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Structure Evolving Systems and Control

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Existing methods in Systems and Control deal predominantly with fixed systems, where components, interconnection topology, measurement-actuation schemes and control structures and dynamics of controllers are specified. The process of overall design of a system (process synthesis-global instrumentation - control) has a cascade nature. As we go through the different stages we have an evolution of structure, topology, properties, model accuracy and behaviour of the overall system. Furthermore, design is an iterative process and thus it is characterised by “early” and “late” stages. Decision making at each stage is largely based on local criteria; this is a consequence of overspecialisation and there is lack of a holistic co-ordination of the overall design. Controlling, or directing such an evolutionary process requires a methodology that is based on results characterising the potential for evolution of system properties (genetic selection of alternatives), explain the link of structure and parameters to invariants and indicators, characterise the “good” or “bad” potential for design, and provide means for addressing “structure assignment” problems. This demonstrates that a new and richer form of Control Theory dealing with the management of structure evolution is required.

The need for integrating process and control design issues has been recognised in the Process, Aerospace and other areas of applications, but with a few exceptions (early work in Process Control ,EU project SESDIP), little attention has been given in the development of an integrated Systems and Control Theory Based Framework that may integrate the overall process. The integration of traditional design stages, such as Process Synthesis (PS), Global Instrumentation (GS) and finally Control Design (CD) is a complex problem that is characterised by different forms of system evolution. This evolution has two main features: The first is linked to the natural evolution of the system structure as this is shaped through the design stages of process synthesis and global instrumentation and it is referred to as structural evolution. The second stems from the need to address design and decision problems at “early” and “late” stages of system design (as part of an iterative design cycle) using models with a variability in their complexity and referred to as design time evolution. The paper aims to describe those two forms of system evolution from a systems and control theoretic viewpoint, review and unify existing results and define a road map for research in structural system methodologies; this is essential for the development of the control theoretic aspects of the complex problem of systems integration and opens up a new field for research for Structural Control Methodologies. The paper addresses a number of control theory issues intimately linked to overall system design, which have a clear structural nature and express aspects and stages of the evolutionary design process. Amongst the issues addressed are:

i. iModelling issues in Early Process Design, well conditioning of “progenitor models” and structure evolution.
ii. Properties of composite systems with given interconnection rule and the problem of completeness.
iii. System properties as functions of the interconnection rule and subsystem input, output structure selection.

iv. Structure assignment by design, or modification of the system interconnection graph, selection of the effective set of inputs, outputs.

v. Lifecycle issues in Systems Design, Re-engineering and graph based evolutions.

vi. Algebraic computations in the presence of parameter uncertainty. Approximations to algebraic notions.

The above areas express new and major challenges in a new paradigm for Control Theory, represented by the family of Structure Evolving Systems (SES). This family departs considerably from the traditional assumption that the system is fixed and its dominant features are:

I. The topology of interconnections is not fixed but may vary through the life cycle of the system (Variability of Interconnection Topology Complexity).

II. The overall system may evolve through the early-late stages of the design process (Design Time Evolution).

III. There may be Variability and/or uncertainty on the system’s environment during the lifecycle requiring flexibility in organization and operability (Lifecycle Complexity).

IV. The system may be large scale, multi-component and this may impact on methodologies and computations (Large Scale – Multi-component Complexity).

V. There may be variability in the Organizational Structures of the information and decision-making (control) in response to changes in goals and operational requirements (Organizational Complexity Variability). The paper provides a framework for discussing the fundamentals of this new challenging paradigm, reviews existing results and defines a research agenda with a clear structural framework.

Biography

Professor Karcanias received the Diploma in Mechanical and Electrical Engineering, with specialisation in Electrical (five year degree), from the National Technical University of Athens in 1972 and the M.Sc and Ph.D degrees in Control Engineering from UMIST, England in 1973 and 1976 respectively. His research involved the development of dynamical, algebraic and geometrical aspects of the fundamental concepts of poles and zeros of Linear Systems. He received his DSc from City University in 1990 for his contributions to Control Theory.

During the period 1974 to 1980 he has carried out research in the Control and Management Systems Group of the University of Cambridge as a Research Assistant and then Research Fellow working on the development of an algebraic approach to the characterisation of the basic concepts and tools of the Geometric Control Theory. In 1980 he joined the Department of Systems Science of City University as a Lecturer and then joined the Electrical Engineering Department of the same university where he was promoted to a personal chair in 1993 as Professor of Control Theory and Design. He is now Associate Dean for Research in the School of Engineering and Mathematical Sciences and he is Director of the Systems and Control Centre of the School.

His research has been in the development of the algebraic, geometric and algebra-geometric methods for Control Theory, where two novel approaches based on Matrix Pencils and Exterior Algebra-Algebraic Geometry have been introduced. His research on the Control fundamentals has been accompanied by an effort to migrate Systems and Control to Complex problems, such as the development of a Control based methodology to Systems Integration and the development of methodology for Systems Based Instrumentation. This research has been supported by EPSRC and a number of EU projects. He has been the author/co-author of over two hundred scientific publications, the holder of a number of research grants including eight major EU grants and supervisor of over twenty completed PhD thesis. His research publications are in the areas of Linear Systems, Mathematical Systems Theory, Control Theory and Design, Algebraic Computations, Mathematical Methods for Control, Systems Theory of Measurement,
Systems and Control to Complex Systems, Integrated Systems Design, and History of Systems and Control. The main drive of his current research is the development of systems and control for complex systems, by developing the theory required for the new systems paradigm of "structure evolving systems".

He is Fellow of IET (IEE), Fellow of IMA and senior member of IEEE. He is a member of EPSRC College since its establishment, member of many EU panels on research, Editor of IMA Journal of Mathematical Control and Information, member of Editorial Board of IEEE Control Conferences and serves on the editorial Board of a number of Journals and Conferences.