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A Challenge for a New Organization in Systems and Control Curricula

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Abstract: The traditional control curricula organization is not adequate for the new generations of students. This paper proposes the challenge to change completely the sequence of traditional control subjects. Firstly it proposes to develop control as a branch of information processing sciences. Paradigms for information are proposed: integral-differential paradigm, data-paradigm, linguistic paradigm. The control curricula in undergraduate education should start by fuzzy control, exploiting heuristics, games, intuition, in order to stimulate the student's interest for the area. Control may be faced as a branch of machine learning and controllers have learning capabilities that can be classified into a proposed hierarchical structure. One introductory course for systems and one for control are proposed with syllabus oriented by this view.

1. INTRODUCTION

It is becoming harder and harder to recruit bright young students for the control area. This problem, faced worldwide, brings about the necessity of a deep reflection from the control community. Young generations have a brain trained in a significant different manner from the times of their fathers. They are very well developed in learning by examples, heuristic, video computer games, etc. By contrary structured abstract thinking, to which traditional organization of control curricula is oriented, is a hard task for them.

The control curricula in undergraduate education should take these differences into consideration. The way a student feels the first course determines if he will follow others courses in the same subject. A deep change in control curricula is needed to attract more students. However, as (Samad,1999) pointed out, no significative changes have been made and Control education has remained relatively invariant during the last decades. Generally the sequence of control curricula is as it was 40 years ago: "classical" continuous control, "modern" continuous control, digital control, optimal control, etc., in most cases limited to the model based framework. Recent experiences, such as those of (Gravdahl, 2004), (Djaferis, 2004)and (Murray, 2004) proposed significant and interesting improvements, but principally in learning methodologies to follow that old sequence.

The education in systems thinking is recognized as more and more important in all fields, particularly in engineering and science. New programs of systems and control curricula, with enough flexibility to efficiently address the educational needs of distinct groups of students are needed, as pointed out by (Djaferis, 2007). This is presently the main challenge to our community of systems and control.

This paper proposes to change completely the systems and control education at introductory levels. Firstly it proposes to develop control as a branch of information processing science. Paradigms for information are proposed: integral-differential paradigm, data-paradigm, linguistic paradigm.

In Section 2 the information space is proposed for the third synthesis of control, according to a proposed historical perspective. Section 3 proposes some taxonomy for intelligence and learning in systems. Section 4 briefly proposes a new organization of the curricula in systems and control fields, according to which Section 5 proposes a syllabus for introductory courses in systems and control, with the aim to increase the interest of the field as discussed in the Conclusions Section 6.

2. A PERSPECTIVE OF THE CONTROL HISTORY LEADING TO THE INFORMATION HYPERSPACE

The History of Control may be visualized by Figure 1 (Dourado, 2004)). For extensive treatment of control History see for example (Mayr, 1970), (Bennet, 1986), (Lepschy, 1992). After the Ancient artist phase the Classical Control Theory emerged in 1950 as a synthesis of all previous developments. Briefly two separated roads started: the complex domain and the time domain (state variables), generating the first schism in control. Robust Control, by 1970, synthesized the two roads but immediately a second schism started- the Model Based and the Intelligent (non-model based) approaches, leading to intense and some times violent discussions. See for example (Zadeh, 1996).

In the last decade there has been an explosion of works to synthesize both roads, profiting from the potentialities of both approaches. It is time for the third synthesis in control.

This synthesis (the third one in Control History) can probably be made in the framework of Information Hyperspace, an extension of State Space to include non numeric (verbal) and qualitative information. In Information Space the quantitative

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information forms a sub-space. Fuzzy state-space has already been introduced for example by (Grupta, 1996).

In fact a quantitative measure can be considered as a particular case of fuzzy set (qualitative information). For example, 10.3 is the value of a variable that can be represented by the fuzzy set of Fig. 2a), whose support is the interval 10.25 to 10.35. It can be made if we have an instrument with such precision; if not then we have for example 10 (Fig. 2b)), defined by a fuzzy set with support 9.5 and 10.5. Still with lower precision (in decades) we would have a fuzzy set with support [0.5 1.5] (Fig. 2c)), and so on, until the measurement is verbalized (Fig. 2d)).

