Summer School "Dynamic Models in Life Sciences"

The Summer School "Dynamic Models in Life Sciences" was coorganized by the Centro Internacional de Matemática (http://www.cim.pt), the European Society for Mathematical and Theoretical Biology (http://www.esmtb.org) and the European Mathematical Society (http://www.euro-math-soc.eu/) with financial support from the Fundação para a Ciência e a Tecnologia (http://www.fct.pt) and Centro de Matemática e Aplicações (Universidade Nova de Lisboa), Centro de Matemática e Aplicações Fundamentais (Universidade de Lisboa) and Centro de Investigação em Matemática e Aplicações (Universidade de Évora).

These summer schools are organized every year in a different European country. This was the first time Portugal hosted the event.

During one week in the warm weather of Evora in Summer (24th to 30th July 2011), 6 speakers presented the state-of-the art in their respective fields to more than 40 participants coming from 13 different countries. Participants mostly consisted of PhD students and post-docs in Mathematics, Biology and Physics. An important point was the Portuguese presence in the event, larger than expected.

Apart from the mini-courses (listed below), there was a poster session, where students could present their work and receive feedback from leading specialists in the field.

One afternoon was reserved to a visit to the Ducal Palace in Vila Viçosa followed by a traditional Alentejano dinner with local music.

Mini-courses: Dynamical models of Cancer (David Dingli, Mayo Clinic, USA); Adaptive dynamics and the evolution of pathogens (Eva Kisdi, University of Helsinki, Finland); Modelling Meso-evolution: adaptive dynamics and beyond (Hans Metz, Leiden University, The Netherlands); Stochastic and Deterministic Processes in Spatial Population Dynamics (Sergei Petrovskii, University of Leicester, UK); Mathematical Models in Hemodynamics. (Adelia Sequeira, Universidade Técnica de Lisboa, Portugal); Ecology and Eco-epidemiology. (Ezio Venturino, Universitá di Torino, Italy).

Organizers: Fernando Carapau (Évora), Fabio Chalub (Lisbon), Francisco Santos (Lisbon), Nico Stollenwerk (Lisbon).

An Interview

with Carla Gomes

by **JoãoGama** [Fac. de Economia da Univ. do Porto]
and **Márcia Oliveira** [LIAAD-INESC TEC, and FEP, Univ. do Porto]

Carla Gomes is a professor of computer science at Cornell University, with joint appointments in the computer science, information science, and Dyson School of applied economics and management departments. Her research has covered several themes in artificial intelligence and computer science, from the integration of constraint reasoning, operations research, and machine learning techniques for solving large-scale constraint reasoning and optimization problems, to the use of randomization techniques to improve the performance of exact search methods, algorithm portfolios, multi-agent systems, and game play.

Recently, Gomes has become immersed in the establishment of computational sustainability, a new interdisciplinary field that aims to develop computational methods to help balance environmental, economic, and societal needs to support a sustainable future. Gomes has started a number of research projects in biodiversity conservation, poverty mapping, the design of "smart" controls for electric cars, and pattern identification for material discovery (e.g., for fuel cell technology). Gomes obtained a PhD in computer science in the area of artificial intelligence and operations research from the University of Edinburgh. She also holds an MSc in applied mathematics from the Technical University of Lisbon. Gomes is the lead principal investigator on an award from the National Science Foundation's Expeditions in Computing program, the director of the newly established Institute for Computational Sustainability at Cornell, and a fellow of the Association for the Advancement of Artificial Intelligence. Gomes is currently a Fellow at the Radcliffe Advanced Study Institute at Harvard University.

Carla Gomes was an invited speaker at the 10th Intelligent Data Analysis Symposium, held in Porto from 29 to 31 October. The opportunity of having Carla Gomes in Porto motivated the present interview.

How and why did you start working in the field of Computational Sustainability?

