

Hanse



Wissenschaftskolleg

WORKSHOP SUMMARIES

5th European Neuro-IT and Neuroengineering School - Cognition & Action -

Delmenhorst, July 15 – 21, 2007

Organizers

Prof. Dr. med. Andreas K. Engel
University Medical Center Hamburg-Eppendorf

Prof. Dr. Alois Knoll
Technical University of München

Prof. Dr. Rolf Pfeifer
University Zürich

Sponsored by

EU-Network euCognition

EU-Network NEURO-iT

Hanse



Wissenschaftskolleg

Lehmkuhlenbusch 4
27753 Delmenhorst

| | |
|--|-----------|
| <u>PROBABILISTIC REPRESENTATIONS IN CORTEX</u> | 4 |
| BRUNO AVERBECK | 4 |
| <u>MECHANISMS OF DEEP BRAIN STIMULATION</u> | 6 |
| IZAHR BAR-GAD | 6 |
| <u>GESTURE AND FACIAL EXPRESSIONS FOR EMOTIONAL HUMAN-ROBOT INTERACTION</u> | 8 |
| PAOLO DARIO | 8 |
| <u>COMPANIONS, FRIENDS, TOOLS OR TOYS? – ROLES OF ROBOTS IN HUMAN SOCIETY</u> | 11 |
| KERSTIN DAUTENHAHN | 11 |
| <u>ACTION-ORIENTED VIEWS ON NEURAL PROCESSING</u> | 13 |
| ANDREAS ENGEL | 13 |
| <u>EYE MOVEMENTS AND VISUAL SEARCH</u> | 15 |
| JOHN FINDLAY | 15 |
| <u>REAL-TIME FMRI: PRINCIPLES, POSSIBILITIES AND LIMITATIONS</u> | 17 |
| RAINER GOEBEL | 17 |
| <u>LOCOMOTION CONTROL IN ANIMALS AND ROBOTS</u> | 19 |
| AUKE IJSPEERT | 19 |
| <u>COMPETING (?) THEORETICAL APPROACHES TO JOINT ACTION</u> | 21 |
| GUENTHER KNOBLICH | 21 |
| <u>UNDERSTANDING RECEPTIVE FIELDS</u> | 23 |
| PETER KÖNIG | 23 |
| <u>NORMATIVE MODELS IN NEUROSCIENCE</u> | 24 |
| KONRAD KÖRDING | 24 |

| | |
|---|-----------|
| <u>CORTICAL MOTOR PLANNING</u> | 26 |
| HANS SCHERBERGER | 26 |
| <u>BEHAVIOR AS MOTOR OUTPUT</u> | 28 |
| ANDREW SCHWARTZ | 28 |
| <u>DOES EMPATHY FOR PAIN INVOLVE A SENSORY COMPONENT OR NOT?</u> | 30 |
| TANIA SINGER | 30 |
| <u>DO ROBOTS NEED EMOTIONS?</u> | 33 |
| TOM ZIEMKE | 33 |
| <u>LIST OF REFERENCES</u> | 35 |

Probabilistic representations in cortex

Bruno Averbeck

Institute of Neurology, University College London
London, UK

Summary by: Martin Beck

The workshop started with the premise that behavior is noisy and contains uncertainty. There are two interrelated facets here: Firstly, for any given action there are many possible alternatives and decisions need to be made as to which action should be performed at that particular time; secondly the decisions on which this choice is made are also subject to uncertainty. Thus the question arises as to how uncertainty is represented in the first place, and how reasoning is performed in the light of uncertainty. Thus the core issues are that of representation and process.

In the first paper, Averbeck et al (2006) noted that goal directed behaviors are made up from a sequence of movements. The neuronal activity underlying this behavior is not only related to the movement being made, but also to the sequence which the movement is a part. To examine this, monkeys were trained on a sequential eye- movement task, where each sequence required three movements. By changing the correct sequence unpredictably the monkey was forced to adopt a trial and error approach to find the new sequence. A total of eight sequences were used. Using a Bayesian decoding analysis of activity in the prefrontal cortex, it was found that as the monkey learned the correct sequence the probability of the neural activity predicting the correct sequence increased.

In a cue selection task Cisek and Kalaska (2005) hypothesized that decision making is embedded in motor control neuron systems. Moreover this decision making capability arises even when the stimuli underlying the response choice comes from differing modalities. The authors note that systems can simultaneously represent several targets (responses) at once, and the prefrontal cortex is able to represent this uncertainty in choosing a target.

Given there is this uncertainty, then we need techniques enabling us to reason with this uncertainty, i.e. the process. Ma et al (2006) note how humans make Bayesian optimal decisions and show how the uncertainty represented in the cortex can be resolved through a Bayesian inference technique. This is achieved by developing a theoretical framework using Poisson distributions and 'probabilistic population codes' which reduce Bayesian inferences to a simple linear combination of neural activities. The authors present empirical evidence in support of this hypothesis.

Thus taken together these three papers provided insights into how behavioral uncertainty is represented in the pre-frontal cortex (Averbeck et al; Cisek and Kalaska) and how the process of reasoning is achieved (Ma et al) in the light of this uncertainty.

REFERENCES:

- 1) Averbeck BB, Sohn JW, Lee D. Activity in prefrontal cortex during dynamic selection of action sequences. *Nat Neurosci.* 2006; 9:276-82

- 2) Cisek P, Kalaska JF. Neural correlates of reaching decisions in dorsal premotor cortex: specification of multiple direction choices and final selection of action. *Neuron*. 2005;45:801-14
- 3) Ma WJ, Beck JM, Latham PE, Pouget A. Bayesian inference with probabilistic population codes. *Nat Neurosci*. 2006;9:1432-8

Mechanisms of deep brain stimulation

Izahr Bar-Gad

Gonda Brain Research Center, Bar-Ilan University,
Ramat-Gan, Israel

Summary by: Andrew Sharott

The general theme of this workshop was the mechanism by which deep brain stimulation (DBS) of the subthalamic nucleus (STN) produces therapeutic effects in Parkinson's disease. The paper by Hashimoto et al. challenges the previously held hypothesis that DBS leads to inhibition of STN neurons leading to a "virtual lesion" of that structure. This hypothesis held much weight, given that a true lesion of the STN has similar effects to DBS. This study, however, clearly demonstrates that STN neurons are not inhibited but excited by DBS and that this modulation of STN firing breaks down the abnormal firing patterns of their targets in the GP, which are thought to underlie the motor symptoms of the disease. The review by Garcia et al. considers this study, along with many others, with the aim to further characterise the effects of DBS on STN neurons and the subsequent effect on basal ganglia physiology and the relief of Parkinsonian symptoms. The authors consider the evidence for two general mechanisms of DBS action, which they label the "less" mechanism and the "more" mechanism. Evidence for the less mechanism, the silencing of STN neurons to cut out pathological activity, comes mainly from *in vitro* studies, that do not include the whole network, and studies using short trains of stimulation that do not accurately mimic therapeutic conditions. More recent studies, including that of Hashimoto et al, support the more mechanism suggesting that DBS replaces pathological, antikinetic rhythms in the STN and the basal ganglia with a different high frequency rhythm that is prokinetic. The final paper by Meissner et al provides further evidence for this hypothesis by showing that the main effect of DBS on STN neurons is a decrease in oscillatory activity and that decreases in firing rate result from the resetting of firing probability of STN neurons to virtually zero by the stimulus pulse.

The following discussion began by considering these various lines of evidence as to the mechanism of STN DBS. The consensus of the group was that the DBS was, as suggested by Garcia et al., likely to impose a new rhythm on the basal ganglia network, breaking up and replacing the oscillations that have been proposed to underlie Parkinson's disease. The group then considered the general premise that oscillations lead to parkinsonism and if so what is the dominant frequency of these oscillations. There are studies suggesting that beta frequency (around 25Hz) oscillations in the local field potentials (LFPs) are correlated with akinesia, a cardinal symptom of the disease. Dr Bar-Gad was of the opinion that oscillations around the alpha range may be a more likely substrate for the disease, given that they are more common than beta oscillations in the MPTP-primate model of Parkinson's disease. In addition, Dr Bar-Gad pointed out that some studies in humans that report beta oscillations in single neurons, actually report frequencies as low as 12Hz, which are closer to those seen in the primate model. The group considered the possible reasons that these differences might occur including species difference, the size and extent of the dopamine lesion and differences in methodology. The conclusion was that low frequency (below gamma) oscillations are an important part of the disease pathology and that the frequency may not be the most important factor. However,

oscillations may not be the only factor in the disease pathology and other mechanisms such as rate coding and plasticity may also have a role.