So the quantitative information space is relative to the measurement precision we can afford. If the concept of granularity of information is introduced, then it can be said that granularity is the additional dimension transforming the state-space into information (hyper)space. Quantitative information has smaller granularity, while qualitative information has bigger granularity. Granularity may be tentatively defined as the minimum difference between two pieces of information such they can be distinguished.

But the lack of precision (bigger granularity) cannot be an obstacle to control (we guide our cars in complex everyday life with granular information …). Fuzzy control is one way to do it when the information has very low precision (in traditional sense). Probably new mathematical tools are needed to obtain a unifying approach.

Being granularity the additional dimension of information space, models may be developed with different granularities. Since nowadays in this context models are almost always to be programmed in computers we may define model as a representational tool reducible to a piece of computer code enabling the computer to represent some part of the world. With that code it can process perceived information from that world and produce other information about that world with some usefulness.

Models may be defined in the framework of three paradigms: (i) the Integral-Differential paradigm, where systems start to be represented by integral and/or differential equations obtained by first principles knowledge, (ii) the Data paradigm where only data is available, not first principles knowledge, and (iii) Linguistic paradigm where systems are described by words issued from empirical knowledge. These paradigms will structure the organization of systems and control fields.

Computational models of systems, meaning basically discrete models, can be studied in the framework of ARX and ARMAX time series, as a consequence of the memory content of dynamic systems. In this framework with the support of algebra of blocs, it is possible to face the controller synthesis as a block-building task in order to obtain a pre-defined closed loop behavior. This study can be made using the forward and backward operators instead of the Z-transform.

3. DEFINITIONS OF INTELLIGENCE AND LEARNING

The terms "intelligent systems" and "intelligent control" are intensively used nowadays in control community and outside it. However there is not yet an agreement about what intelligence should be considered in this context. This fact creates walls to communication, and sometimes different people use the same term to express different things or use different terms to say the same thing.

Long discussion have been made about what should be an Intelligent Systems (see for example (Antsaklis, 1993)), but there is still no consensus. If one can accept the general simple definition that a system is intelligent if it can sense its environment, detect its changements and adapt its behavior and goals to these changements (to pursue its own goals) then it is easy to arrive to a definition of intelligent control.

Definition 1. Intelligent controller. A controller is intelligent if it can percept changements in the controlled system or in the environment of the controlled system and adapts itself to those changements in order to maintain the performance of the control system.

Adaptation in this definition is a consequence of intelligence. How can the controllers developed during the last decades be included in this definition? How broad and unifying is this definition?

Usually adaptation, in the control community, is associated with parameter estimation. In order to give to it a more general meaning, learning is proposed as the extension (in the information space) of adaptation.

Definition 2. Learning. Learning is the procedure (sequence of operations) used by an intelligent controller to change its own behavior as a consequence of the changements in the behavior of the controlled system.

Several levels of learning may be defined:

Level L^0 - corresponds to the fixed control theories, including the several levels of robustness controllers.

Level L^1 – parameter learning- includes controllers with on-line parameter estimation in linear case, in neural networks (connection weights and parameters of activation functions), in fuzzy systems (scale factors for fuzzification and defuzzification, centers and widths of membership functions).

Level L^2 – structure learning- includes gain-scheduling controllers, switching controllers, on-line order estimation, on-line fuzzy rule base construction (number of antecedents, association of antecedents and consequents, number of rules), on-line pruning and growing techniques in neural networks and neuro-fuzzy systems, etc.. Controller reconfiguration in fault diagnosis could also be included here.

Level L^3 – trajectory learning-optimization methods at supervision level for process control, robot path planning, etc.

Level L^4 – task learning- short-term production planning in process control, autonomous agents (robot) task planning.

Level L^5 – goal learning – includes long-term production planning in process control, the capability of a system to find its own goals in a complex multi-system structure (for example in a set of autonomous robots working together).

