us develop task-based fusion schemes, as well as give insight into multimodal speech recognition.

In "Applying capacity analyses to psychophysical evaluation of multisensory interactions", Hugenschmidt et al. present a mathematical analysis of multisensory integration data obtained from psychophysical experiments on humans. By applying capacity analyses, they attempt to compare what benefit integration can give over unisensory processing, as compared in different age groups performing a simple task. The task presented a red or blue visual (colored circle) or auditory stimulus (spoken color word), interspersed with congruent visual and auditory multisensory stimuli. This paper highlights the focus of activity in neuroscience research into multisensory stimuli—we understand that the integration of such stimuli is prevalent in natural cognitive systems, but not how it develops or changes.

The article "Information Fusion for Anomaly Detection with the Dendritic Cell Algorithm" by Greensmith et al. considers a biologically-inspired algorithm for data fusion. The authors present a development of the dendritic cell model, inspired from biological immune system processes. Working directly from biological data, an algorithm is developed for anomaly detection that fuses different data sources. As a proof-of-concept, it is applied to recognition of port scans, a key tool in initiating attacks on computer system integrity, and frequently used in 'insider attacks'.

This theme of exploiting immune system analogies to design new approaches to computer security is continued in "Information Fusion in the Immune System" by Twycross and Aickelin. The paper presents a succinct summary of some of the biological information fusion mechanisms seen in the human immune system, and describes how these mechanisms have been implemented as artificial immune systems (AISs). Twycross and Aickelin continue to describe an anomaly-based intrusion detection system able to adapt to changing patterns of normal computer usage behaviour.

In "Motion Extrapolation of Auditory-Visual Targets", Wuerger et al. undertake a psychophysical study of auditory and visual information fusion. Specifically, they investigate the extent to which the simultaneous presentation of auditory and visual signals enhances the estimation of motion speed and prediction of instantaneous position of a target by human observers. Observers' performance is found to improve significantly when input from both the visual and auditory modality is available. Results are presented in terms of variability of arrival-time judgement and the bias in this judgement. The variability observed is consistent with optimal integration of the auditory and visual speed signals, in that the bimodal variability is minimal given the unimodal variances. Bias is found to be dependent on target speed and independent of modality, suggesting it is not due to motor control.

Continuing with the emphasis on psychophysical methods, Dixon et al. employ eye-tracking measures to study the effectiveness of image fusion in "Scanpath Assessment of Multi-Sensor Video Fusion in Complex Scenarios". Here, the term "Scanpath" refers to the specific sequence of eye movements associated with viewing a certain visual representation. Noting that the integration of visible light and infrared (IR) representations occurs naturally in some animals (e.g., the rattlesnake), the authors explore different ways of fusing and presenting visible and IR information about walking human targets in cluttered environments, using the scanpath technique to quantify accuracy of detection and reaction times.

The Guest Editors hope that you find reading about this mixture of disciplines interesting and helpful. One of the challenges in bringing together different domains has been to unify some of the terminology, or at least provide explanations as required. We know there is a long way to go before life and physical scientists are in a position to work together seamlessly; language and cross-discipline training being just two of the barriers that need to be overcome. We would like to think that this Special Issue goes some way towards crossing these barriers, providing examples of how the community's priorities are already being addressed.

Let us return to the two questions we asked at the beginning. First, can knowledge of biological multisensory processing help develop robust fusion schemes? Four articles in this Special Issue give examples of how this is currently being achieved. Second, can we use biological or behavioral models to help us understand how and why multisensory integration occurs in animals and humans? More is yet to be done here, but two of the articles herein show how work in this area is progressing.

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