Journal of Computational Science 4 (2013) 242–244

Contents lists available at SciVerse ScienceDirect

Journal of Computational Science

journal homepage: www.elsevier.com/locate/jocs

Preface

Scientific computing for the cognitive sciences

1. Introduction

The methodology of Scientific Computing is widely regarded as the third pillar of science, complementary to experiment and theory. While it triggered countless breakthroughs and innovations in technology, engineering, and the natural sciences, a combination with cognitive sciences is yet a rather young field full of opportunities. This special issue is meant to stimulate interdisciplinary research in the Cognitive Sciences, based on state-of-the-art methods in Scientific Computing.

The focus of this special issue is on the modeling, simulation, optimization, and visualization of processes related to the Cognitive Sciences. Topics of interest include, but are not limited to, measurement and performance in complex problem solving, psychological aspects of method-based decision making, perception and creation of art works, emotional body language in dynamic movements, artistic expressions in motions, perception and action in complex environments, learning algorithms for natural and artificial systems, numerical cognition and functions of the brain, e.g., learning and memory.

The idea for the Special Issue dates back to the Symposium on Scientific Computing in the Cognitive Sciences which has been organized by the three guest editors at the Internationales Wissenschaftsforum Heidelberg (IWH) in fall 2010. The Symposium attracted around 50 participants from Cognitive Sciences, Psychology, Scientific Computing, Mathematics and Robotics and consisted of oral and poster presentations as well as interdisciplinary discussions. The Special Issue was announced in an open call, not limited to Symposium Participants. Twelve papers have been submitted following this call, seven of which have been selected in a careful review process.

2. Overview of the different contributions

Michael Engelhart, Joachim Funke and Sebastian Sager present with their contribution "Decomposition approach for a new test-scenario in complex problem solving" the results of a fruitful cooperation between psychology and mathematical optimization research. In problem solving research, computer-simulated scenarios have been used in the last three decades a stimulus for eliciting problem solving behavior in complex and dynamic situations. The idea of the authors is to evaluate the performance of participants in such scenarios and to correlate it with certain attributes, such as the participant's capacity to regulate emotions (e.g., [1]). However, two important questions can only be answered with the help of modern optimization methodology. The first one considers an analysis of the exact situations and decisions that led to a bad or good overall performance of test persons. The second important question concerns performance, as the choices made by humans can only be compared to one another, but not to the optimal solution, as it is unknown in general (for a solution, see [2]).

Another line of development relates to the construction of such scenarios. Usually, these test-scenarios have been defined on a trial-and-error basis. The more complex models become, the more likely it is that unforeseen and unwanted characteristics emerge in the simulation. To overcome this handicap, the authors propose to use mathematical optimization methodology not only as a tool for analysis and training, but also in the design stage of the complex problem scenario. To illustrate their idea, they present a novel test scenario, called the "IWR Tailorshop", with functional relations and model parameters that have been formulated based on optimization results. For that scenario, a tailored decomposition approach is available that solves the resulting mixed-integer nonlinear programs with nonconvex relaxations and shows some promising results of this approach.

Martin Leonhard Felis, Katja Mombaur, Hideki Kadone and Alain Berthoz deal with "Modeling and identification of emotional aspects of locomotion".

In Cognitive Sciences, there is a growing interest in emotional body language as well as emotional facial expressions. This paper presents a study of emotional body language during walking motions, based on scientific computing techniques, namely mathematical modeling, simulation and optimization. The work is based on the widely held belief, that human motions are optimal according to some criterion and that different emotions can be described as the effect of different optimization criteria acting on the dynamics of the human body. The authors use a detailed three dimensional mechanical multibody system model using realistic dynamic parameters for all body segments. At first human walking measurements are used to identify parameters, and then, forward optimal control is used to generate optimal walking for different objectives using efficient direct multiple shooting techniques.

The approach to modeling emotions proposed by the authors based on dynamic models and optimization presents in interesting alternative to the existing approaches in Cognitive Sciences, such as the kinematic models combined with motions primitives proposed by Omlor and Giese [3]. The work presented here forms the basis for further studies to determine the objective functions underlying different emotions using inverse optimal control techniques.

Cleotilde Gonzalez, Varun Dutt and Christian Lebiere address with their paper "Validating instance-based learning mechanisms outside of ACT-R" an important issue, namely the validity of the

http://dx.doi.org/10.1016/j.jocs.2012.12.001

modules of the cognitive architecture ACT-R when used in isolation. It is important to show this because ACT-R models are complex and it is sometimes unclear what the contributions of the individual modules are. Instance-based learning theory (IBLT; see [4]) has explained human decision-making in several decision tasks. IBLT works by retrieving past experiences (i.e., instances) using a subset of cognitive mechanisms from a popular cognitive architecture, ACT-R. Until recently, most IBLT models were built within the ACT-R architecture. However, due to an integrated view of cognition and ACT-R's complexity, it is difficult to distinguish between the specific contributions of ACT-R mechanisms used in IBLT from all the other mechanisms existent in ACT-R. Also, models built within the ACT-R architecture are often difficult to explain, communicate, and reuse in other systems. The paper validates the main mechanisms of IBLT when used within ACT-R and when used in isolation, outside of ACT-R. The results show that an IBLT model performs equally well in capturing human behavior within and outside of ACT-R, demonstrating the independence of these mechanisms from any complex interaction with other mechanisms in ACT-R. This pattern of results has implications for a modular view of cognition that is discussed by the authors.

