Report of the ERNI-HSF meeting on Computational Principles of Sensorimotor Learning

SCIENTIFIC REPORT

Summary

The aim of the workshop was to bring together world leaders in computational approaches to motor control with European early career research scientists. The ERNI-HSH network therefore asked three experts in the field, Professor RC Miall, Professor DM Wolpert and Dr J Diedrichsen to take charge of the detailed organization of the meeting. The workshop was held in Monastery Kloster Irsee, Kaufbeuren, near Munich, Germany. Eighty participants attended including 14 invited speakers, the 3 organizers and an ESF representative, Prof Gjedde. One member of the ERNI-HSF network , Prof Jackson, had to withdraw at the last minute because of illness. Participants arrived on the evening of September 13, 2009, and departed on the morning of September 16, 2009. The meeting itself included 2 extended tutorials, 16 oral presentations, and 50 poster presentations.

The meeting ran accordingly to plan, with a good level of discussion during and between talks, and with excellent participation during the poster sessions. We formally timetabled 5 hours for poster discussion, but informal discussion around the posters continued during all breaks in the program. Informal feedback from the early career participants on the conference was highly positive.

Supported by the ERNI-HSF-ESF contribution to the costs, 20 early career scientists were offered a bursary of 260 Euro to offset their meeting costs. The travel and full accommodation costs for the speakers were met from the budget, without honoraria, while other participants paid a flat room rate set by the conference centre that covered accommodation and meals. This allowed for an excellent venue at low overall costs: the total budget was €55.6K, of which €29.6K was granted by the ESF.

We thank the ESF for their valued contribution to this meeting.

Scientific content and discussion

Publicity for the meeting was achieved by use of a number of email distribution lists, including the Advances in Computational Motor Control list and the Computational Neuroscience list, and advertisements on Frontiers in Computational Neurosience, Federation of European Neuroscience Societies, British Neuroscience Association, Neural Control of Movement society, and by word of mouth. The meeting was heavily over-subscribed and an early decision was made to increase numbers from 50 to 80. This was an accommodation constraint imposed by the chosen venue, but was also about the upper size that was felt to be consistent with a small, interactive meeting. A number of withdrawals were easily replaced from a waiting list, and we regret that some interested parties were not able to attend.

It was decided to hold the workshop at a location central to Europe, facilitating attendance from across the EU. The venue, the Monastery Kloster Irsee, proved to be outstanding. It is recommended by the organizers for any future appropriate ESF events. Basic costs were very reasonable and included all conference facilities and full board and lodging. Additional costs were incurred in preparing printed booklets, and in reception drinks and evening social event costs. This allowed the total costs of the meeting to be limited to Euro55K, including refund of the travel and accommodation costs for invited speakers and organizers. The monastery has excellent conference facilities and accommodation, and basement bar and games areas that ensure the entire group remained on site and interacting both during the meeting and the evenings.

The organizers identified two themes central to issues of computational sensorimotor control, and invited two experts to present their research within these themes as extended tutorials, to start each day of the meeting. In addition, 12 speakers were selected and invited to provide broad coverage of the current topics, bearing in mind our desire to choose speakers able to engage the participants in lively discussion. These 14 invited contributors were complemented by invitations to the lead members of the ERNI-HSF network and by the three organizers, who were to take on a role as discussants to ensure active and positive discussions across the workshop. We felt that the most productive format would be to limit overall numbers to approximately 50-80, to maximize interaction between all attendees. The three organizers and one ERNI-HSF

member (Prof Jackson) were to be session chairs, the latter replaced at the last minute by Prof Jeroen Smeets – with our thanks - chosen as an experienced chairman able to maintain timeliness and active discussion.