Level L^6 - learning organizations – including the concepts of medium and long term learning in a multi-system changing organization of agents (systems) with complete autonomy.

In the highest levels of learning one meets Artificial Intelligence and Machine Learning. This will be a necessary step to enlarge the autonomy of decision of automatic systems. It will also be the opportunity to maintain Control, as a scientific and technical field, in the foreground of progress. In this framework, control is mainly the art and the science of information processing in order to make a decision (by an artificial controller or an agent) to act over mass and energy to reach some target defined by the system builder.

This definition allows to include all existent approaches for controller synthesis and those to come yet.

4. A NEW LEARNING SEQUENCE

Actually most of the Universities use a sequence of courses as illustrated in Fig. 3. Most of the introductory courses are basically as they were 50 years ago, despite the deep revolution in all aspects of life and technology. Each course deeps its subject in a detailed fashion.

However a very different sequence is possible, where the division is according to the level of complexity, as in Fig.4. In each level the student is faced with the three paradigms.

5. INTRODUCTORY COURSES ON SYSTEMS AND CONTROL THEORY

At this level control subjects must be taught in a way accessible to most of science and engineering students, and the first feelings they will have are decisive. Empirical thinking, learning by doing are the basis for caching their motivation to more formal thinking.

5.1. A course on systems

General notions of dynamic systems should be the starting point. The general systems theory approach, starting in the seminal book of Bertalanphy (1968) seems to be the most adequate perspective, including biological systems so popular now-a-days. A proposal for a program:

1. Systems: definitions and basic concepts. System, subsystem, hipersystem. Input, state, output, boundaries. Synergy and interaction. Entropy. Systemic thinking.

2. Systems representation: overview, objectives and tools. Granularity of information. Different kinds of computational models (according to granularity of information).

3. The linguistic paradigm. Qualitative knowledge, fuzzy logic and fuzzy systems. Fuzzification, inference, defuzzification. Rule-based fuzzy systems

4. The data paradigm. Linear empirical models ARX and ARMAX (deterministic). Parameter learning in the deterministic case (least squares). The nonlinear (neural) network architectures (MLNN, RBF) for NARMAX models. Estimation –learning (the backpropagation algorithm and the RLS technique). Use of computational tools.

5. The integral-differential paradigm. Systems representation by differential and difference equations. Examples of technological, biological, economic, social systems.

6. The transfer function and the state equation for linear systems (mainly discrete formulation) and its relations. Types of dynamics, stability. The characteristic equation, initial conditions and chaotic behavior.

7. Conclusions. The systemic approach to thinking about the world. Case-studies.

5.1. A course on control

In the author opinion to start control with differential equations, Laplace Transform, and complex analysis, is the most effective way to push students away from the area. Nyquist criteria is a very intellectually stimulating concept, but for a starter it is not. Finally, in practical life, will a control engineer use frequently Nyquist criteria for controller synthesis? Now the computational tools are very different from the 1950s. Simulation is more effective, for most people, than formal analysis. Moreover, for real dimension practical problems, there is no model so precise as to allow applying the Nyquist criteria in a reliable way. This does not mean that the most sophisticated tools of classical control are no more useful. As (Lurie, 2007) supports, they did not loose their relevance. The question is where to learn them, at starting or at advanced level? In the author opinion they should move to advanced level specialized courses, where the formal methods, such as Laplace Transform, Root-Locus, Optimal control, Robust Control, etc., should be included.

The linguistic paradigm is proposed here as the first to be faced. Fuzzy controller, in a not very formal way should be the first to be studied and practicized by students as a game. The students should be challenged to develop a fuzzy regulator for a laboratorial process, without any formal modeling of it. This would start the control study as a computer game, challenging the young students and catching their attention, interest and enthusiasm for this important area. The proposed introductory course would be:

1. The control problem: systems and feedback. Fundamental concepts

2. The game of fuzzy control. Synthesis in the linguistic paradigm. Some current fuzzy control systems: the fuzzy two and three term controllers. Implementation issues. Mamdani and Takagi-Sugeno-Kang controllers.