REFERENCES:

- 1) Hashimoto T, Elder CM, Okun MS, Patrick SK, Vitek JL. Stimulation of the subthalamic nucleus changes the firing pattern of pallidal neurons. *J Neurosci.* 2003;23:1916-23
- 2) Garcia L, D'Alessandro G, Bioulac B, Hammond C. High-frequency stimulation in Parkinson's disease: more or less? *Trends Neurosci.* 2005;28:209-16
- 3) Meissner W, Leblois A, Hansel D, Bioulac B, Gross CE, Benazzouz A, Boraud T. Subthalamic high frequency stimulation resets subthalamic firing and reduces abnormal oscillations. *Brain.* 2005;128:2372-82

Gesture and facial expressions for emotional human-robot interaction

Paolo Dario

Scuola Superiore Sant'Anna,
Pisa, Italy

Summary by: Simona Bufalari

Robots are expected to become an ubiquitous presence in most human environments (in health, education, entertainment, home and work environments). Besides technical performance and capabilities (an obvious prerequisite), robots should be provided with human-oriented interaction skills and capabilities to work with us, as well as communicate with and understand us. This introduced the need to formulate proper paradigms of interaction between people and robots; at the moment for the robotic engineer one of the main goals in the design and development of robots is that to improve the human-robot interaction: the ability of a robot to express and understand emotions and gestures improves the communication between humans and robots in applications like education or home and personal assistance of elderly and/or disabled persons. Moreover, from a scientific point of view, the modeling of emotions in autonomous robots can play an important role in improving the knowledge of the generation of emotions and in understanding the neurological and psychiatric disorders in human beings related to impairments in socialization and emotions perception (autism, schizophrenia etc.). The first indication for the design of "emotional" robots comes from the knowledge on how the human brain generates, express and perceives emotions. The discovery of the mirror neuron system (G. Rizzolatti and L. Craighero, 2004) and its role in communication between humans are fundamental for the recognition of emotions, while the research on emotional body language explains how emotions are generated and expressed and how whole-body signals are automatically perceived and understood (De Gelder, 2006). Reproducing human-like emotions is an important goal in order to develop robots able to communicate in a natural way with humans. For this reason many robotic laboratories worldwide are working on the development of "emotional" robots. In this context Roccella presented the design and development of a five-fingered hand for a humanoid expression robot (Roccella et al., 2007).

Beatrice De Gelder, Professor at Tilburg University, reviews how whole-body signals are automatically perceived and understood, and their role in emotional communication and decision-making (De Gelder, 2006). In her paper she suggests a model based on two dynamically integrated systems of emotional body language (EBL). According to it, EBL manifestations are based on reflexes, which are automatically evoked by emotional signals, and on deliberate emotional actions that are underwritten by a cortically- controlled system of reflection and decision making. In this model there are similarities with models based on two separate, relatively independent systems of cortically and sub-cortically based face processing, but there are also significant differences. Future research will need to investigate this. For example the sight of a fearful body is a more direct cue to act than the sight of a fearful face. Another important difference is that EBL might not have the same one-to-one relationship with specific emotions that has been assumed for basic facial

expressions since the work of Ekman in the 1970s. In contrast to an isolated facial expression, EBL provides the emotion as well as the associated action, thus it is a less ambiguous signal and a more direct call for attention and action in the observer. The distinction of a reflex-like and a deliberate emotion- action system will also allow to integrate more complex types of EBL, like that occurs in sophisticated social interactions.

In their review Rizzolatti and Craighero (2004) present data on a neurophysiological mechanism - the mirror-neuron mechanism - that appears to play a fundamental role in both action understanding and imitation. A category of stimuli of great importance for primates, humans in particular, is that formed by actions done by other individuals. If we want to survive, we must understand the actions of others. Furthermore, without action understanding, social organization is impossible. In the case of humans, there is another faculty that depends on the observation of others' actions: imitation learning. Unlike most species, we are able to learn by imitation, and this faculty is at the basis of human culture. A series of experiments demonstrate that during the event observation-to-imitate there was activation of a cortical network that coincided with that which is active during observation-without-instruction-to-imitate and during observation in order not to imitate. Mirror neurons represent the neural basis of a mechanism that creates a direct link between the sender of a message and its receiver. Thanks to this mechanism, actions done by other individuals become messages that are understood by an observer without any cognitive mediation.

Roccella et al. present the design and development of two five-fingered robotic hands for a humanoid upper body able to generate and express emotions (Roccella et al., 2007). The knowledge of the mechanisms of emotional communication and its neural basis is fundamental to the aim to design and develop an "emotional robot". The specific design goals in this study were to develop a mechanically simple, light hand, with a lower number of basic functionalities but sufficient for the robot to achieve grasping abilities and expression of emotions through hand gestures, as a complement to facial expression of emotions. The paper presents the design process of the robotic hands, named RCH-1 (Robocasa Hand No. 1). The human gesture and grasping capabilities have been studied and they have been considered as the starting point of the design process of the new hand. The kinematics and the dynamics of the resulting robot hands are very close to the human ones and they improve the expressiveness and the grasping capabilities of the robot. Experimental tests with the new hands confirmed the capability of the new hand to grasp different objects with different grasping strategies, as well as the capability to perform different gestures with the position of the fingers. The new Emotion Expression Humanoid Robot, named WE-4RII (Waseda Eye No.4 Refined II), has been evaluated through experiments with human subjects, who were given questionnaires. The experimental results showed that an anthropomorphic hand plays an important role in improving the grasping capability of the robot and its emotional expressiveness, and thus its capabilities for human-robot interaction. Developing a truly human-like artificial hand is probably one of the most widely known challenges for robotics technology.

The start point of the discussion in the group was the interdisciplinarity of the neuro-robotic area: it involves neuroscientists, psychologists, physiologists, as well as physicians and engineers. The approach in developing robots is that to consider robots as part of human environments: robots have to live with us and our parents, so we first have to ask if we really would like a robot as a caregiver for us and our

parents (for ex. for aged people) and how we would like such robots to be. In this context we explored the main points of the new field of emotional body language: the link between facial and bodily expression of emotions, the link between emotions and movement and action and the structure of the system that sustains the perception and the recognition of emotions. The most discussed point was the difference between human and animal perception of bodily expressions: animals are just instinctive while in humans the recognition of bodily emotions comes from the interaction of two systems: a reflex-like system and a conscious system that is responsible for the elaboration of information. Actually neuroscientists are more interested in human emotions and behavior rather than in human basic functions. In this context the discovery of mirror neurons was a fundamental and disruptive one: the mirror neuron system is the essence of social behavior because of its role in learning by looking. An example of an "emotional robot" is that developed by Prof. Dario and his colleague, in collaboration with a Japan institute, named RCH-1. This robot expresses emotions not only by his face but also by means of his hands: the robotic hands are able to grasp and to reproduce a variety of human-like gestures; the capability to combine facial expression with hand gestures enrich the emotional content conveyed by the robot. The discussion focused on the differences between facial and bodily expression of emotions: the six basic facial expressions of emotions (anger, surprise, happiness, sadness, disgust, fear) are universally recognized while bodily expressions of emotions are culture-related. According to the discussed questions, the main conclusion was that the insight into neurology could yield the solution to create an intelligent robotic system.

REFERENCES:

- 1) de Gelder B. Towards the neurobiology of emotional body language. *Nat Rev Neurosci.* 2006; 7:242-9
- 2) Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci.* 2004; 27:169-92
- 3) Roccella S , Carrozza MC, Cappiello G, Cabibihan J, Laschi C, Dario P. Design and development of five-fingered hands for a humanoid expression robot. *International Journal of Humanoid Robotics* 2007; 4:181–206

Companions, Friends, Tools or Toys? – Roles of Robots in Human Society

Kerstin Dautenhahn

School of Computer Science, University of Hertfordshire
Hatfield, UK

Summary by: Oscar Javier Avella González

For the Artificial Intelligence (AI) framework, the understanding of the Human-Robot Interaction (HRI) plays a transcendental roll. The development of novel types of machines with autonomous behavior, able to make decisions, interact between them and with us making our lives easier and comfortable despite their presence, demands the necessity to design rules and define the context and the limits for this interaction.

To achieve this goal, Dr. Dautenhahn and colleges developed pioneering experiments in which they involved both, the presence of humans and robots, in usual spaces shared just among people, but also conditioning the behavior of these robots to assume certain attitudes which could be considered as friendly, indifferent or completely unfriendly. Some remarkable results of those works, related to the the acceptance or the refusal of these machines, reflects the fact that people see the robot not as an ordinary machine, such as a computer or a radio, but as another interacting autonomous “subject” which, in order to not interfere with their routine, must follow certain “behavioral rules”. Those rules involve aspects like the minimal distance at which the robot must stay from the person, the type of service the robot should show, etc.

Within the same context but from a therapeutic point of view, “Social Intelligent Agents” technology have used robots as an important mean for the treatment of autistic children in games that involve the expression of social skills, that they are unable to exhibit in front of other normal people but extraordinarily they show in the work with robots, project Aurora focuses on the use of robots in a technology assistive framework.

The workshop-discussion sustained after the presentation of the reference papers (Dautenhahn 2003, 2007; Kahn, et al., 2006), drove us to consider the social function of these new technologies and the biological limitations imposed for the nature over our binary electronic technology. Nevertheless, part of the emphasis on our discussion focused on remarking the implications of the level of development reached by these technologies in the last decade, until being able to reproduce human characteristics such as our physiognomy (facial expression). Could this kind of characteristics say something about the humanity of the machine? If normally humans try to anthropomorphize inanimate things, what would we expect from our reaction in front of robots that look like us?

How can we decide if these devices must be treated as machines or humans, if they exhibit natural attitudes which – until now - have just been corresponding to human beings? What kind of duties must those androids perform? Could those humanoids be a new race of human? of slaves?