The two opening tutorials were themed around human sensorimotor control and intelligent robotics. The first was by Prof Reza Shadmehr, Dept BioEngineering, Johns Hopkins, and was an excellent introduction to the current issues in understanding human movement and motor learning from a computational perspective. Informal feedback from the students was highly positive. The second tutorial was presented by Prof Stefan Schaal, Computer Science and Neuroscience, University of Southern California, and introduced the theories and concepts behind adaptive robotics, robotic learning from imitation of humans, and efficient learning algorithms based on reinforcement. This tutorial was interesting and of clear relevance, although student feedback suggested that the second half of the tutorial had been less successful, as it was aimed at too advanced a level to benefit some in the audience. Nevertheless, the organizers are grateful to both speakers for taking time and effort to present these extended tutorials, and for encouraging interaction and discussion throughout the sessions. The presentations for both tutorials and for the majority of the talks were hosted on the workshop website, http://www.bangor.ac.uk/~pss412/Irsee/ and we are hopeful that the remaining speakers will submit their presentations to the website shortly.

Another important organizational decision was to invite all registrants to submit abstracts of their work, most of which would be presented as posters during the meeting. The three organizers independently rated these abstracts for relevance and quality, excluding any from within their own three research groups. The top 4 scoring abstracts (from 3 early and 1 mid-career scientist) were invited to present their work orally, joining the remaining 12 invited speakers. This allowed some additional spread of the topics to be discussed at the meeting. Finally, the 16 selected talks were grouped into 4 themes for presentation across the 2 days. These themes were Adaptation; Variability and uncertainty; Reinforcement learning and optimality; and Discovering structure. Each themed session was represented by 3 invited and 1 selected speaker, giving 20-25 minute talks followed by 5-10 minute discussion.

Adaptation: This session started with a discussion by Etienne Burdet of motor learning without proprioceptive error. He showed that the slow adaptation of movements could be prevented by providing visual feedback of a virtual trajectory predicted by the lateral forces experienced by participants. Feedforward learned in the virtual environment transfers well to the real dynamics, and exhibit after-effects similar to normal learning with proprioceptive error. These results suggest that skill learning and rehabilitation may be carried our using simple passive devices and suitable feedback. Next Maurice Smith presented data on fast and slow adaptation processes: both contribute to initial learning but only one provides a gateway to long-term memory formation. He argues that an understanding of these mechanisms to will allow design of training and rehabilitation paradigms which optimize learning and retention. John Krakauer then argued that a number of ideas have recently been introduced to explain changes in the learning rate of adaptation are inconsistent with recent data from his laboratory, and cast doubt on some of these explanations. Finally, Simon Gizter presented data from an animal model of gait, working towards brain-machine interfaces that might be of importance in recovery of locomotion after spinal injury. They show rats adapt to use their neural activity in a closed-loop BMI to drive useful actions, opposing applied loads. This framework allows examination of the neural bases of adaptation and skill learning in both normal tasks and in artificial BMI arrangements never experienced before in evolution.

Variability and uncertainty: Dagmar Sternad discussed how variability in performance is ubiquitous, even in highly skilled performance and can serve as a useful window into the determinants of skill acquisition and control. Her group parses observed variability into three components: tolerance, noise and covariation and examine questions of: What aspects of variability decrease with practice? Are actors sensitive to their intrinsic noise in selecting strategies? How can variability or its components be manipulated by interventions? This led to the presentation by Gjorde Mitrovic, on a theory of impedance control based on internal model uncertainty. He showed a computational model able to predict impedance control phenomena from first principles, and that optimization to minimize uncertainty can conceptually explain the origins of co-activation in volitional human reaching tasks. Jeroen Smeets then argued that in performing goal-directed movements, minimum variance is considered as optimal,

whereas accuracy is neglected, leading to a weighted average that depends only on the precision of the sensory information. They found that subjects can rapidly change the weights given to the cues, giving less weight to the cue that provided incorrect information, and conclude that optimality is guided by a combination of precision and correctness. Finally, David Knill discussed the problem of how the visual system learns the statistical regularities needed to interpret pictorial cues; in particular, how it adapts its internal model to environments with very different statistics. He described a family of unsupervised adaptive mechanisms that support these functional properties and show that they provide a good fit to human data in tasks of sensory cue integration and sensorimotor learning.

