Tutorial for the

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Unconventional Real Time Control of Dynamical Complex Systems

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This tutorial is focused on mutual intersection of a few interesting fields of research whose core topic are bio-inspired algorithms in general. It discusses recent progress in bio-inspired algorithms that can be used for real-time control. Bio-inspired algorithms, based on its nature, are capable of real-time control of various systems, as will be reported and discussed in this tutorial. The structure of tutorial is as follows:

1. An introduction into bio-inspired methods. Light introduction into bio-inspired methods will be given with attention on evolutionary algorithms. The main principles and ideas will be explained and demonstrated by online simulations and videos. At the end will be explained and suggested under what conditions evolutions can be used on real-time control.
2. The second part introduce three showcases of real-time control of three different types of systems, a) the plasma reactor control by mans of three selected evolutionary algorithms in competition with human operator (*we have done in Oxford and published in books and Elsevier journal*), b) real-time deterministic chaos control (*1D chaos and CML-coupled map lattices systems, published in book and Elsevier journal*) and c) robot control by means of evolutionary synthesis of control commands (*published in the Springer book and journals*). The details of all three showcases are:
    a. **Showcase 1.** In this showcase, the performance of a self-organizing migration algorithm (SOMA), has been compared with simulated annealing (SA) and differential evolution (DE) for an engineering application. This application is the automated deduction of fourteen Fourier terms in a radio-frequency (RF) waveform to tune a Langmuir probe in real-time. Langmuir probes are diagnostic tools used to determine the ion density and the electron energy distribution in plasma processes. RF plasmas are inherently nonlinear, and many harmonics of the driving fundamental can be generated in the plasma. RF components across the ion sheath formed around the probe distort the measurements made. To improve the quality of the measurements, these RF components can be removed by an active-compensation method. In this research, this was achieved by applying a real-time evolutionary controlled RF signal to the probe tip that matches both the phase and amplitude of the RF signal generated from the plasma. Here, seven harmonics are used to generate the waveform applied to the probe tip. Therefore, fourteen mutually interacting parameters (seven phases and seven amplitudes) had to be tuned on-line. In previous work SA and DE were applied successfully to this problem, and hence were chosen to be compared with the performance of SOMA. In this application domain, SOMA was found to outperform SA and DE. This

control has been done on real-time running plasma reactor in the Oxford university lab. Evolutionary algorithms has handled with reactor as with real-time black box system, because mathematical description of the system was not defined.

b. **Showcase 2.** This showcase introduces continuation of our investigation on deterministic chaos real-time control by means of selected evolutionary techniques. Real-time-like behavior is specially defined and simulated with the spatiotemporal chaos model based on mutually nonlinearly joined n equations, so-called coupled map lattices (CML). Four evolutionary algorithms are used for chaos control here: differential evolution, self-organizing migrating algorithm, genetic algorithm and simulated annealing in a total of 12 versions. For modeling of real-time spatiotemporal chaos behavior, the CML were used based on logistic equation to generate chaos. The main aim of this investigation was to show that evolutionary algorithms, under certain conditions, are capable of real-time control of deterministic chaos, when the cost function is properly defined as well as parameters of selected evolutionary algorithm. Investigation consists of four different case studies with increasing simulation complexity. For all algorithms, each simulation was repeated 100 times to show and check robustness of used methods. All data were processed and used in order to get summarizing results and graphs. The importance of such control is based on fact that in contemporary engineering design it is vitally important to be able to identify presence of chaos in it or design devices, that are chaos free and/or be able to control system behavior out of such danger regimes.

c. **Showcase 3.** The showcase deals with a novelty tool for symbolic regression – Analytic Programming (AP) which is able to solve various problems from the symbolic regression domain including setting an optimal trajectory for robots in space and other industries. In this showcase the main principles of AP are described and explained how AP was used for setting an optimal trajectory for robot according the user requirements is in detail described. An ability to create so called programs, as well as Genetic Programming (GP) or Grammatical Evolution (GE) do, is shown in that part. AP is a superstructure of evolutionary algorithms which are necessary to run AP. In this showcase SOMA and DE as two evolutionary algorithms were used to carry simulations out that has been compared with already published results from GP.

At the end will be outlined frontiers i.e. future possibilities of bioinspired algorithms and it use on complex systems control. Reported methodology and results are based on actual state of art (that is a part of this tutorial) as well as on our own, already published, research.

Tutorial is designed as an **introduction**; no advanced or expert knowledge from complex systems, chaos and control is expected.

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Time of duration: according to program of the RCAR
Level of expected expertise: Introductory
Supporting material: presentation in PDF, examples in *Mathematica* and C#

Speaker bibliography:

Ivan Zelinka (born in 1965, ivanzelinka.eu) is currently associated with the Technical University of Ostrava (VSB-TU), Faculty of Electrical Engineering and Computer Science. He graduated consequently at the Technical University in Brno (1995 - MSc.), UTB in Zlin (2001 - Ph.D.) and again at Technical University in Brno (2004 - Assoc. Prof.) and VSB-TU (2010 - Professor).

Prof. Zelinka is responsible supervisor of several grant researches of Czech grant agency GAČR as for example *Unconventional Control of Complex Systems*, Security *of Mobile Devices and Communication* (bilateral project between Czech and Vietnam) and co-supervisor of grant FRVŠ - Laboratory of parallel computing amongst the others. He was also working on numerous grants and two EU projects as member of team (FP5 - RESTORM) and supervisor (FP7 - PROMOEVO) of the Czech team. He is also head of research team NAVY http://navy.cs.vsb.cz/.

Prof. Zelinka was awarded by Siemens Award for his Ph.D. thesis, as well as by journal Software news for his book about artificial intelligence. He is a member of the British Computer Society, Machine Intelligence Research Labs (MIR Labs - http://www.mirlabs.org/czech.php), IEEE (committee of Czech section of Computational Intelligence), a few international program committees of various conferences, and three international journals. He is also the founder and editor-in-chief of a new book series entitled *Emergence, Complexity and Computation* (Springer series 10624, see also www.ecc-book.eu).