3. Project in the integer-differential paradigm (discrete transfer function). Block diagram and algebra of blocks. Closed loop shaping (RST parametric controller) and Diophantine equation. Integral control. Minimal Prototype

and Deadbeat controllers and the problem on model inversion. Computation and implementation issues. Synthesis in data paradigm with minimal knowledge. Knowledge extraction from data: identification. Three term controllers (discrete) and learning of its parameters (tuning). Recursive (on-line) parameter learning in linear case and adaptive control.

4. Linear State variables feedback. Main characteristics and advantages. Eigenvalue assignment. Comparison with RST controllers.

5. Comparison of the different approaches and a unified view. Conclusion.

One may argue that this is too ambitious. It would be in fact if a very formal and detailed development would be adopted. However an intuitive approach, using only the strictly needed formalism (for example not using the Z Transform but just the backward and forward shift operator), supported by good existing software and based on experimentation.

6. CONCLUSIONS

The proposed learning sequence in systems and control aims to resolve the fact that most students find control a very difficult subject, too abstract, too mathematical. Developing the student's intuition and profiting from their generally recognized well developed ability for empiric learning, it may give an important contribution to stimulate their interest, motivating them for further studies. By this way they may disseminate control as a well accepted and important subject in most of science and engineering discipline.

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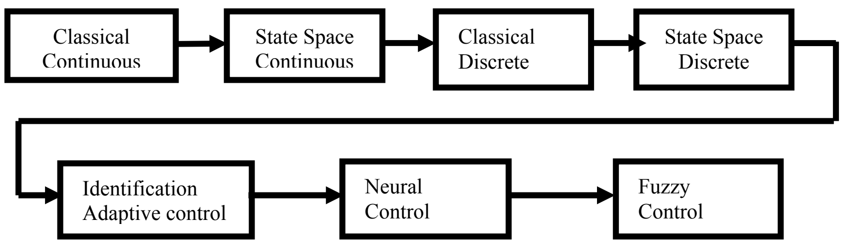

Figure 3. The traditional sequence of Systems and Control Courses.

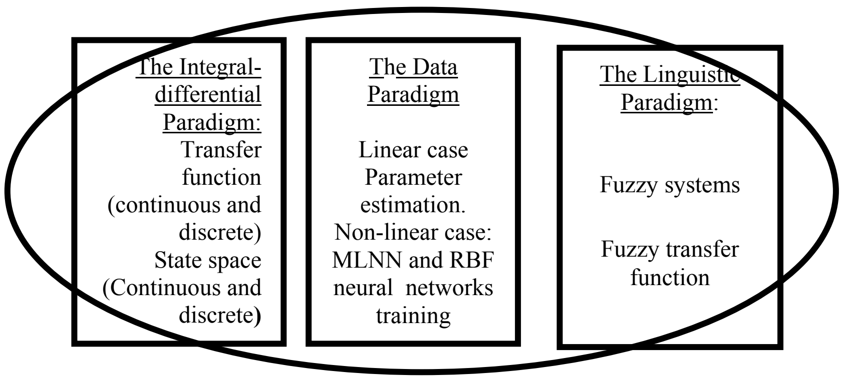

Figure 5. The proposed construction of an introductory control course in information space