Reinforcement learning and optimality: Andrew Barto introduced the view that intrinsic reward mechanisms facilitate the learning of reusable skills, giving as an example recent robotics research from the Laboratory for Perceptual Robotics at the University of Massachusetts Amherst. He put intrinsic reward into an evolutionary context, arguing for an optimal reward function given an agent's evolutionary fitness function and its environments. Extrinsically and intrinsically motivated behaviors may emerge from such optimal reward functions. Jan Peters presented wok on reinforcement learning in robotics, and presented a general framework based on generating a representation of motor skills by parameterized motor primitive policies, as building blocks of movement generation, and on a learned task execution module that transforms these movements into motor commands. The resulting algorithm learns smoothly without dangerous jumps in solution space, and works well in complex high degree-of-freedom robots. Micheal Sherback brought the meeting back towards human health with a paper on the prompt yet slower corrections of movements in the elderly, data consistent with a Bayesian optimal adaptation to disorder in the sensorimotor system. His results complement recent work in brain imaging of aged subjects in choice-reaction tasks. And to conclude the session Lawrence Maloney presented collaborative work with Julia Trommershauser on how subjects can compensate for their own motor uncertainty in simple economic motor tasks. They showed participants compensate for experimenter-imposed increases in Gaussian variance of their performance error, and also tested whether subjects can compensate for non-Gaussian motor uncertainty.

Discovering structure: To open this session, Emo Todorov argued that many theoretically-inspired control systems tend to be monolithic, whereas the human motor system is distributed and hierarchical. Thus hierarchical optimal controllers may be more plausible biologically. He asked how such controllers would operate, and how the computations underlying optimal control would be distributed to simplify the problem while preserving optimality. Daniel Braun showed how the motor system could constrain task difficulty by learning structure or by critical parameter adjustments that conform to the covariance between the task's control parameters. He presented a series of experiments to test for such structural learning and found that subjects showed key features of structural learning such as facilitated learning of different tasks with the same structure, and preferential exploration along learned structures. He suggested that skill generalization relies on task variation and structural learning. Sethu Vijayakumar argued for a powerful Bayesian observer approach to generatively model perceptual and motor tasks, focusing on causality. He investigated this hypothesis with examples from multi sensory cue integration and sensorimotor adaptation paradigms, an approach that raised some subsequent discussion with Jeroen Smeets on the necessity or otherwise of calibration of separate sensory streams. Last but not least, Georg Martius talked about how processing of sensory information should be matched to environmental affordances, studying robotic implementations as models of biologically embodies behaviours. He argued that further development of these modeling approaches may lead towards myoelectric prothesetic devices, brain-machine interfaces and adaptive robotic agents. That concluded the oral presentations.

Finally, to maximize interactions, we ensured that all posters were displayed throughout the 2 day meeting, adjacent to the main conference room in the corridors used to serve drinks and refreshments. Poster presentation sessions were scheduled for each day, and all participants were encouraged to spend as much time as they liked in discussion of these posters. The organizers felt, and informal feedback confirmed, that this had been successful and valuable. Poster abstracts are available on the workshop website.

Results and impact of the event

Summary statistics are that the invited speakers and discussants included 8 North Americans and 12 Europeans (three of these from the ERSI-HSF were unable to attend). While perhaps more heavily weighted towards the US than desirable, this distribution accurately reflects the state of leading research in this area. It is an interesting point that of these 8 US speakers, 4 were European-trained scientists who have established their careers in the states. One European speaker (Dr Julia Trommershauser, Eissen) had to withdraw a few weeks before the meeting and was replaced by her long-term collaborator, Prof Lawrence Maloney, New York University, who was on a collaborative visit in Germany at the time of the meeting. The remaining registrants included 53 from Europe (including 2 Israelis); 8 non-Europeans, including Australia, Argentina and Canada (2) and US (5). Feedback from registrants was uniformly positive, and the organizers are confident that the meeting met its primary aims of introducing the leading international research in computational motor control to European early-career research scientists, and allowing intensive discussion and interaction between leaders in the field and their audience.

Assessing the future impact of this meeting is of course rather difficult. We feel it fully met its aims. We expect increasing translation of these computational theories towards clinical questions, epitomized by a paper published in the same month (Nature Neuroscience 12, 970 - 972 (2009) using computational sensorimotor theory to expose stronger than normal links between voluntary movement and proprioceptive feedback in autistic children; predictive of their impairments in social function and imitation.

