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Control and Machine Learning

Control, or Cybernetics, according to the term coined first by Ampère and then popularized through the works of Wiener, is the science of control and communication in animals and the machines. The motivation goes back to ancient times: machines that automatically carry out man's work so that he can be freer and more efficient.

The goals of Control are therefore, to a large extent, those of the modern discipline of Machine Learning.

In this talk we shall present some fundamental mathematical notions and techniques in Control that have strongly influenced the emergence and development of the field of Machine Learning.

We will do it analyzing Neural Ordinary Differential Equations (NODEs) from a control theoretical perspective to address some of the main challenges in Machine Learning:Supervised Learning and Universal Approximation.

We adopt the perspective of the simultaneous or ensemble control, according to which, each item to be classified or learned corresponds to a different initial datum for the Cauchy problem of a NODE. The challenge is then to control the ensemble of solutions to the corresponding targets by means of one sole control. We present a genuinely nonlinear and constructive method, allowing to show that such an ambitious goal can be achieved, estimating the complexity of the control.

This property is rarely fulfilled by the classical dynamical systems in Mechanics and, as we shall see, it is intimately related to the very nonlinear nature of the activation functions governing the NODEs under consideration. It allows deforming half of the phase space while the other half remains invariant, a property that classical models in mechanics do not fulfill.

Analyzing the natural consequence of Universal Approximation, we shall also establish the link with optimal transport.

We shall also illustrate how, classical concepts and tools of Control Theory, such as the"turnpike property"allow the training of Neural Networks ina more stable and robust manner.

Joint work with BorjanGeshkovski, Carlos Esteve, Domènec Ruiz-Balet and Dario Pighin.

Bio

Enrique ZuazuaIriondo (Eibar, Basque Country – Spain, 1961) holds a Chair of Dynamics, Control and Numerics – Alexander von Humboldt Professorship at FAU-Friedrich–Alexander University, Erlangen–Nürnberg (Germany). He also leads the research project "DyCon: Dynamic Control", funded by the ERC – European Research Council at the Department of Mathematics, at UAM – Autonomous University of Madrid and Deusto Foundation, University of Deusto – Bilbao (Basque Country, Spain),where he holds secondary appointments as Professor of Applied Mathematics (UAM) and Director of CCM – Chair of Computational Mathematics (Deusto).

His research in the area of Applied Mathematics covers topics in Partial Differential Equations, Systems Control, Numerical Analysis and Machine Learning, and led to fruitful collaborations in different industrial sectors such as the optimal shape design in aeronautics, the management of electrical and water distribution networks and the design of recommendation systems.

His research hada high impact (h-index 44) and he has mentored a significant number of postdoctoral researchers and coached a wide network of Science managers.

He holds a degree in Mathematics from the University of the Basque Country, and a dual PhD degree from the same university (1987) and the Université Pierre et Marie Curie, Paris (1988). In 1990 he became Professor of Applied Mathematics at the Complutense University of Madrid, to later move to UAM in 2001.

He has been awarded the Euskadi (Basque Country) Prize for Science and Technology 2006 and the Spanish National Julio Rey Pastor Prize 2007 in Mathematics and Information and Communication Technology, the Advanced Grants NUMERIWAVES in 2010 and DyCon in 2016 of the European Research Council (ERC) and the SIAM W.T. and Idalia Reid Prize 2022.

He is an Honorary member of the of Academia Europaea and Jakiunde, the Basque Academy of Sciences, Letters and Humanities, Doctor Honoris Causa from the Université de Lorraine in France and Ambassador of the Friedrisch-Alexandre University in Erlangen-Nurenberg, Germany.

He was an invited speaker at ICM2006 in the section on Control and Optimization.
From 1999-2002 he was the first Scientific Manager of the Panel for Mathematics within the Spanish National Research Plan and the Founding Scientific Director of the BCAM – Basque Center for Applied Mathematicsfrom 2008-2012.

He is also a member of the Scientific Council of a number of international research institutions such as theINSMI-CNRS and CERFACS in France and member of the Editorial Board in some of the leading journals in Applied Mathematics and Control Theory.