The answer to these “science fiction” questions will be given by the time but the thinking of some of the participants is that the ability to reproduce biological patterns of behavior requires more than the ones and zeros of our electronic

technology and for that reason robots, although considered as enormous results of our knowledge as civilization and interacting subjects, will never acquire an individual humanity. The controversy is open.

The work of professor Dautenhahn and colleges is inscribed in a very novel framework, ready to be explored, and for that reason, sets of experiments like these allow us to obtain qualitative rather than quantitative results. Nevertheless, an important and transcendental conclusion from this kind of works is that the use of robots as assistive therapeutic instruments with autistic children, and other types of behavioral diseases in the future, are per se more than a goal and becomes a stimulus to continue researching in the HRI field.

REFERENCES:

- 1) Dautenhahn K. Roles and Functions of Robots in Human Society - Implications from Research in Autism Therapy. *Robotica* 2003; 21:443-452
- 2) Dautenhahn K. Socially intelligent robots: dimensions of human - robot interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2007; 362:679-704
- 3) Kahn PH, Friedman B, Perez-Granados DR, Freier NG. Robotic pets in the lives of preschool children. *Interaction Studies* 2006;7:405–436
- 4) MacDorman K, Ishiguro H. The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies* 2006;7:297–337

Action-oriented views on neural processing

Andreas Engel

Department of Neurophysiology, University Medical Center Hamburg-Eppendorf
Hamburg, Germany

Summary by: Andrew Sharott

The focus of the workshop by Andreas Engel was the role of oscillations in information coding and the disruption of this process in neurological diseases. To this end, the group was given a presentation on the review paper by Engel and colleagues considering the putative role of oscillations in top down processing by the cerebral cortex. The paper discusses the weaknesses of the traditional bottom up approaches to understanding sensory perception, whereby external stimuli lead to an internal representation. More recently, it has been proposed that much of perception consists of expectations based on previous experience, which constantly influence the processing of incoming information. At the neuronal level, there is much evidence to suggest that this process is at least in part mediated by the dynamic formation of coherent assemblies of cortical neurons which are bound by the intrinsic oscillatory properties of forebrain networks. In particular, coherent gamma oscillations within and between cortical areas are highly correlated with the attentional (top down) aspects of many tasks involving sensory perception.

Prof. Engel was keen to emphasize that these processes are also prominent in the motor system. Several neurological movement disorders, including Parkinson's disease and dystonia are accompanied by dramatic increases in oscillations and correlation between neurons at specific frequencies in the cortex and basal ganglia. These findings raise several interesting questions. Firstly, why do these changes lead to disease processes? Secondly, how do oscillations at different processes lead to different types of motor disorder? Finally, are these oscillations related to those naturally present in the healthy motor system? These issues were discussed by the group with particular attention paid to Parkinson's disease (PD). In relation to the first issue, it is clear that the loss of the dopaminergic cells of the substantia nigra must dramatically alter the dynamics of the entire network, biasing towards correlated activity. It therefore seems likely that dopamine has some role over the control of these processes in the healthy brain. The answers to the second and third issues are likely to be related. For example, under normal movement conditions activity in the beta band (around 25Hz) in cortex and muscle is strongly associated with sustained muscle contractions, which are a crucial part of functional movement. If a disease process, such as the loss of dopamine, leads to too much beta activity, as is hypothesized in PD, the result would be the loss of dynamic motor control.

The remaining discussion focused on whether oscillations and in particular coherent oscillations between different parts of neuronal circuits could provide a common coding scheme for higher brain functions. This has been suggested by the theoretical and experimental work of Pascal Fries, who suggests that gamma oscillations provide optimal time windows in which coding can take place. More specifically he postulates that two areas which are synchronized at close to zero phase will communicate more effectively than areas that are not closely synchronized and that this mechanism can be utilized in top down processing. The group discussed how this process might also be utilized by the motor system and deranged

in neurological and psychiatric diseases. The issue of the role of different frequencies was also discussed at length. It was concluded that this could differ at least partly between the sensory and motor systems given the possible relevance on the frequency of output to the peripheral motor system, which is not an issue in the sensory cortices.

REFERENCES

- 1) Engel AK, Fries P, Singer W. Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Reviews Neuroscience* 2001; 2:704-716
 - 2) Fries P. A mechanism for cognitive dynamics: neuronal communication through neuronal coherence. *Trends Cogn Sci.* 2005;9:474-80
 - 3) Uhlhaas PJ, Singer W. Neural synchrony in brain disorders: relevance for cognitive dysfunctions and pathophysiology. *Neuron.* 2006;52:155-68
- More articles to be found at <http://www.40hz.net/Downloads.html>

Eye movements and visual search

John Findlay

Department of Psychology, University of Durham
Durham, UK

Summary by: Jörg Hipp

In this workshop we discussed 3 papers addressing the topic of saccade planning. The papers of Caspi et al. (2004) and Godijn and Theeuwes (2002) investigate the nature of saccade planning by means of physiologically and psychophysically methods. The paper by Najemnik and Geisler makes an attempt to explain eye movement trajectories as an optimal search in the Bayesian sense.

In the study by Godijn and Theeuwes (2002) participants were required to make a saccade to a uniquely colored target while ignoring the presentation of an onset distractor. The results provide evidence for a competitive integration model of saccade programming that assumes that endogenous and exogenous saccades are programmed in a common saccade map. The model incorporates a lateral interaction structure in which saccade-related activation at a specific location spreads to neighboring locations but inhibits distant locations. In addition, there is top-down, location-specific inhibition of locations to which the saccade should not go. The authors show that the time course of exogenous and endogenous activation in the saccade map can explain a variety of eye movement data, including endpoints, latencies, and trajectories of saccades and the so-called “global effect”.

Caspi et al. (2004) study the time course of visual information guiding accrual eye movement decisions. Saccadic eye movements are the result of neural decisions about where to move the eyes. These decisions are based on visual information accumulated before the saccade; however, during an approximately 100ms interval immediately before the initiation of an eye movement, new visual information cannot influence the decision. The authors address whether the brain simply ignores information presented during this brief interval or if the information is used for the subsequent saccade. To do so they introduce a new technique, saccade-contingent reverse correlation, that measures the time course of visual information accrual driving the first and second saccades. In the task observers searched for a contrast-defined target among distractors. Independent contrast noise was added to the target and distractors every 25 ms. Only noise presented in the time interval in which the brain accumulates information will influence the saccadic decisions. Therefore, the authors can retrieve the time course of saccadic information accrual by averaging the time course of the noise, aligned to saccade initiation, across all trials with saccades to distractors. The results show that before the first saccade, visual information is being accumulated simultaneously for the first and second saccades. Furthermore, information presented immediately before the first saccade is not used in making the first saccadic decision but instead is stored and used by the neural processes driving the second saccade.

Najemnik and Geisler (2005) study optimal eye movement strategies in visual search. To perform visual search, humans, like many mammals, encode a large field of view with retinas having variable spatial resolution, and then use high-speed eye movements to direct the highest resolution region, the fovea, towards potential target locations. Good search performance is essential for survival, and hence mammals

may have evolved efficient strategies for selecting fixation locations. In this paper the authors address two questions: what are the optimal eye movement strategies for a foveated visual system faced with the problem of finding a target in a cluttered environment, and do humans employ optimal eye movement strategies during a search? The authors derive the ideal bayesian observer for search tasks in which a target is embedded at an unknown location within a random background that has the spectral characteristics of natural scenes. Their ideal searcher uses precise knowledge about the statistics of the scenes in which the target is embedded, and about its own visual system, to make eye movements that gain the most information about the target location. The authors find that humans achieve nearly optimal search performance, even though humans integrate information poorly across fixations. Analysis of the ideal searcher reveals that there is little benefit from perfect integration across fixations - much more important is efficient processing of information on each fixation.

REFERENCES:

- 1) Godijn R and Theeuwes J. Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology. Human Perception and Performance* 2002;28:1039-1054
- 2) Caspi A, Beutter BR, Eckstein M. The time course of visual information accrual guiding eye movement decisions. *PNAS* 2004; 101:13086-13090
- 3) Najemnik J and Geissler WS. Optimal eye movement strategies in visual search. *Nature* 2005; 434:387-391

Real-time fMRI: Principles, possibilities and limitations

Rainer Goebel

University of Maastricht
Maastricht, Netherlands

Summary by: Motoaki Kawanabe

Typically functional Magnetic Resonance Imaging (fMRI) data are analyzed by multiple statistical procedures after experiments are finished. In the last decade, efficient software implementation and increasing computational power enabled us to develop real-time fMRI (rt-fMRI) systems. This workshop aimed at learning algorithmic principles of rt-fMRI and discussing about its possible applications and limitation by current technologies.

At the beginning, the following three papers were summarized briefly. Cox et al.(1995) presents the first rt-fMRI system with recursive calculation of partial correlation coefficients. Weiskopf et al.(2007) gives a good overview of applications of rt-fMRI. These applications can be categorized into four major fields. (1) online quality assurance of data, (2) functional localization (adaptive experimental designs), (3) interactive training on fMRI and (4) BCI and neurofeedback. deCharms et al.(2005) presents one of the most successful applications of neurofeedback by rt-fMRI. They show that feedback training to control the activity of the anterior cingulate cortex (ACC) helps to reduce chronic pain. Prof. Goebel remarked that the modulation of ACC activity requires mental concentration of the subject. However after some neurofeedback training the subjects can learn to utilize such pain control technique outside of an fMRI scanner. A participant suggested that meditation or empathy might be helpful in pain control, which is an interesting future direction.