Besides being a professor at the computer science and information science departments at Cornell University, I am also a professor at the Dyson School of applied economics and management, which is actually part of the college of agricultural and life sciences. So, at some point, some of my students from Dyson were working on problems concerning the wildlife corridors. Since they were designing corridors using very simplistic approaches, they asked my help in order to design them in a more rigorous way. Besides this, due to the land-grant missions of Cornell University and my previous intensive research on latent squares, I started working on the design of experiments involving fertilizers, using the so called spatially balanced latent squares. The scope of this work was, as I said, within the land-grant missions of Cornell. This means that, a long time ago, the State gave land to the Cornell University and so Cornell, as a counterpart, has to, at some extent, provide services to the community. One of the services is to advise farmers in how to use fertilizers. To do so, Cornell researchers run experiments on different fertilizers and tell farmers the amount of fertilizers they should use depending on the soil, on the weather, etc. Since my all career was based on working on latent squares, one day researchers from the crop and soil science asked my help in doing this. At that time, I thought that would be an easy problem to solve but I found out it was not, since we could only build spatially-balanced latent squares for squares of 6 by 6, which was too small, since they needed to experiment up to 30/35 fertilizers at the same time. And I got intrigued. After thinking deeply about the problem, we were able to make incredible progress and I started getting interested in learning about so many problems for which you really need serious computation. Due to my intersections with the college of agricultural and life sciences, pretty soon I realized that a lot of the problems in these fields involve management of resources, highly dynamic systems and huge volumes of data. For instance, you need to gather data to monitor the environment and then analyze and interpret it. But how can you extract and analyze patterns from such large volumes of data? In fact, I realized that in ecology, in biology and in environmental sciences, a lot of the problems have tremendous computational challenges and there are not that many computer scientists working in this area. That's why NSF (National Science Foundation) held a program called "Expedition in Computing", which aimed at providing grants to truly transformative research in computer science, that would set a new research direction for the field. Ideally, also with broad societal impact. This was a very competitive program and the entire USA submitted proposals (MIT, Stanford, Berkeley, Cornell, etc.). After several phases, they ended up selecting three proposals. One of them was our proposal. Since the topics of this program were really up to the candidates, I proposed to create this new field of Computational Sustainability and invest dramatically in terms of research in this area, especially because the computational challenges are so dramatic.

How Computational Sustainability will be transformative in terms of the impact in the future?

From NSF perspective, they were very much interested in programs that would be transformative in terms of computer science, but also with broad impact. From our perspective, we believe that Computational Sustainability can be transformative in the sense that the issues concerning sustainability are really deep research questions which often force us to look at aspects, such as dynamics, that we have not encountered when studying other problems. Since sustainability means planning today and thinking in terms of the future, you absolutely need to consider dynamics. So, basically, by looking at these problems, computer scientists are exposed to new issues that they haven't really worked with before and, therefore, we really need to have methodological advances to address them. This is the main reason why our own research is centered on these three topics: "dynamical systems", "constraint reasoning and optimization and statistics", "machine learning and data mining" (Figure 1). The most interesting thing in this is that the problems in each area per se really push the frontiers of the state-of-the-art today, and if we work at the synthesis of methodologies from different areas, this will lead to fundamental new methodological developments in the field. For example, the problem of material discovery that I've talked about in my presentation at IDA 2011, is a good example where data mining and machine learning per se are not going to solve the problem. Optimization per se is not going to solve the problem. You really need to develop methodologies that bring together ideas from different fields. And that it is really exciting.

People from optimization and from dynamical systems are model-based. In Machine Learning and Data Mining models are generated from data. There are different ways of using data and different mental attitudes.

My background is more in terms of optimization and reasoning but I realized that all these real-world models need to learn the parameters from older models. So, what you would say it is a machine learning problem, maybe I would say it is what we call an in voice optimization problem, in the sense that you know there's an optimization problem and now you want to know the parameters that minimize or maximize something. What's interesting is that all the models rely on data, so this artificial separation between optimization and machine learning does not make much sense. For instance, in the decision making process, one of the steps is "data acquisition". Here, you have sensors that collect data, for instance, about flight calls or signals, but what you want to know is species. So, after collecting data, you need to interpret it. To do so, it is common to perform model fitting. But, sometimes, you need to go back because you realize that your initial samples are very biased, and so you need to collect more data to increase the accuracy of the models. Another important step is related to policy optimization: I am going to make decision in terms of what areas to protect for the birds, which is based on the data I got. And, because of data, I may even have to go back to define my procedures in terms of collecting data, and even to reformulate my own objectives, because this project is not linear and gives you a lot of feedback.

This is a very iterative process, even though in terms of disciplines you have people doing machine learning, optimization, etc., but clearly there are interactions that have to be effective.

Your research topic – Computational Sustainability - involves very different areas.

Yes, we have a very interdisciplinary group, which involve mathematicians, biologists, sociologists, computer scientists, and that's exactly the point of our project.

You succeed in a very competitive society. What are your recommendations for those who aspire to become leaders on their research field?

