Delayed Complex Systems DCS09 – Scientific report

Summary: A complex system normally involves interaction of subunits, and depending on the time scales the propagation speed of information may become relevant for the dynamics. Thus, dynamics with time delay is going to play a vital role in new emerging fields of science and technology, for instance, because the speed of modern data processing does not allow to neglect finite propagation times of signals any more. The workshop *Delayed Complex Systems* (DCS09) addressed a wide range of such topics, covering fundamental aspects and applications. We think this interdisciplinary workshop may stimulate future developments and will encourage new interactions between different lines of research within this rapidly expanding vibrant field of delayed complex systems.

The workshop was very generously supported by the *Max Planck Institute for the Physics of Complex Systems* (MPIPKS). We have received an enormous amount of positive feedback from the participants, and the workshop has been seen as an overall success. MPIPKS is widely known for its excellent workshop and seminar program which is managed to the highest standards. The support by the local organisation committee, in particular by Ms. Roscina, was extraordinary, and the perfect organisation of the event was appreciated by all participants. We as scientific coordinators of the workshop are extremely grateful to MPIPKS for having been given the opportunity to organise DCS09 at the Max Planck Institute.

Scientific focus: The new era of complexity science faces two challenges, namely dealing with the nontrivial topology of interacting subunits, and the challenge caused by time delay with the associated dynamics taking place in infinite dimensional phase spaces. Within the last fifteen years the research activities have considerably increased as many new applications have emerged in different areas, such as electronic engineering, controlling chaos, laser physics, or neuroscience. In particular, there are striking analogies between lasers and neural systems in both of which delay effects are abundant. The dynamics of complex systems with time delay is thus one of the emerging fields in dynamical systems' theory with a high impact on applications in science and engineering. The workshop addressed this issue on a very broad basis. The event covered both applications and experiments as well as mathematical foundations. The workshop had a particular focus on interdisciplinary science, bringing together researchers from different scientific disciplines to stimulate cross-fertilisation of research.

Key participants: The very generous support by MPIPKS enabled us to invite more than 30 invited speakers, all world leading experts in their field, 22 of whom gave keynote review talks. Among these main contributions a few were highlighted by evening and opening lectures, and the MPIPKS colloquium. Among the key participants were, e.g., Bernd Krauskopf (Bristol), Fatihcan Atay (Leipzig), Thomas Erneux (Brussels), and Bernold Fielder (Berlin) with respect to mathematical foundations, Ingo Fischer (Palma), Wolfgang Kinzel (Würzburg), and Rajarshi Roy (Maryland) with regards to coupled laser systems, Daniel Gauthier and Joshua Socolar (Durham) on Boolean electronic networks, and Kestutis Pyragas (Vilnius) on control. Unfortunately Michael Mackey (Montreal), a pioneer in modelling biological systems by time delay dynamics, had to cancel his visit at short notice because of personal circumstances.

Early career researchers: In total, 75 participants from 22 countries attended the workshop. Due to generous support by MPIPKS we could allocate substantial resources to support young researchers, i.e. PhD students and post-docs at an early stage of their career. 12 applicants were selected for an oral presentation, and the others could present their results in extended poster sessions. The 22 posters were on display during the whole workshop. In addition, the programme contained plenty of time for discussions, e.g., during coffee and lunchtime breaks, and further discussions were stimulated by evening events. It was very much appreciated that we could offer partial support for travel expenses, even for non-invited speakers. We gave priority to requests from young researchers from developing countries.

Dissemination and Impact: Selected plenary talks will be published by the end of this year as a theme issue on *Delayed Complex Systems* in the *Philosophical Transactions of the Royal Society A*. All contributions have been refereed and the theme issue is in print. The theme issue will considerably contribute to the dissemination of the scientific results of the workshop. From a a wider cross-disciplinary perspective the workshop was quite successful in establishing links between different scientific communities, in particular with regards to fundamental aspects in mathematics, engineering and experimental laser physics, as well as neuroscience. This claim is supported by the outcome of the very fruitful round table discussion on *Future trends in in nonlinear dynamics with delay* which was held at the workshop (the minutes are attached as an appendix). Thus, academic beneficiaries are already visible by enhancing and stimulating research across different disciplines, in particular linking science with applications of technological relevance. In that respect the workshop may even have considerable socio-economic impact on a longer time scale, by knowledge transfer of modern developments in complex dynamical systems' theory from science to technology.

Wolfram Just, Axel Pelster, Michael Schanz, Eckehard Schöll 26.10.2009

Appendix: Future trends in nonlinear dynamics with delay

Round table discussion held at DCS09, October 8, 2009. This text summarizes the round-table discussion on future trends in nonlinear dynamics with delay. Minutes by courtesy of Philipp Hövel.