During the workshop, many questions were asked by the participants including experts on fMRI and neurofeedback. I picked up the following three points among all interesting questions/answers.

The rt-fMRI was compared with state of the art neurofeedback with EEG (and ECoG). One disadvantage of rt-fMRI is time delay (about 5 seconds) between command execution and feedback. Therefore, for example, pure operand conditioning is impossible with rt-fMRI, since the link between cause and behavior becomes rather vague. Professor Goebel mentioned various technological frontiers to improve temporal resolution, e.g. exploiting the "initial dip" in the fMRI signal, DTI (axonal activities) and MREG with local coils. On the other hand, fMRI can extract richer structures of brain activities than EEG, because it has much finer spatial resolution and can also measure deeper brain regions. One participant pointed out the potential application of rt-fMRI in lock-in patients, since it can mine activities which are ignored by EEG.

High field fMRI devices will probably replace currently widely used 3T fMRI scanners because they will drastically improve the spatial resolution of the signals. Presently 9.4T fMRI is under development and will be available in near future. For high field fMRI, safety issues are much more important, because small movements of subjects' body/head can induce a large electric current in such high magnetic field. It was mentioned that this possible danger might lead to a restriction on high field fMRI in Europe in the near future. This may have a large negative impact on brain research in this region.

Recently, higher-order brain functions such as empathy and decision making have been investigated by fMRI. Rt-fMRI may open a way to analyze social interactions which are very complicated and highly non-stationary processes. Professor Goebel mentioned his forthcoming project on this topic. He intends to study how mutual trust is cultivated in trust games and how apes/children build relationships with strangers.

To sum up, I think that (rt-)fMRI is hard to beat for clinical applications, even though there are some limitations, in particular the low temporal resolution. Good news is that the current technical state of fMRI is not the end of the story, but that it has much more potential. Many ideas on new MRI hardware and techniques are under development, e.g. MREG with local coils, molecular MRI by using special molecular tags to be traced and mobile MRI. Sophisticated software/machine learning technology will be necessary to handle the bad signal to noise ratio of high field MRI which can become a powerful tool for future development of neuroscience.

REFERENCES

- 1) Cox R, Jesmanowicz A, Hyde JS. Real-time functional magnetic resonance imaging. *Magnetic Resonance in Medicine* 1995;33:230-236
- 2) Weiskopf N, Sitaram R, Josephs O, Veit R, Scharnowski F, Goebel R., et al. Real-time functional magnetic resonance imaging: methods and applications. *Magnetic Resonance Imaging* 2007;25:989-1003
- 3) deCharms C, Maeda F, Glover GH, Ludlow D, Pauly JM, Soneji D, et al. Control over brain activation and pain learned by using real-time functional MRI. *PNAS* 2005;102:18626-18631

Locomotion control in animals and robots

Auke Ijspeert

School of Computer and Communication Sciences, EPFL
Lausanne, Switzerland

Summary by: Petko Kiriazov

The investigation of animal or insect behavior is not only interesting with respect to specific solutions to specific problems, but, on a more general level, it is important to understand how an autonomous system should be designed and constructed.

In vertebrates, the generation of rhythmic activity in hind limb muscles does not require sensory input but is generated by central pattern generator networks (CPGs). CPGs offer an interesting approach to solving the problem of online trajectory generation by using the limit cycle behavior of coupled oscillators to produce the motor commands in real time.

A spinal cord model implemented in amphibious salamander robot is presented in [1]. It demonstrates how a primitive neural circuit for swimming can be extended by phylogenetically more recent limb oscillatory centers. The model explains the ability of salamanders to switch between swimming and walking and predicts that limb oscillatory centers have lower intrinsic frequencies than body oscillatory centers. Moreover, it suggests neural mechanisms for modulation of velocity, direction, and type of gait that are relevant for all tetrapods.

In the next paper, Walknet - a useful scientific tool to study insect walking - is presented [2]. This simulation model can describe the control of step rhythms of individual legs, coordination between legs as well as the control of swing and stance movement. It is found that central commands are only necessary to determine the beginning and end of walking as well as its speed and direction. Moreover, it is proved that turning does not require explicit calculation of leg trajectories using, for example, the desired curve radius and the geometrical parameters of the legs; simple proportional commands to the legs are sufficient. The Walknet as well as the salamander model [1] are both based on behavioral and neurophysiological studies of the respective biological systems.

In the final paper [3], three well-studied examples of simple circuits are considered: pacemaker type; locomotor burst activity; and respiratory core activity. The following points are discussed: complex patterns of activity for coordinating unit CPGs; visuomotor coordination of cortical and spinal processing; and the point whether the commands from the motor cortex are gated at the spinal level.

One important conclusion from the workshop is that the CPG-based control allows to reduce the dimensionality of the locomotion control problem while remaining highly flexible to continuously adjust velocity, direction, and type of gait according to the environmental context. Biologically inspired sensory feedback can be used to achieve such adaptivity. A major challenge for the future is to understand how motor behaviors are generated at the molecular, cellular, and synaptic level—that is, an understanding at the microcircuit level—the interface between neurons and global brain functions. Two approaches will prove essential, [3]. One will combine developmental, molecular, genetic, and neurophysiological approaches. The other will rely on comparisons between animals of different complexity—from lamprey and zebrafish to amphibians and mammals—to obtain crucial comparative insights.

REFERENCES

- 1) Ijspeert A, Crespi A, Ryczko D, Cabelguen, JM. From swimming to walking with a salamander robot driven by a spinal cord model. *Science* 2007;315:1416-1420
- 2) Cruse H, Kindermann T, Schumm M, Dean J, Schmitz J. Walknet - a biologically inspired network to control six-legged walking. *Neural Networks* 1998; 11:1435-1446
- 3) Grillner S. Biological pattern generation: the cellular and computational logic of networks in motion. *Neuron* 2006;52:751-766

Competing (?) theoretical approaches to joint action

Guenther Knoblich

Rutgers University,
Newark, USA

Summary by: Heinrich Johann Schneider

“No man is an island, entire of it selfe,”² wrote John Donne, in the 17th century, regarding such lofty notions as religion and mortality. Now, in the early 21st, the idea, that, such much crasser things as, action and cognition also may not be entire of [hu]man’s selfe, but probably owe much to interaction with others, has led to various interesting works in psychology and neuroscience. This joint action cognition research can be divided into three schools of thought. First there is the 'ecological', which looks at joint action as a property of an organism and its environment. Then the 'embodied' approach, which emphasises situated cognition and representation sharing. Lastly the 'dialogue' school uses a more linguistic approach wherein joint action is coordinated using intentional language use.

The social features of joint action have been explored in several ways. The 'individual-level' approach focusses on the interaction between an actor and a target. It assumes the actor's attempt to uncover from a target any information relevant for interaction and that this will result in an actor adjusting his actions based on the received information. The 'cognitive dynamics' approach, on the other hand, emphasises the investigation of the effect that a target has on the dynamic internal psychological state of an actor and how this influences interaction. Marsh et al. propose a third, 'social synergy', approach. This ecological approach is based on the interaction between an actor and its environment; a niche. It assumes that any interaction creates, from its actors, a collective. This collective itself can be understood as a new actor within its own environment. The resulting social niche then offers a new level of understanding of social aspects of perception, action and knowledge.⁴

The embodiment school of joint action research assumes that, as any part of cognition, joint action, can only be understood in the framework of being situated in an actor's body and environment. One version of this embodied approach is known as the 'common coding' theory of perception and action. This is related to the work done on mirror-neurons and has a precursor in the ideomotor principle. In its most basic form it states that action and perception share a common representation in the mind that allows for predictions based on mutual prior knowledge. I.e.: “any perceptual event that can potentially result from one's own actions leads to a resonance with the action system”³. As such the repertoire of one’s actions can help predict the results of perceived other actions. In a social context this action representation becomes the core of joint action. Joint attention and sharing perceptual input leads to shared action representations and thus a common conception of the expected outcome. Ultimately this embodied common coding allows one to predict the results of a joint action.^{3,5}

Joint activities, according to Bangertter and Clark, usually, consist of hierarchical projects. This hierarchy requires a means of navigation; language. Any transition within or between projects of this hierarchy is accompanied by a

coordinating dialogue. Such dialogue consists of simple phrases, such as: “uh-huh”, “yeah”, or “okay”. Traditionally these are seen as simple feedback signals or turn-taking devices. These phrases, however, which are rather useless outside of joint action, likely also serve another purpose. Namely to signal whether co-actors are continuing within a project or moving up or down the hierarchy.¹

When reviewing these three approaches to joint action several things may be noticed. Firstly, there is the role that is assigned to the ‘other’ in each of the approaches. The ecological approach is group-centred. In a way, it dissolves and merges the actor and the other into a greater organism that occupies a social niche. It is this niche, that determines the properties of the group’s (and therefore the actor’s and the other’s joint) perception and action. This contrasts with the theories of embodiment. These maintain separate actors, but propose that each internalises the perception and action repertoire of the other. Thus they are able to predict each other’s actions and come to a coordinated joint action. Then, when focusing on dialogue as the coordinating mechanism of joint action, the other becomes almost irrelevant. Save for the provided verbal input, the various actors factor very little in each other’s cognitive strategies.