Be passionate about your research. Always set high-standards, have the courage to ask and address very hard and risky questions, since those are the most rewarding when you succeed. Be driven and committed. Work hard, very hard. Focus on important questions and not trivial ones, and be obsessed about that. For women, you need to be really confident and positive, since they tend to think they are not good enough. Challenge yourself. In terms of research topics it is very important to know what the community is doing and to be aware of the hard topics, not only for you to follow the literature, but at the same time for you to have a chance to pose different questions, but related to those of the community. Sometimes you do not really know the answers to your problems, but you need to be able to deal with this kind of uncertainty. One thing that is very important is collaborations and networking. That it is how you make progress in research, how you bridge together areas that are completely different and that will generate fundamental new ways to solve the problems. For the young people, it is important to network, go to conferences, to try to interact with researchers, to actively look for collaborations, to get involved in research projects, to network a lot, to travel a lot, to be on program committees, etc. Basically, you need to learn how to "sell your work", which means that it is important to do great work, but it is also very important to be able to talk about your work in a way that's going to be easy to communicate with people. You need to learn how to give talks that are going to be appealing, that people find exciting, so they can get interested and follow up on your work. Write beautiful papers. Publish a lot, otherwise you may perish. It is often good to do a Pos-doc so that you can go and collaborate and get a lot of research going. Finally, make your own luck, your serendipity, and create opportunities by interacting, collaborating and doing a lot of things, since as Louis Pasteur said "chance favors the prepared minds".

Sympletic surface group representations and Higgs bundles

by Peter Gothen*

1. Introduction

A surface group is the fundamental group of a surface. In this article we survey some results on representations of a surface group on a real vector space preserving a symplectic form. We emphasize in particular some results which have been obtained using holomorphic and algebraic geometry, through the use of Higgs bundles and a fundamental result known as the non-abelian Hodge Theorem. Though this theory itself is rather involved, the results on surface group representations can be explained without bringing it into play and this is one of our main aims.

This paper is organized as follows. After some preliminaries, we start by focusing on the case of representations in $\mathbb{R}^2$ with its standard symplectic form. Here we explain some seminal results of W. Goldman which are closely related to uniformization of surfaces by the hyperbolic plane.

We then move on to higher dimensional representations and explain some results which generalize those of Goldman and also point out some differences with the 2-dimensional situation.

Finally, we briefly outline how methods from holomorphic and algebraic geometry can be applied to the study of surface group representations through Higgs bundles and the non-abelian Hodge Theorem. This beautiful theory involves algebra, geometry, topology and analysis and has a long history. A few important milestones can be found in the work of Narasimhan-Seshadri [22], Atiyah-Bott [1], Donaldson [5], Hitchin [17], Corlette [4] and Simpson [24].

We have left out many important and fascinating aspects of surface group representations. To finish this introduction we mention a few places where the interested reader may find further information and references and also other points of view. Nice surveys are provided in Goldman [14] (emphasizing the point of view of geometric structures on surfaces) and Burger-Iozzi-Wienhard [3] (emphasizing methods from bounded cohomology). For an application of Higgs bundle theory to representations in isometry groups of hermitian symmetric spaces of the non-compact type, see the survey [2].

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2. Surface group representations and character varieties

Let Σ be a compact oriented surface without boundary of genus g. The fundamental group of Σ has the standard presentation

$$\pi_1\Sigma = \langle a_1, b_1, \dots, a_g, b_g \mid \textstyle\prod_{1\le i\le g}[a_i, b_i] = 1\rangle \qquad (2.1)$$

in terms of generators and relations.

Let G be a connected semisimple Lie group. In this paper we are mainly interested in the case when $G = \mathrm{Sp}(2n,\mathbb{R})$ is the real symplectic group but we shall also have occasion to consider the cases $G = \mathrm{GL}(n,\mathbb{C})$ and $G = \mathrm{PSL}(2,\mathbb{R}) := \mathrm{SL}(2,\mathbb{R})/\{\pm I\}$. Since all of these groups are defined via a linear action on a vector space, the motivation for the following definition is clear

Definition 2.1.—A *representation* of $\pi_1\Sigma$ in G is a homomorphism

$$\rho : \pi_1\Sigma \to G.$$

In view of (2.1) a representation ρ is uniquely prescribed by a $2g$-tuple $(A_1, B_1, \dots, A_g, B_g)$ of matrices in G satisfying the relation $\prod[A_i, B_i] = 1$. Thus, if we denote the set of all representations by

$$\mathrm{Hom}(\pi_1\Sigma, G) = \{\rho : \pi_1\Sigma \to G\}.$$

we get an identification

$$\mathrm{Hom}(\pi_1\Sigma, G) \cong \Big\{(A_1, B_1, \dots, A_g, B_g) \mid \textstyle\prod_{1\le i\le g}[A_i, B_i] = 1\Big\} \subset G^{2g}. \qquad (2.2)$$

with a subspace of the set of $2g$-tuples of matrices in G.

3. Fuchsian representations

Consider the upper half plane model of the hyperbolic plane

$$\mathbb{H}^2 = \{z = x + iy \mid y > 0\}.$$

The metric is $ds^2 = (dx^2 + dy^2)/y^2$ which has constant curvature -1. The group of orientation preserving isometries of $\mathbb{H}^2$ can be identified with $\mathrm{PSL}(2,\mathbb{R})$, acting on $\mathbb{H}^2$ via