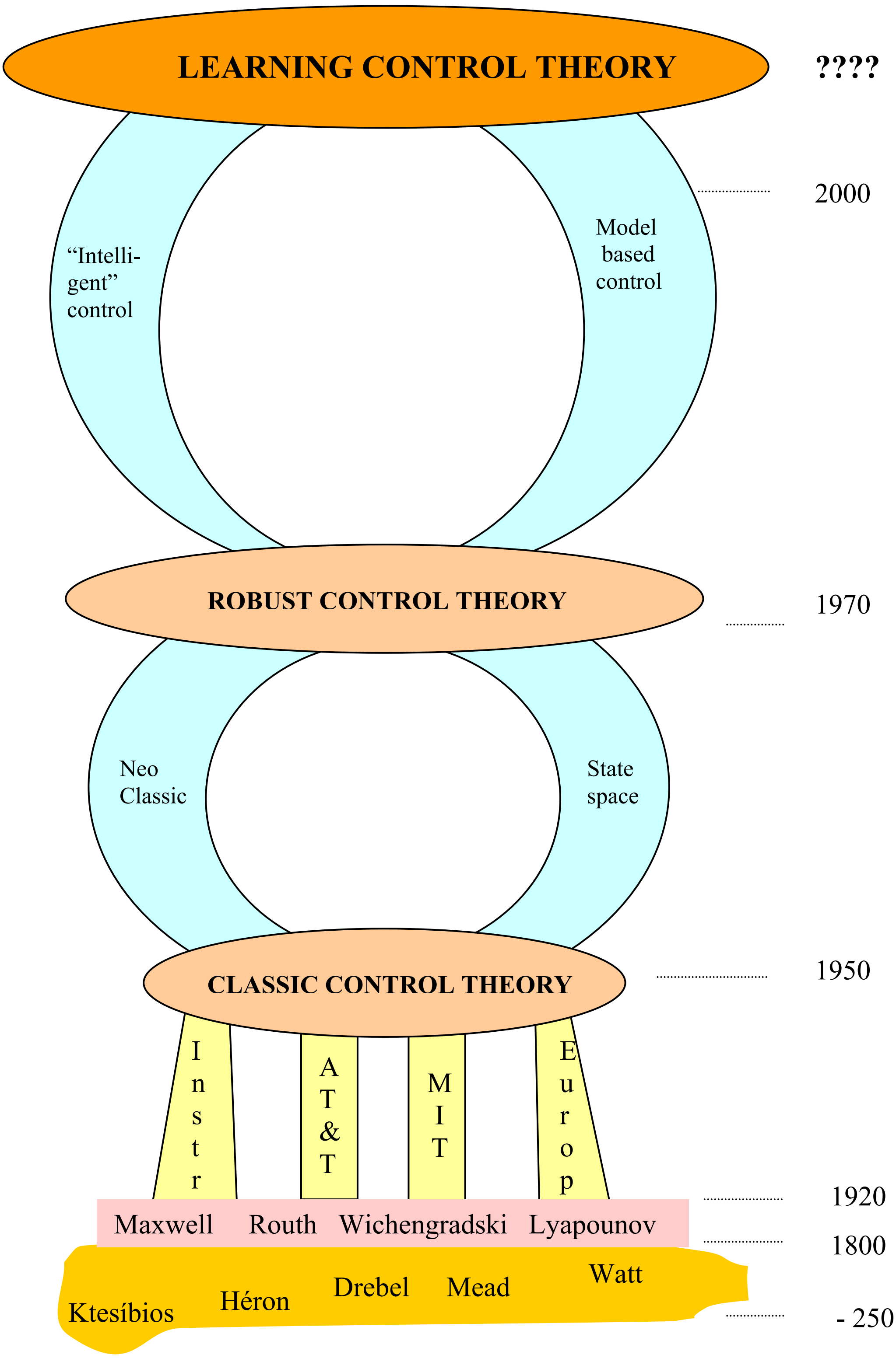

Figure 1. A vision of the control history.