Finally, it may be asked whether these approaches cover the same or even similar factors of joint action. Perhaps each proposes a different model for joint action, because they deal with different levels of interaction. The level at which people talk to each other to coordinate their actions in, for instance, moving a heavy object together, is arguably a whole other than that at which they automatically and unconsciously control their motor and muscle output to adjust to each other while actually moving that object. Also, it is quite likely that even within an ecological context; within a group, individuals still could benefit greatly from, based on individual and shared perception, being able to interpret, predict and adjust to each other’s actions. Then the question no longer is, which of these approaches is *the* approach to study joint action. Instead, now, the points of interest are where these models overlap and in which way the accompanying levels of joint action interact.

REFERENCES:

- 1) Bangerter A, Clark HH. Navigating joint projects with dialogue. *Cognitive Science*. 2003; 27:95-225
- 2) Donne J. Meditation XVII, Devotions Upon Emergent Occasions. 1624
- 3) Knoblich, G. Bodily and motor contributions to action perception. In R. Klatzky et al. (Eds): *Embodiment, Ego-space, and Action*. Proceedings of the 34th Carnegie Symposium on Cognition. LEA. (in press)
- 4) Marsh KL, Richardson MJ, Baron RM. Contrasting approaches to perceiving and acting with others. *Ecological Psychology*. 2006; 18:1-38
- 5) Sebanz N, Bekkering H, Knoblich G. Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences*. 2006;10:70-76

Understanding receptive fields

Peter König

Institute for Cognitive Science, University of Osnabrück,
Osnabrück, Germany

Summary by: Aurel Vasile Martiniuc

Discussions were based on the concepts of objective functions and optimal representations of natural and relevant stimuli. The receptive fields of simple cells in mammalian primary visual cortex can be characterized as being spatially localized, oriented bandpass filters.

Olshausen and Field (1996) proposed that a coding strategy that maximizes sparseness is sufficient to characterize localized, oriented and bandpass receptive fields. They show that a learning algorithm that attempts to find sparse linear codes for natural scenes will develop a complete family of receptive fields similar to those found in primary visual cortex. Discussions pointed out that localized, oriented and bandpass receptive fields emerge only when two global objectives are placed on a linear coding of images: that the information be preserved and the representation be sparse. Also it has been discussed that this model is not motion-sensitive and topographical characterization is not possible (overlapping receptive fields). For these the temporal component should not be missing.

Wyss et al. (2006) investigate the adaptation and specialization of areas in a hierarchically organized visual processing stream using both real world robot, as well as a simulated virtual approximation. The model discussed here shows that generic computational principles, temporal stability and local memory, can underlie the generation of different levels of processing within one modality and that the variability in functional organization can be accounted for, in terms of the statistics of the inputs each level is exposed to.

The unsupervised learning algorithm for slow feature analysis (SFA) discussed by Wiskott and Sejnowski (2002) yields a high dimensional, non-linear input-output function that extracts slowly varying components from a vectorial input signal. The algorithm can be applied repeatedly so that complex input-output functions can be learned in a hierarchical network of SFA modules with limited computational effort. SFA is somewhat unusual in that direction of minimal variance rather than maximal variance are extracted. Discussions pointed out that SFA can be only a component in a more complex self-organizational model. Aspects such as attention, memory and recognition (more sophisticated than implemented here) need to be integrated to form a more complete system.

REFERENCES

- 1) Olshausen BA, Field, DJ. Emergence of simple-cell receptive field properties by learning a sparse code for natural images. *Nature*. 1996; 381:607-9
- 2) Wyss R, König P, Verschure PF. A model of the ventral visual system based on temporal stability and local memory. *PLoS Biol*. 2006 4:e120
- 3) Wiskott L, Sejnowski TJ. Slow feature analysis: unsupervised learning of invariances. *Neural Comput*. 2002;14:715-70

Normative models in neuroscience

Konrad Körding

Northwestern University
Chicago, USA

Summary by: Hanna Krause

Konrad P. Körding is Assistant Professor for Physiology as well as Physical Medicine and Rehabilitation at Northwestern University, Chicago, since 2006 and associated with the Rehabilitation Institute of Chicago. His work is focused, among others, on applications of Bayesian Decision Theory in neurosciences, especially in the context of information processing and problem solving of the nervous system in the presence of uncertainty.

The workshop addressed characteristic features of normative models and their application in neuroscience. A normative model derives from the assumption what the CNS should optimize, or, if the functioning of the nervous system is assumed to be some kind of problem solving, learn how it should solve certain problems. Whereas the lecture referred to normative models in motor control, in the workshop a broader scope of application of these models was discussed and specific examples were presented.

In the first paper presentation the work of Chklovskii and Koulakov (2004) about organization principles of cortical maps was summarized. In their work, the authors argue that “cortical maps reflect the connectivity properties of intracortical circuits as a consequence of wiring optimization”. They emphasize the importance of the wiring optimization principle (for example for the existence of retinotopic maps and multiple cortical areas) and regard cortical maps as solutions that minimize the wiring costs in the presence of a given intracortical connectivity. Furthermore, they assume that the wiring optimization approach could provide a general framework that is not restricted to the domains in which it has been investigated in the past, but that it helps to structure existing and future experimental data on cortical architecture. Following the paper presentation traditional ways of finding an optimal decision rule using Bayesian Decision Theory were discussed. According to these approaches, finding the optimal decision for a given problem is based on certain assumptions about costs, utility and constraints. This way of identifying the optimal decision or solution was compared to Inverse Decision Theory, which is used in diverse other fields like economics.

In the second paper by Körding et al. (2007) a coherent computational framework is introduced in which a Bayesian solution to the problem of adaptation of motor commands during learning is proposed. The main assumption is that the nervous system faces a specific problem in controlling the body that originates from the fact that any changes of properties of muscles (due to, for example, fatigue, disease, exercise or development) can be considered as disturbances with different underlying timescales. Specifically, with regard to performance errors the problem of credit assignment appears: What is the timescale of the disturbance and what should be the related consequences for the following ongoing processes of adaptation? By focussing on characteristics of the oculomotor system during learning, Körding et al. show that their computational framework can account for a broad range of experimental data. The issue of different timescales was discussed in the workshop,

with a special focus on the effects of long versus short range timescales and the way these timescale differences affect memory and memory-related processes.

The key idea of the third paper discussed in the workshop (Körding and Tenenbaum, 2006) is that the human perceptual system infers the causal structure that underlies the representation of cues from several modalities. The problem of cue combination as a specific aspect of integrative processes of the nervous system is examined, i.e. situations when information from different sources is combined to form a coherent percept. Specifically, the authors emphasize the problem of uncertainty about the causal structure. For example, in experiments where auditory and visual stimuli are presented that may or may not come from the same position and subjects are asked to estimate which direction the tone is coming from, they need to decide if there is a single cause or two causes before they can estimate the direction. These integration processes of the nervous system are modeled as a Bayesian Estimation Problem. The analyses of Körding and Tenenbaum (2006), in which the results of their Bayesian model are compared with empirical data, show that the problem of crossmodal integration is much more complicated than it appears to be at first sight, if the necessity of inference of the causal structure is taken into account. The questions regarding the contents of this paper that were discussed after the paper presentation focused primarily on the nature of cue combination, i.e., what a cue is, and the aspect of nonlinear cue combination. Furthermore, the role of learning was discussed, with an emphasis on the question of adaptation of the estimates according to contexts, and whether environmental changes might be a challenge for the model.

In a finalizing discussion questions referred to probabilities and how they are represented in the brain, the matter of different timescales - especially short periods of time-, and noise, which are some of the most important variables in the second paper presented. Regarding the results of the third paper, the participants of the workshop were primarily interested in the question how cues are combined and what the mechanisms leading to an optimal combination of cues could look like. In conclusion, the main focus in all the discussions laid on the possible advantage of different applications of normative models and comparisons with traditional ways of assumption generation, for example linear models in psychophysics which often turn out not to satisfyingly fit experimental data.

REFERENCES:

- 1) Chklovskii DB, Koulakov AA. Maps in the brain: what can we learn from them? *Annu Rev Neurosci.* 2004;27:369-92
- 2) Kording KP, Tenenbaum JB, Shadmehr, R. The dynamics of memory as a consequence of optimal adaptation to a changing body. (forthcoming)
- 3) Kording KP, Tenenbaum JB. Causal inference in sensorimotor integration . NIPS2006

Cortical motor planning

Hans Scherberger

Institut für Neuroinformatik, University and ETH Zürich
Zürich, Switzerland

Summary by: Oliver Herbort

Many different brain areas are involved in the seemingly simple task to select a target for a reaching movement and execute this movement. Besides (mainly) sensory areas, which encode the visual perception of different possible movement targets, and (mainly) motor areas, which reflect planned or ongoing movements, also sensorimotor areas are involved. One of these areas is the parietal reach region (PRR) in the posterior parietal cortex. This area processes both, perceptual as well as motor related information and is involved in the selection of targets for reaching movements. In the following, three articles are summarized and briefly discussed that focus on the role of PRR in target selection and on the information represented in this area (Musallam, Corneil, Greger, Scherberger, & Andersen, 2004; Scherberger & Andersen, 2007; Scherberger, Jarvis, & Andersen, 2005).