C Miall
J Diedrichsen
D Wolpert
12-10-2009

Final programme of the meeting.

Sunday, Sept. 13

18:00 Welcome reception

19:00 Dinner

Monday, Sept 14

9:00	Reza Shadmehr	Internal models: an introduction

10:30 Coffee & Tea

Adaptation (Chair: Steve Jackson)

11:00	Etienne Burdet	Learning without proprioceptive error?
11:30	Maurice Smith	Optimizing Training by Understanding the Mechanisms for Credit Assignment & Decay in Motor Adaptation
12:00	John Krakauer	The trouble with savings
12:30	Simon F. Giszter	A model system for both routine and unusual motor adaptations: a Brain-Machine-Interface (BMI) platform using neural activity changes in trunk/hindlimb cortex of rats during locomotion.

13:00 Lunch

14:00 Posters

Variability and Uncertainty (Chair: Chris Miall)

16:00	Dagmar Sternad	Variability, Noise, and Sensitivity to Error in Learning a Motor Task
16:30	Djorde Mitrovic	A Theory of Impedance Control based on Internal Model Uncertainty
17:00	Jeroen Smeets	Learning to deal with incorrect information

17:30	David Knill	Flexible, adaptive use of Bayesian priors for sensory cue integration

18:00 Posters and open Discussion

19:00 Dinner

Tuesday, Sept 15

9:00	Stefan Schaal	Representations, Imitation, Modularity, and Learning in Motor Control: A Computational Theory

10:30 Coffee & Tea

Reinforcement learning and Optimality (Chair: Daniel Wolpert)

11:00	Jan Peters	Reinforcement Learning of Motor Skills in Robotics
11:30	Andrew Barto	Intrinsic Motivation and Motor Learning
12:00	Michael Sherback	Prompt yet slower corrections are an optimal adaptation to increased noise in the elderly
12:30	Laurence T Maloney	Learned and prior structure in the selection of movements

13:00 Lunch

14:00 Posters

Discovering Structure (Chair: Jörn Diedrichsen)

16:00	Emo Todorov	Hierarchical optimal control
16:30	Daniel Braun	Structural Learning in Motor Control
17:00	Sethu Vijayakumar	Model Selection and Structure Inference in Sensory and Motor Learning
17:30	Georg Martius	Self-organization of Sensory-motor control

18:00 Open Discussion

19:00 Dinner

Wednesday, Sept. 16

Breakfast and Departure

Full list of speakers

Speakers

Andy	Barto	MIT	US	Speaker
Daniel	Brown	Freiburg	Germany	Speaker
Etienne	Burdet	Imperial College	UK	Speaker
Joern	Diedrichsen	Bangor	UK	Discussant
Albert	Gjedde	ESK	Denmark	ESF
Stephen	Jackson	Nottingham	UK	Discussant
David	Knill	Rochester	US	Speaker
John	Krakauer	Columbia	US	Speaker
Larry	Maloney	Psych & Neural Science	New York State	Faculty
Chris	Miall	Birmingham	UK	Discussant
Jan	Peters	Tuebingen	Germany	Speaker
Stefan	Schaal	USC	US	Speaker
Reza	Shadmehr	Johns Hopkins	US	Speaker
Jeroen	Smeets	Amsterdam	The Netherlands	Speaker
Maurice	Smith	Harvard	US	Speaker
Dagmar	Sternad	Boston	US	Speaker
Emo	Todorov	San Diego	US	Speaker
Sethu	Vijayakumar	Edinburgh	UK	Speaker
Daniel	Wolpert	Cambridge	UK	Discussant