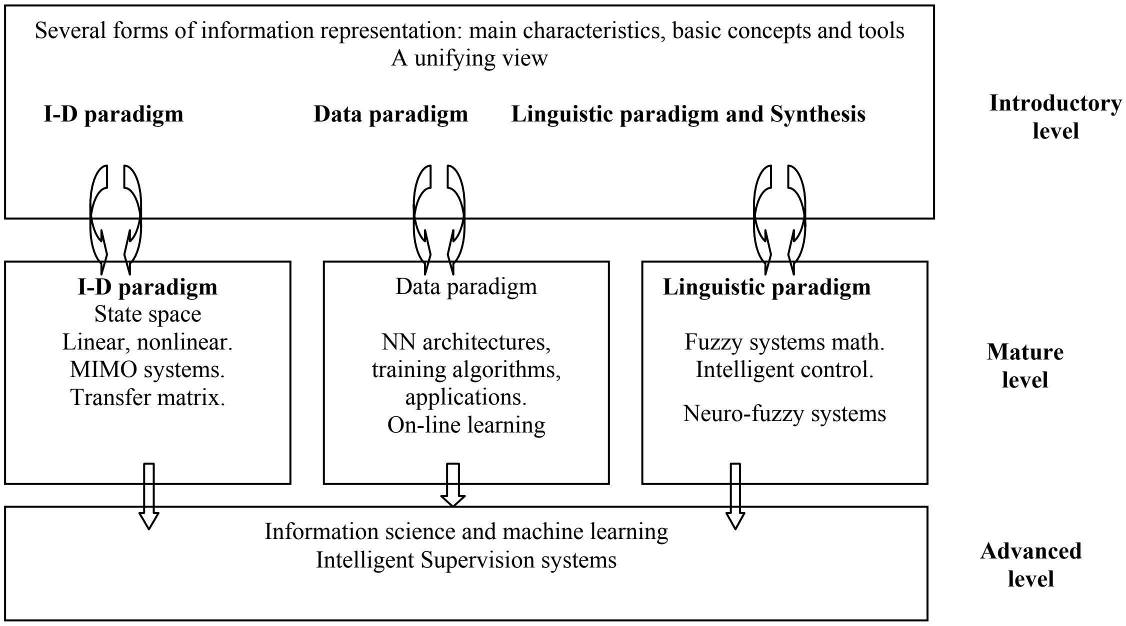

Figure 4. The three levels of complexity to organize courses in the framework of the three paradigms.

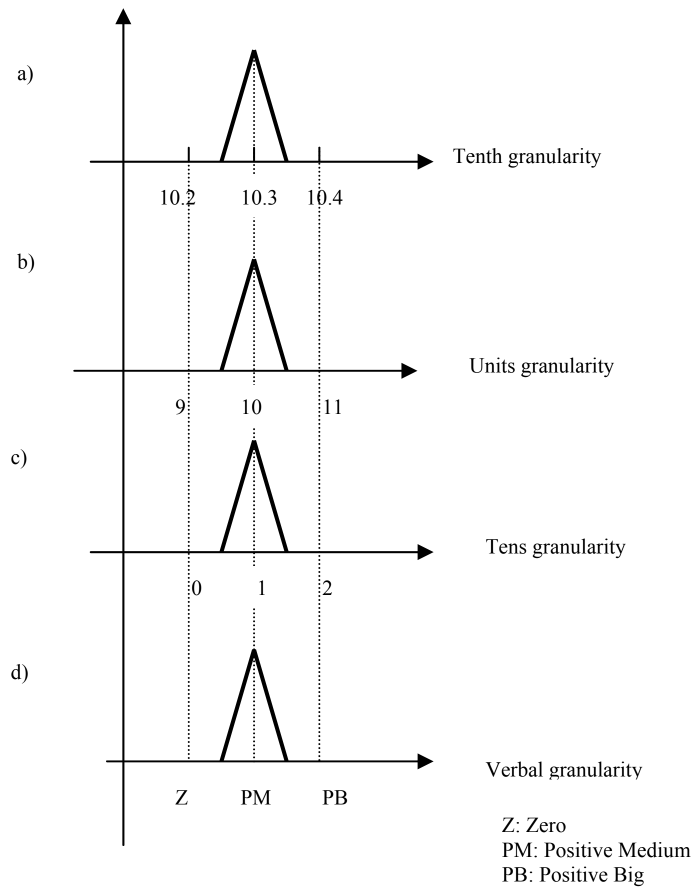

Figure 2. Information in several sizes of granularity. Fuzzy sets are defined in a verbal granulariry. The scale changes with granularity. The type of information (quantitative, qualitative) is connected to muti-scale representation. In the vertical axes one has values for the characteristic function, maximum is 1.