To investigate the role of PRR, Scherberger and Andersen (2007) recorded spiking activity from this area in two monkey, which performed a reaching task. The experimental protocol required the monkey to either reach or saccade to a target after a short period of time (delayed reaching/saccade task). The target could be determined by the experimenter or the monkey had to make a free choice. The neural activity strongly encoded the targets, which monkeys selected for reaching movements but only weakly encoded the targets selected for saccades. Thereby, most cells seemed to be related to the planning or preparation of the movement whereas only few cells responded before the stimuli were presented or during movement execution. However, neural activity was also sensitive to visual input suggesting that also visual information is processed in PRR. In conclusion PRR is an area that is specifically involved in the target selection for arm reaching movements.

Neural activity is often measured with electrodes (single cell recording). The electrodes record action potential from a single neuron (spiking activity) as well as local field potentials (LFP). LFPs reflect the summed dendritic activity of a small area around the tip of a recording electrode. Scherberger et al. (2005) analyzed and compared both, spiking activity and LFPs taken from PRR of a monkey performing a delayed reaching/ saccade task. LFPs and spiking activity encodes different aspects of a movement. Whereas the monkeys movement direction could be reconstructed from both, however more reliably from spiking activity, the LFPs and spiking activities of the same electrode seem to respond to different movement directions. Additionally, LFPs are sensitive to the type of behavior the monkey exerts, for example if it is planning a saccade or a reach. In summary, LFPs complement information that may be inferred from spiking activity.

Finally, Musallam et al. (2004) trained monkeys to control a cursor, whose movements depended on signals recorded from PRR. The monkeys were able to place the cursor on rewarded targets within weeks of training. Thus, not only recordings from 2 motor cortical areas, which encode low level movement parameters, can be used to develop neural prosthesis but also much more abstract signals extracted from earlier processing stages. Furthermore, the signals decoded

from PRR not only reflected the target choice but also reward-related properties of the target like the quality, magnitude or probability of a reward.

The discussion during the workshop focussed mainly on the exact role of PRR. Apparently it is neither a specific motor nor a specific sensory areas but integrates sensory and motor information. On the one hand, PRR is mostly involved in target selection for reaching movements but plays only a minor or no role at all for target selection for saccades. Additionally, the selection of a specific target for action has a high impact on PRR activity, even if the visual input does not change. Thus, PRR cannot be a merely visual or sensory area. On the other hand, PRR is also not exclusively motor related because neural activity depends on the direction the monkeys looks when it prepares the movement or the visual stimulus configuration, independent of the executed action. Thus, PRR cannot be a merely motor area. In conclusion, this areas seems to participate in the integration of visual and motor information for selecting targets for reaching movements. However, if the decision to reach to one target or the other is actual made or only represented in this area cannot be concluded from the discussed experiments because no causal relationships can be concluded from correlating neural activity and behavior. Finally, it seems promising to further investigate how far neural prostheses could be based on recordings from PRR. One advantage of PRR is, that it is placed relatively early in the stream from perception to motor output. In paralyzed patients that might require a neural prosthesis, solely recording from motor cortical areas might be problematic because these areas might also be impaired. Additionally, the detection of abstract goal representations like the desired location of the hand might facilitate the control of a prosthesis, because the patient only has to deal with the goal of the movement and not the actual movement kinematics and dynamics. Finally, the possibility to extract the expected reward of a target or other cognitive signals might proof helpful to monitor patients motivations.

REFERENCES

- 1) Musallam S, Corneil BD, Greger B, Scherberger H, Andersen RA. Cognitive control signals for neural prosthetics. *Science* 2004;305: 258–262
- 2) Scherberger H, Andersen RA. Target selection signals for arm reaching in the posterior parietal cortex. *Journal of Neuroscience* 2007; 27:2001–2012
- 3) Scherberger H, Jarvis MR, Andersen RA. Cortical local field potential encodes movement intentions in the posterior parietal cortex. *Neuron* 2005;46: 347-354

Behavior as motor output

Andrew Schwartz

University of Pittsburgh,
Pittsburgh, USA

Summary by: Sebastian Lehmann,

Volitional arm movements are a combination of directing the involved effectors together with ongoing sensory and visual control of the actual performed movement. The information processing and transformation takes place in several cortical areas. Analyzing cortical mechanisms of arm movement generation is an interesting topic in neuroscience, while online decoding of arm movements from motor cortex is an important step towards the development of brain computer interfaces (BCIs) and the control of neural arm prostheses in monkeys and humans.

By recording single-cell activity in primary motor cortex of macaques during reaching and drawing tasks, Schwartz and Moran (2000) showed that directional tuning curves were modulated by the speed of movement. This was reflected in the magnitude of population vectors calculated from firing rates of a large population of cells. Directional and speed representation is robust across both reaching and drawing. This neural representation of velocity in motor cortex can be used to visualize the dynamics of motor cortical activity.

Taylor et al (2002) showed that the three-dimensional movement of neuroprosthetic devices can be controlled by the activity of cortical neurons when appropriate algorithms are used to decode intended movement in real time. Subjects in this study had real-time visual feedback of their brain-controlled trajectories. It was shown that cell tuning properties of neuronal units changed when used for brain-controlled movements. Using control algorithms that track these changes, subjects were able to perform 3D movements using even fewer cortical units than expected.

Schwartz et al. (2004) studied the differential representation of perception and action in the frontal cortex. In order to separate perception of arm movement from the actual movement, a motor illusion was created. Constructing trajectories from cortical activity in monkeys performing this illusion task showed that the actual movement was represented in the primary motor cortex, whereas the visualized trajectories were found in the ventral premotor cortex. This result shows that perception and action representation can be recognized differentially in the brain.

When looking at movement generation, the movement of the effector (in this case an arm movement) appears to be relatively simple, but it involves complex mechanics and cortical mechanisms. The neuronal activity underlying voluntary movements is widely distributed across multiple cortical and subcortical structures. When analysing brain functions, one should not only look at (hierarchical) structures, nodes and nuclei, but also keep an eye on the big picture, because anatomical wiring is not ultimate proof of functional wiring and separated structures are not proof of specialized function.

Regarding the cortical control of three-dimensional (3D) neuroprosthetic devices, it was pointed out that a key feature of the control algorithm is "coadaptation", which means that the computer algorithm adapts to the monkeys' cortical activity and the cortical activity itself adapts to the algorithm as well.

More philosophical questions during the workshop dealt with ideas and models of the brain structure and brain activity that are influenced by and commonly compared to structures, knowledge and ideas that we already know from other fields,

often following technical achievements, e.g. comparing brain structures to machine structures. Here, other ideas could and should be considered, for example comparing brain structures to social structures in the everyday world (“neuronal unit as an individual with certain roles in neuronal society?”).

While developing models to understand the brain mechanisms is important and useful, one should be aware that the associated algorithms and processes, like for example the “population vector”, might not actually be employed by the brain.

One possible future project would be to expand the sensory feedback in BMIs, i.e. as well as visual feedback, include somatosensory feedback by using force sensors at the robot fingers and microstimulation in somatosensory cortical areas.

Another idea would be to record from e.g. 200 cells in motor cortex, using only 100 cells for the prosthetic control while studying the changes that might occur in the remaining 100 cells.

REFERENCES:

- 1) Schwartz AB, Moran DW. Arm trajectory and representation of movement processing in motor cortical activity. *Eur. J. Neurosci.* 2000;12:1851-1856
- 2) Taylor DM, Helms Tillery SI, Schwartz AB. Direct cortical control of 3D neuroprosthetic devices. *Science.* 2002;296:1829-1832
- 3) Schwartz AB, Moran DW, Reina GA. Differential representation of perception and action in the frontal cortex. *Science.* 2004;303:380-383

Does empathy for pain involve a sensory component or not?

Tania Singer

Institute for Empirical Research in Economics, University of Zurich.