Panelists: Roy, Stepan, Fischer, Longtin, Huijberts, Socolar, Pyragas, Schöll (moderator)

Opening statement by Schöll:

- effects of delay: instabilities, complex bifurcation scenarios, multistability; stabilisation of unstable states (chaos control)
- delay is ubiquitous (different systems: mechanical, electronic, optical, biological ...)

Initial statements by panelists concerning *hot topics*:

- Roy: personal remark concerning first meeting with Jack Hale at Georgia Tech in 1989 (*When do you set up that delay laser experiment?*), communication with lasers (sensitive devices, networks, propagations, synchrony, if delay changes in time, diluting changes of coupling strength in networks)
- Stepan: stabilization/destabilization, delay differential equations (DDE) vs. partial differential equations (PDE) (both have infinite dimensions), importance of meetings (get-together across different fields, interaction between theory and experiment), state-dependent delays
- Fischer: *Am I fed up with delays (which have been present for more than 30 years in the laser community)?* Answer: this workshop (coherent questions and number of different motivations of same topic), advances in experimental techniques (more complex setups and designs), prior: delay effects useless/nuisance, now: new feature, crucial role of delay, parallel universes (neuro and lasers)
- Socolar: fun to see complicated bifurcation diagram, question: on a microscopic level everything is local in time (propagation of light according to Maxwell's equations - all this is summarized by a delay term), physical delay model of interest (genetic models, fundamental structure), which systems need delay term/DDEs? new topics: using DDE where ODE are not helping
- Longtin: state-dependent delays important, e.g., in cases where low stimulus yields small velocity and large stimulus yields fast propagation, more intuitive mathematical knowledge (*Who is this guy Martin Gale?*), delay usage in real life, coupled delay systems
- Socolar: *Although we love Jack Hale, that book (he wrote) is hard to read!*
- Huijberts: *Happiness is a Banach space!* enthusiastic due to this conference, remark on importance of delay in the Netherlands (1992/3: completely neglected, nowadays: more attention), future: reach out to control theory, connect nonlinear dynamics and control theory, these communities should move together (currently: 90 percent of submitted control papers rejected straight away and additional 5 percent after review), talk to control theory
- Pyragas: most interesting talk at this workshop: Boolean networks/chaos

Discussions/remarks from the audience:

- Gauthier: nerve problems (delay in dependence on size of stimulus), nonlinear wave equations vs. state-dependent delay, genetics/biology (*delay is wrong*-thinking)
- reply by Longtin: heuristic way of throwing in a delay
- reply by Socolar: *Where do we need delay?*
- Schöll: hierarchy of descriptions (microscopic, macroscopic levels): *What can one describe with which model?*
- Jirsa: sequence (decade of the brain, connection between brain and anatomy, functionality), many different delays, large-scale modelling of brain dynamics
- Roy: 38×38-model with different delays/heterogeneity, value of simple (*toy*) models, which provide a test bed and limiting case to test against

- Socolar: theory of networks (10^6 neurons), statistical models, random networks, ensembles, distributions
- Schöll: all different levels of modeling are necessary: complex models, simple models, statistical analysis
- Orosz: delay in traffic models (3 cars only created a laugh in community, but finally introduced a new feature)
- Stepan: develop physical sense, importance of time delay unbelieved in many fields (sensor delays in robotics, tiny delays, which eventually result in large-scale dynamics)
- Atay: ODEs form a group (mathematically speaking) and can be traced forward and backward. Life, however, has a direction and so do DDEs (semi-group).
- Schöll: control theory and nonlinear dynamics, which used to exist in parallel, can profit from interaction.
- Huijberts: control engineering (see IFAC conferences), analysis and control of complex systems
- Just: reach out over disciplines (*If it is hard to talk to engineers, we must broaden our own mind. Think of important aspects in other fields.*), use tools to visualize, look for applications in control theory introducing the knowledge about delay, interaction between theory and experiment (*What are the experimental features? Where is delay important?*), power networks, social networks
- Schöll: experimental aspects: new technological developments and better experimental tools, anticipate new questions
- Garcia-Ojalvo: circadian clocks (write down equations plus delay, is the mechanism understood?), design experiments to test for necessity of introducing delay
- Longtin: *It is a challenge to convince experimentalists to do what theorists like.*
- reply by Stepan: in an experiment the frequency is easiest to measure, test for delays
- Schöll: coupled lasers and neural networks have grown together (*How far can the analogy take us?*), complex network topologies with lasers can now be realised via mode coupling (Amann talk), role of network motifs
- Fischer: consider the start (single laser) and what we have achieved until now. There was demand for laser networks already at a meeting 9 years ago, optics and neuroscience are many orders of magnitude apart, still similar effects and mechanisms can be found, history-dependent delay, backup from nonlinear dynamics for laser community
- Roy: remember the pioneers Arecchi and Haken (connecting people from different fields: fluids and lasers, quantum optics/noise and laser/chaos), listen to students for new (unusual) ideas and cross-links where others (including ourselves) are blind by prejudice, use these opportunities in workshops like this one