Michel Taix, Tuan Minh Tran, Philippe Soueres, and Emmanuel Guigon contribute a paper with the title "Generating human-like reaching movements with a humanoid robot: A computational approach".

This paper presents a computational method that aims at implementing ideas from the field of neuroscience to the field of robotics. In humanoid robotics, one of the major problems still remains to mimic human behavior on robotics systems that have human-like shape, but still lack far behind humans in terms of performance. Simple trajectory copying does not work and does not lead to any insights about the motion. This paper aims at transferring principles of human motor control to humanoid robots using a recent computational theory of motor control. It uses a neurobiological model which is based on the theory that the energy of motoneurons is minimized and that there is a separation between dynamic and static efforts. Optimal reaching movements for the humanoid robot HRP-2 [5] are then generated using this neurobiological model and a dynamic model of the robot arm. The optimization problem is solved using a direct transcription method and an NP solver. The optimal movements can be encoded using motor primitives which are obtained from principal component analysis. This allows to generate new movements more easily, based on these primitives and a simple low dimensional optimization problem solution which determines the appropriate combination of principal components for the new movement.

Dimitri Volchenkov and Bettina Blaesing deal with "Spatio-temporal analysis of kinematic signals in classical ballet".

The authors propose a novel method for movement analysis of ballet dancers which allows to perform classifications of the movements and to determine the level of expertise of the dancer. The availability of high precision measurement devices makes it possible to collect precise data for even very long ballet sequences. Motion capture measurements are using markers arranged on the human body that would in principle allow to reconstruct the trajectories of all joints of the dancer's body. But instead, the authors are focusing directly on the motions of the markers and approximate them by piecewise linear trajectories.

As presented in this paper, the composition of the approximating linear trajectories highlights the essential movement traits and reveals the level of movement expertise of the respective dancer. The authors also introduce the notion of the entropy of shape, which captures the changes in body shape during complex motions. A computational method is presented and applied to six different figures from classical ballet which are performed by 24 different dancers representing different levels of different expertise.

Thomas Augustin, Cord Hockemeyer, Michael Kickmeier-Rust, Patrick Podbregar, Reinhard Suck and Dietrich Albert present a paper entitled "The simplified updating rule in the formalization of digital educational games" that addresses issues in the context of the Competence-based Knowledge Space Theory (CbKST; see [6]). This theory is a well-fitting basis for realizing personalization in technology-enhanced learning. Especially in the area of educational game-based learning, however, some extensions and improvements are needed. Personalization in a serious game cannot be regarded simply as the selection of game assets according to the individual learner's current competences but it must also heed to the up-keeping of a storyline, so that no part of a story is omitted that may be necessary to understand a later part. Therefore, a CbKST-compatible Markovian model for storytelling within digital educational games is proposed.

A second issue of the paper deals with the ongoing, non-invasive assessment of the learner's current competences during the game. Every action of the learner within the game should be taken into account for the competence assessment, and the assessment must be done in real-time, i.e. without any delay caused by the assessment that would interrupt the flow of the game. A simplified update procedure for competence assessment within CbKST is suggested by the authors that can solve this issue, and simulation results are presented that compare the new procedure with the classical one.

Albert Mukovskiy, Jean-Jacques Slotine and Martin Giese present a manuscript with the title "Dynamically stable control of articulated crowds". This paper also investigates human movements for complex whole-body movements, but this time the focus is on interactive movements of crowds of people which can adapt to changing environment. The particular challenge is to create such movements in real time, which addresses an important topic for computer graphics and animation. Dynamic modeling of the multibody system (in the mechanical sense) is not possible, since the resulting computation times would be too large to be run online. Instead, kinematic models, motion primitives and learning algorithms are successfully used, which are also capable to handle multi agent systems.

The authors present Contraction theory as a tool to study and improve stability properties of these interactive human movements. They discuss conditions for global stability and compute convergence rates for several walking scenarios. This work is an interesting new and systematic approach for the generation of stable collective movements of crowds of people.

3. Final remarks

For us as the guest editors of this Special Issue, it was a pleasure to cooperate with the authors and with our reviewers. We thank the authors for their interesting contributions and the anonymous reviewers for their careful evaluation of the papers. Revisions have been made in due time by the authors, and suggestions of the reviewers have hopefully increased the quality of the collected papers. For organization of the initial symposium we thank the Heidelberg Graduate School of Mathematical and Computational Methods for the Sciences at the Interdisciplinary Center for Scientific Computing at the University of Heidelberg and Carola Barth, Holger Diedam, Michael Engelhart, Martin Felis und Alexander Schubert for their support. Modeling, simulation, optimization, and visualization of processes turn out to be helpful instruments for cognitive scientists. We hope that our readers find this special issue as interesting and stimulating as we do!

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Sebastian Sager*
Institute for Mathematical Optimization Faculty of Mathematics Otto-von-Guericke-University of Magdeburg

Katja Mombaur[1]
Interdisciplinary Center for Scientific Computing, Im Neuenheimer Feld 368, 69120 Heidelberg, Germany

Joachim Funke[2]
Department of Psychology, University of Heidelberg, Hauptstrasse 47, 69117 Heidelberg, Germany

* Corresponding author. Tel.: +49 3916 718745.
E-mail addresses: sager@ovgu.de (S. Sager), kmombaur@uni-hd.de (K. Mombaur), joachim.funke@psychologie.uni-heidelberg.de (J. Funke)

[1] Tel.: +49 6221 548867.
[2] Tel.: +49 6221 547388.

Available online 20 December 2012