Zurich, Switzerland

Summary by: Simon Vogt

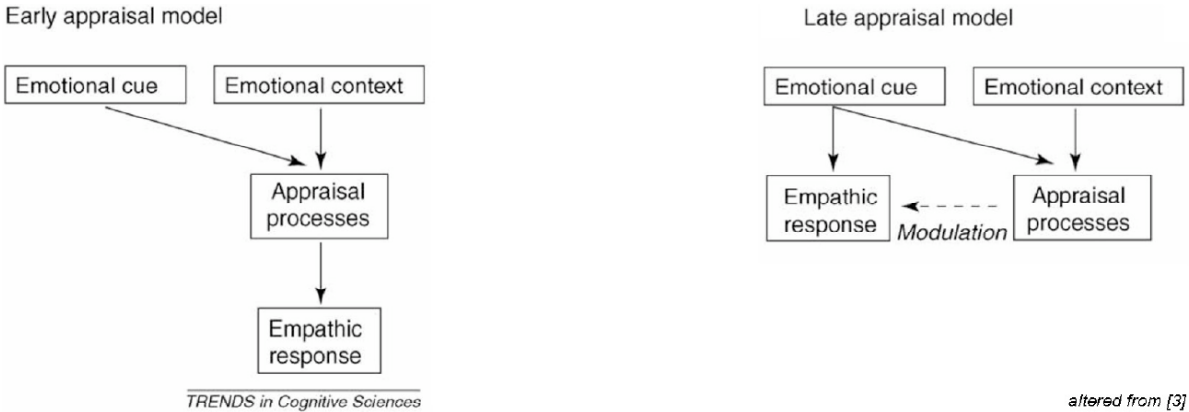
As Frederique de Vignemont and Tania Singer put it nicely in [3], empathy in a broad sense can be described “as an understanding of another person's feelings, affect sharing or as an affective response more appropriate to another's situation than one's own. So defined, empathy subsumes phenomena such as emotional contagion, sympathy, personal distress or even cognitive perspective-taking”. In the narrower sense used here, empathy is only present when (i) one is in an emotional state, (ii) this state is equivalent to another person's emotional state, (iii) this state is caused by the observation or imagination of another person's emotional state, and (iv) one knows that the other person is the source of one's own emotional state (altered from [3]). The core aim of this workshop was to discuss whether empathy is based on bottom-up automatic simulation of sensory inputs or on top-down task- and appraisal-dependent activation of existing emotional representations.

The first paper ([1]) states that some human brain regions involved in processing actual physical pain are also active when watching an other loved person experiencing pain. Functional MRI scans show that the bilateral anterior insula (AI), rostral anterior cingulate cortex (ACC), brainstem, and cerebellum are all active on both occasions while the posterior insula/secondary somatosensory cortex, the sensorimotor cortex (SI/MI) and the caudal ACC only light up on actual pain induced on the subject. The authors conclude that only the part of the pain network associated with its emotional qualities, but not its sensory qualities, mediates empathy.

The second paper ([2]) reports a decrease in amplitude of motor-evoked potentials during transcranial stimulation after subjects had watched videos of painful needle pricks to hands or feet in a human model. The muscles inhibited seemed to be exactly those injured in the videos. The paper concludes that this empathic inference and automatic embodiment of other's pain in the observer's own motor system may play a crucial role in social learning of reactions to pain.

The third paper ([3]) questions the assumption that people automatically share the emotions of others due to the wiring of neural pathways, as suggested by some recent publications, by reporting on a study that shows empathic responses being dependent on an empathiser's characteristics, the situation context and his or her relationship with the target ([4]) . The article also introduces the concept of early appraisal and late appraisal models, where the early appraisal model tries to explain situation-dependent empathy by assuming an intermediate process assessing the emotional cues and context before setting off an empathic response. The late appraisal model explains the variation of empathy through a network model in which the formation of an automatic empathic response begins simultaneously with a process of assessing emotional cues and contexts that may modulate this ongoing empathic response. [3] suggests to devise more experiments to explicitly examine

the correctness of these two appraisal models. The article also proposes two major reasons for empathy. The first is an information-gathering role to provide information about the future actions of other people and important environmental properties, while the second is to serve as an origin for social behavior, enabling the notion of altruism and cooperation.



Some of the main points of discussion during the workshop were how and to which extent empathy exists in animals, which special cases involving empathy there are, and which implications the contradicting statements of the papers may have.

The first point of discussion was mainly concerned with an experiment about measuring empathy in mice, where a Canadian group used the amount of stomach contraction as a measure for pain sensation. First, mice were put under stomach pain, and the amount of contraction was measured. Then, the mouse was put into a cage with another mouse which was instead put under pain, and the reactions in terms of stomach contraction of the first mouse were measured again. Tania Singer pointed out that this alone could just be an example of emotion contagion, without actual self-other distinction being present. This self-other distinction has only been explicitly proven for humans, higher monkeys, dolphins and, recently, elephants. However, Singer continued to explain that the Canadian experimenters found the stomach response to be stronger when the mouse under pain was known to the mouse under surveillance. This suggests that we are not just dealing with a simple contagious effect. Another hint on the origin of empathy may be given by John Allman's Von Economo (spindle) neurons [5], which are found only in humans and apes and are thought to have a role in rapid decision-making in social situations.

Some special cases of behavior related to empathy were discussed. One question asked was whether (altruistic) compassion, as seen in Tibetan monks towards their torturers, can be compared to (biological) attachment such as the mother-child relationship. Some workshop participants suggested that the same system could be involved in this, with simply different scales for mother-child, family, friends and rest-of-humanity relationships. Although the exact mechanism of this is unknown, it may also be possible that there are two separate networks for loved ones and for the rest of humanity. More examples included counsellors or physicians, who may actively need to reduce their empathy towards patients to avoid a burnout phenomenon; masochists, which seem to have an active reward network for things that most people would expect to be painful; and finally psychopaths, which have either no amigdala response in empathic tests at all (Type 1, most dangerous,

"approx. 25% of psychopaths") or have an extremely high amigdala response (Type 2, easily punch you, "approx. 75% of psychopaths").

Concerning the papers presented in the workshop, the question of how we control empathic reaction was asked. The appraisal models mentioned above were compared to the outcome of an fMRI study (paper [4]), which shows no increase in anterior insula (AI) activity on punishment of mean players, which speaks for the early appraisal model being valid here. If the late appraisal model had been applicable, the fMRI scans should have shown at least some AI activity, followed by no empathic response due to late suppression. Another question thrown up by the papers was why the muscle response in the TMS study (paper [2]) was reduced at the position where the "needle penetration" had taken place in the video. A possible expectation could have been to see an excitational activation for withdrawal of the affected area due to some anticipation of pain. An answer to this is that the reduction of response may be due to an activation of the pain resonance system, also in response to the "pain" from the video being projected onto oneself. This would put the seemingly injured limb into a healing mode and therefore avoid any kind of movement.

In the future, additional experiments should be designed to distinguish between the two appraisal models mentioned during the workshop and in [3]. One idea is to use other imaging techniques that provide a better time resolution than fMRI and repeat the experiment with the unfair players. Would there still be no activity increase in the anterior insula? Or would it be possible to watch a time dependence between empathic reaction and its suppression?

REFERENCES

- 1) Singer T, Seymour B, O'Doherty J, Kaube H, Dolan RJ, Frith CD. Empathy for pain involves the affective but not sensory components of pain. *Science*. 2004;303:1157-62
- 2) Avenanti A, Buetti D, Galati G, Aglioti SM. Transcranial magnetic stimulation highlights the sensorimotor side of empathy for pain. *Nat Neurosci*. 2005;8:955-60
- 3) de Vignemont F, Singer T. The empathic brain: how, when and why? *Trends Cogn Sci*. 2006;10:435-41
- 4) Singer T, Frith C. The painful side of empathy. *Nat Neurosci*. 2005;8:845-6.
- 5) The John Allman Lab - <http://www.allmanlab.caltech.edu/allman.html>

Do robots need emotions?

Tom Ziemke

School of Humanities & Informatics, University of Skovde,
Skovde, Sweden

Summary by: David Gamez,

This workshop looked at the modelling of emotions in robotic systems and at the relationship between emotions in robots and emotions in the brain. Emotions can be a good learning mechanism and they have the potential to improve the ability of robots to make decisions for themselves. The expression of emotions is also a fast and simple way in which robots can communicate with humans.

The first paper discussed in the workshop was by Cañamero (2005), which asked a lot of theoretical questions about emotions and robotics and identified many key areas that need further investigation. This paper was judged to be a useful summary of the conceptual challenges facing work on emotions and robotics. The second paper by Arbib and Fellous (2004) looked at the different roles of emotions in robotics and at the possible implementations of emotions in a cognitive architecture. This paper also included a fairly detailed summary of emotions in the brain and discussed how emotions could be used to select between a system's different operating modes. The general impression about this paper was that although it contained useful information, it was not well integrated overall and it was difficult to detect a single overall argument or theme. The third paper by Arkin, Fujita, Takagi and Hasegawa (2003) summarised the work they had done on implementing an ethological and emotional model in an AIBO robot. The general consensus amongst the workshop participants was that although this paper described interesting work, it was a bit thin on implementation details and could have done more to explain its many diagrams.

After the papers had been presented, the workshop discussion focused on a number of different aspects of emotion and robotics:

- The lack of clarity in the concept of emotion. There are several different aspects to emotions in the brain and many different ways of implementing emotions in robots. More theoretical work is needed to bring this together into a more unified theory about the emotions. Many of the questions raised by the first paper were relevant to this issue.
- The distinction between the neuroscientific perspective on emotion, which focuses on the brain structures associated with emotion in the brain, and the psychological and social dimensions of emotion.
- The relationship between emotion and consciousness in both humans and machines. Damasio (1999), for example, makes an explicit link between the structures responsible for emotion in the human brain and human consciousness and it is an open question whether embodied emotions will be necessary for machine consciousness.
- Many of the functions of emotions can be implemented without using emotions at all. This raises the problem whether emotions make a real difference to a system and how the usefulness of emotions can be systematically evaluated.