2. Participants

First	Last	Inst	Department
Masaki	Abe	Northeastern University	Biology
Daniela	Balslev	University of Birmingham	School of Psychology
Korem	Beiser	Technion - IIT	Mechanical Engineering
Armin	Biess	BCCN	MPI for Dynamics and Self-Organistation
Lukas	Brostek	BCCN Munich	
Martin	Butz	University of Wurzburg	Psychology
Robin	Bye	University of New South Wales	Neuroengineering Laboratory, School of Electrical Engineering and Telecommunications
Jennifer	Cook	University College London	Institute of Cognitive Neuroscience
Marco	D'Alonzo	Biorobotics	Scuola Superiore Sant'Anna
Antonine	Deplancke	Universite Lille	Psychology
Johannes	Drever	Ludwig-Maximilians Universität München	Neurology
Alexander	Duschau-Wicke	ETH Zurich	Sensory-Motor Systems Lab, Institute of Robotics and Intelligent Systems
Thomas	Eggert	Ludwig-Maximilians Universität München	Neurology
Aldo	Faisal	University of Cambridge	Engineering
Sae	Franklin	University of Cambridge	Engineering
Dave	Franklin	University of Cambridge	Engineering
Christos	Giachritsis	University of Birmingham	Psychology
Simon	Giszter	Drexel University	Neurobiology
Paul	Gribble	The University of Western Ontario	Psychology
Emmanuel	Guigon	Universita Pierre et Marie CNRS	Institut des Systemes mes Intelligents et de Robotique
Olivier	Herbort	University of Waerzburg	Psychology
Rosana	Herrera	Universidad de	Computer Science

		Buenos Aires	
Michael	Herrmann	University of Edinburgh	School of Informatics
Ian	Howard	University of Cambridge	Engineering
Markus	Huber	Ludwig-Maximilians University Munich	Centre for Sensorimotor Research
James	Ingram	University of Cambridge	Department of Engineering
Jun	Izawa	John Hopkins University	Bio-Engineering
Carl	Jackson	University of Birmingham	School of Psychology
Marek	Kopick	University of Birmingham	Computer Sciences
Jesper	Lundbye-Jensen	University of Copenhagen	Department of Exercise and Sports Sciences & Department of Neuroscience and Pharmacology
Wolfgang	Maass	Graz University of Technology	Institute for Theoretical Computer Science
Laurent	Madelain	Ureca, Université Lille Nord de France	Psychology
Georg	martius	BCCN Goettingen	
Jérémie	Mattout	INSERM U821	Brain Dynamics and Cognition
Djordje	Mitrovic	University of Edinburgh	School of Informatics
Herman	Mueller	JLU Giessen	Sport Science
Arne	Nagengast	university of Cambridge	Engineering / Experimental Psychology
Kia	Nazarpour	University of Birmingham	School of Psychology
Dimitri	Ognibene	ISTC CNR	Laboratory of Autonomous Robotics and Artificial Life
Jean-Jacques	Orban De Xivry	John Hopkins University	Biomedical Engineering Department
Jacinta	O'Shea	University of Oxford	Oxford Centre for Functional MRI of the Brain
Celine	Paeye	Laboratoire Ureca	Psychology
Gerulf	Pedersen	University of Wuerzburg	Psychology
Giovanni	Pezzulo	National Research Council of Italy	0

Clare	press	University College London	Wellcome Trust Centre for Neuroimaging
Andrew	Pruszynski	Queen's University	Centre for Neuroscience Studies
Konrad	Rawlik	The University of Edinburgh	School of Informatics
Andreas	Reichelt	Universirt of Vienna	Philosophy of Science / Cognitive Science
Saber	Sami	Birmingham University	Psychology
Ian	Saunders	University of Edinburgh	Institute of Perception, Action and Behaviour
Mark	Schram Christensen	University of Copenhagen	Department of Exercise and Sports Sciences
Luc	Selen	University of Cambridge	Department of Engineering
Michael	Sherback	Cornell	Mechanical Engineering
Lore	Thaler	The University of Western Ontario	Psychology
Roland	Thomashke	University of Wurzburg	Psychology
Edward	Turnham	University of Cambridge	Engineering
Francisco	Valero-Cuevas	University of Southern California	Biomedical Engineering
Heike	Vallery	ETH Zurich	Sensory-Motor Systems Laboratory
Robert	Van Beers	VU University Amsterdam	Human Movement Sciences
Tobias	Wiestler	Bangor University	Psychology
Jeremy	Wyatt	University of Birmingham	Computer Sciences
Minnan	Xu	Johns Hopkins University	Bio-Engineering
Miriam	Zacksenhouse	Technion - IIT	Mechanical Engineering