- The way in which emotions can be used to mediate between different levels of a subsumption architecture.
- Although is easy to create a neural layer or Java class and call it an emotion, this raises the problem of how models of the emotions can be meaningfully grounded in a system. A related question is whether it makes any difference if a real robot is used or whether a good simulation would also be a reasonable way of grounding a model of the emotions.
- The tension between building a system that is autonomous and makes its own decisions and building a system that carries out what you want it to do. Autonomy is good in many situations, but an emotional robot may make decisions that conflict with what the operator wants. This links up with the negative aspects of emotions that were discussed in the second paper.

In conclusion, this workshop showed that our understanding of emotion in the brain is increasing, but we are still far from building detailed functional models of how the different aspects of emotion integrate into a single system. The modelling of emotions in real and virtual robots is only just beginning and suffers from a lack of clarity, with many different approaches currently under investigation. As we build more human-like models of emotion in robots the gap will hopefully start to close between systems that use emotional expression as a way of communicating more effectively with humans (Kismet, for example), and systems that have detailed models of emotion, but do not express their emotions in any human-understandable way.

REFERENCES

- 1) Cañamero, L. Emotion understanding from the perspective of autonomous robots Research Neural Networks. 2005;18:445-455
- 2) Arbib M, Fellous JM. Emotions: from brain to robot. Trends in Cognitive Sciences, 2004;8:554-561
- 3) Arkin R, Fujita M, Takagi T, Hasegawa R. An ethological and emotional basis for human–robot interaction. Robotics and Autonomous Systems. 2003;42:191-201

List of references

- 1) Arbib M, Fellous JM. Emotions: from brain to robot. *Trends in Cognitive Sciences*, 2004;8:554-561
- 2) Arkin R, Fujita M, Takagi T, Hasegawa R. An ethological and emotional basis for human–robot interaction. *Robotics and Autonomous Systems*. 2003;42:191-201
- 3) Avenanti A, Buetti D, Galati G, Aglioti SM. Transcranial magnetic stimulation highlights the sensorimotor side of empathy for pain. *Nat Neurosci*. 2005;8:955-60
- 4) Averbeck BB, Sohn JW, Lee D. Activity in prefrontal cortex during dynamic selection of action sequences. *Nat Neurosci*. 2006; 9:276-82
- 5) Bangerter A, Clark HH. Navigating joint projects with dialogue. *Cognitive Science*. 2003; 27:95-225
- 6) Cañamero, L. Emotion understanding from the perspective of autonomous robots *Research Neural Networks*. 2005;18:445-455
- 7) Caspi A, Beutter BR, Eckstein M. The time course of visual information accrual guiding eye movement decisions. *PNAS* 2004; 101:13086-13090
- 8) Chklovskii DB, Koulakov AA. Maps in the brain: what can we learn from them? *Annu Rev Neurosci*. 2004;27:369-92
- 9) Cisek P, Kalaska JF. Neural correlates of reaching decisions in dorsal premotor cortex: specification of multiple direction choices and final selection of action. *Neuron*. 2005;45:801-14
- 10) Cox R, Jesmanowicz A, Hyde JS. Real-time functional magnetic resonance imaging. *Magnetic Resonance in Medicine* 1995;33:230-236
- 11) Cruse H, Kindermann T, Schumm M, Dean J, Schmitz J. Walknet - a biologically inspired network to control six-legged walking. *Neural Networks* 1998; 11:1435-1446
- 12) Dautenhahn K. Roles and Functions of Robots in Human Society - Implications from Research in Autism Therapy. *Robotica* 2003; 21:443-452
- 13) Dautenhahn K. Socially intelligent robots: dimensions of human - robot interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2007; 362:679-704
- 14) de Gelder B. Towards the neurobiology of emotional body language. *Nat Rev Neurosci*. 2006; 7:242-9
- 15) de Vignemont F, Singer T. The empathic brain: how, when and why? *Trends Cogn Sci*. 2006;10:435-41
- 16) deCharms C, Maeda F, Glover GH, Ludlow D, Pauly JM, Soneji D, et al. Control over brain activation and pain learned by using real-time functional MRI. *PNAS* 2005;102:18626-18631
- 17) Donne J. Meditation XVII, Devotions Upon Emergent Occasions. 1624
- 18) Engel AK, Fries P, Singer W. Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Reviews Neuroscience* 2001; 2:704-716
- 19) Fries P. A mechanism for cognitive dynamics: neuronal communication through neuronal coherence. *Trends Cogn Sci*. 2005;9:474-80
- 20) Garcia L, D'Alessandro G, Bioulac B, Hammond C. High-frequency stimulation in Parkinson's disease: more or less? *Trends Neurosci*. 2005;28:209-16
- 21) Godijn R and Theeuwes J. Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology. Human Perception and Performance* 2002;28:1039-1054

- 22) Grillner S. Biological pattern generation: the cellular and computational logic of networks in motion. *Neuron* 2006;52:751-766
- 23) Hashimoto T, Elder CM, Okun MS, Patrick SK, Vitek JL. Stimulation of the subthalamic nucleus changes the firing pattern of pallidal neurons. *J Neurosci.* 2003;23:1916-23
- 24) Ijspeert A, Crespi A, Ryczko D, Cabelguen, JM. From swimming to walking with a salamander robot driven by a spinal cord model. *Science* 2007;315:1416-1420
- 25) Kahn PH, Friedman B, Perez-Granados DR, Freier NG. Robotic pets in the lives of preschool children. *Interaction Studies* 2006;7:405–436
- 26) Knoblich, G. Bodily and motor contributions to action perception. In R. Klatzky et al. (Eds): *Embodiment, Ego-space, and Action*. Proceedings of the 34th Carnegie Symposium on Cognition. LEA. (in press)
- 27) Kording KP, Tenenbaum JB, Shadmehr, R. The dynamics of memory as a consequence of optimal adaptation to a changing body. (forthcoming)
- 28) Kording KP, Tenenbaum JB. Causal inference in sensorimotor integration . NIPS2006
- 29) Ma WJ, Beck JM, Latham PE, Pouget A. Bayesian inference with probabilistic population codes. *Nat Neurosci.* 2006;9:1432-8
- 30) MacDorman K, Ishiguro H. The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies* 2006;7:297–337
- 31) Marsh KL, Richardson MJ, Baron RM. Contrasting approaches to perceiving and acting with others. *Ecological Psychology.* 2006; 18:1-38
- 32) Meissner W, Leblois A, Hansel D, Bioulac B, Gross CE, Benazzouz A, Boraud T. Subthalamic high frequency stimulation resets subthalamic firing and reduces abnormal oscillations. *Brain.* 2005;128:2372-82
- 33) Musallam S, Corneil BD, Greger B, Scherberger H, Andersen RA. Cognitive control signals for neural prosthetics. *Science* 2004;305: 258–262
- 34) Najemnik J and Geissler WS. Optimal eye movement strategies in visual search. *Nature* 2005; 434:387-391
- 35) Olshausen BA, Field, DJ. Emergence of simple-cell receptive field properties by learning a sparse code for natural images. *Nature.* 1996; 381:607-9
- 36) Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci.* 2004; 27:169-92
- 37) Rocco S , Carrozza MC, Cappiello G, Cabibihan J, Laschi C, Dario P. Design and development of five-fingered hands for a humanoid expression robot. *International Journal of Humanoid Robotics* 2007; 4:181–206
- 38) Scherberger H, Andersen RA. Target selection signals for arm reaching in the posterior parietal cortex. *Journal of Neuroscience* 2007; 27:2001–2012
- 39) Scherberger H, Jarvis MR, Andersen RA. Cortical local field potential encodes movement intentions in the posterior parietal cortex. *Neuron* 2005;46: 347-354
- 40) Schwartz AB, Moran DW, Reina GA. Differential representation of perception and action in the frontal cortex. *Science.* 2004;303:380-383
- 41) Schwartz AB, Moran DW. Arm trajectory and representation of movement processing in motor cortical activity. *Eur. J. Neurosci.* 2000;12:1851-1856
- 42) Sebanz N, Bekkering H, Knoblich G. Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences.* 2006;10:70-76
- 43) Singer T, Frith C. The painful side of empathy. *Nat Neurosci.* 2005;8:845-6.

- 44) Singer T, Seymour B, O'Doherty J, Kaube H, Dolan RJ, Frith CD. Empathy for pain involves the affective but not sensory components of pain. *Science*. 2004;303:1157-62
- 45) Taylor DM, Helms Tillery SI, Schwartz AB. Direct cortical control of 3D neuroprosthetic devices. *Science*. 2002;296:1829-1832
- 46) Uhlhaas PJ, Singer W. Neural synchrony in brain disorders: relevance for cognitive dysfunctions and pathophysiology. *Neuron*. 2006;52:155-68
- 47) Weiskopf N, Sitaram R, Josephs O, Veit R, Scharnowski F, Goebel R., et al. Real-time functional magnetic resonance imaging: methods and applications. *Magnetic Resonance Imaging* 2007;25:989-1003
- 48) Wiskott L, Sejnowski TJ. Slow feature analysis: unsupervised learning of invariances. *Neural Comput*. 2002;14:715-70
- 49) Wyss R, Konig P, Verschure PF. A model of the ventral visual system based on temporal stability and local memory. *PLoS Biol*. 2006 4:e120