FOUR DEFINITIONS AS A CONTRIBUTION TO THE THIRD SYNTHESIS IN CONTROL

António Dourado

CISUC- Centro de Informática e Sistemas da Universidade de Coimbra
Departamento de Engenharia Informática
Pólo II, Pinhal de Marrocos, 3030 Coimbra Portugal
Phone: + 351 239 79 00 00. Fax: + 351 239 701 266
e-mail: dourado@dei.uc.pt

Keywords: systems and control; taxonomy; perspectives in control; control education.

Abstract:

Definitions of some key concepts (model, intelligence, learning, control) are proposed as a contribution to unify the different paradigms and cultures actually existent in systems and control. These definitions are made in the information space, an extension of the state space with the additional dimension of information granularity. The aim is to create a common language and a common framework where all cultures of control can meet and work together for the progress of the science and technology in order to maintain Control as a leading discipline.

1 Introduction

There is actually a big disorder in the Systems and Control field. Several paradigms are being used; people from different scientific cultures are contributing and the resulting situation is a lack of structured organization in such a way that a coherent taxonomy of methods and tools could be defined. This leads to a misunderstanding about the nature of Control as it is today and its socio-economic importance. As a consequence Control, as a scientific and technical field, may loose popularity among academia community in the information era. There have been [5] [2], and are being discussions about the situation and the needs to give a step further (see for example the interesting papers in IEEE Control Systems Magazine vol. 19 nº5, October 1999). For example in control education something must be done, because as Samad [13] pointed out, no significative changes have been made and Control education has remained relatively invariant during the last decades.

In another work [7], a taxonomy of controllers enabling to introduce certain order was proposed. This taxonomy is based on the learning capabilities of the control systems and on the definition of the information space. Definitions of some key concepts for Systems and Control are now proposed. The intention is just to promote discussion in order to stress the needs for a new vison of the theory of Systems and Control, making a synthesis of all existent ones, the third synthesis in the control history (see fig. 2).

In the following sections the concepts of model, intelligence, learning, control will be discussed and defined in this framework. In order to place the proposal in a historical perspective a brief review of the evolution of Control is proposed.

2 Brief review of Control Evolution

The Automatic Control History may be divided into three phases: the artists phase, the prè-scientific phase and the scientific phase [3][4][11].

In the artists phase, from Classic Antiquity to the end of Middle Age (Sec. 14), the inventions were produced by the ability, creativity and genius of some exceptional individuals. The pré-scientific phase goes from 15th to 18th centuries, during Renaissance and Baroque times [3].

The scientific phase started in control after 1867 by the works of the pioneers (the stability theory), passed by the classic theory, the modern theory, the neo-classic theory. Classical control theory was developed from 1920 to 1955. Three important schools contributed to it: (i) the industrial instrumentalists, (ii) The communications engineers (Black, Nyquist, Bode; (iii) The MIT Servomechanism Laboratory and Radiation Laboratory. By the end of the Second World War, the structure of the Classic Control Theory emerged completed with the work of Evans in 1950. These achievements may be considered the first great synthesis in Control (see Figure 1). The information processing was in electrical analog form .

The digital computer lead to the usually called Modern Theory (state space). The microprocessor (in 1972) and real-time operating systems from Computer Science stimulated identification and adaptive control.

However part of control community did not accept the time domain approach. The Neo-Classic school [4] continued to use frequency domain tools and concepts that lead to the development of robust control in the frequency domain. This may be seen as the first schism in Control community. The introduction into robust control of the concepts and tools of state space, leads to the unification of the two approaches (in frequency and in time domain).

The potentialities of digital computers are very much larger than analog computers (they can process several types of information and in very big quantities with the methods and tools developed by Computer Science and Artificial Intelligence communities). A part of the control community looked in that direction and new approaches were used to develop new types of control systems during the last 20 years, founding the so called "Inteligent" Control discipline.

Another part of Control community remained in the quantitative processing methods (usually called the model-based control approach) and further important progress have been and are still being achieved. This lead to the second schism in Control.

As a consequence it can be said that Automatic Control is actually being developed in the framework of three paradigms [6] :
-the integral-differential paradigm, including all control methods using models starting from differential equations (transfer function and state-space),
-the data paradigm, including all control methods based on experimental and empirical data (black-box models, neural models)
- the linguistic paradigm, using qualitative representations like fuzzy systems and controllers.

The following definitions aim to contribute to the unification of these paradigms.

3 Definition of model

In the present times one can assist to the separation of control methodologies into two main classes: the model-based and the non model based. The first one is sometimes called "conventional" [12] and the second one "intelligent" [2], [8]. The question here is to know what and what for is a model. The relation between model and information is also an important question (see for example the very interesting paper of MacFarlane [10]).

After the digital computer dominated the analogue one, models are implemented in digital computer, using some programming language. After compilation in the digital computer the model is translated into a series of 0's and 1's. Figure 2 shows a model. Independently of the starting knowledge used to arrive to Fig. 2, all models assume finally that aspect. They are just pieces of machine code to process information. The computer receives information and processes it (and eventually takes a decision). This is in the author's opinion the main characteristic of a model (in the present context). The concept of **Model** should then be defined in the information space. This is a proposal:

Definition 1. Model. *A model is 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.*

Two keywords appear in this definition: code and information. They are connected to the two main properties of a model (in this definition): *computability* and *granularity* (of information).

Computability measures the adequacy of the representation tool to be translated into a piece of computer code. So this definition of model includes in the same way the conventional, the neural networks, the fuzzy or any other kind of representation that can be programmed in computers. It does not include analogue models (like architectural models).

Granularity of information expresses the type of information the model can use (process):

- high granularity: it expresses and processes qualitative information (like fuzzy and possibilistic models, for example)
- low granularity: it expresses quantitative information (given by numbers in a given numeric scale).

Granularity is the additional dimension (other than time and space) that transforms the state space into the information space. The state space is in this context the sub-space of quantitative information in the information space. Granularity may be tentatively defined as the minimum difference between two pieces of information such they can be distinguished.

4 Definition of intelligence and learning

The term "intelligent control" is 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.

There have been discussion about what should be an Intelligent Systems (see for example Antsaklis [1]), but there is still no consensus on that. 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 2. 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 3. Learning. *Learning is the procedure (sequence of operations) used by an intelligent controller to change its own behavior as a consequence of the chagements in the behavior of the controlled system or its environment*

This very general concept of learning can be analysed in more detail and a taxonomy of controllers can be proposed, as illustrated in Fig. 3, according to the level of their learning ability.

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

H^0 - no robustness
H^1- gain and phase margin controllers
H^2 - optimal controller

… until Hinf controllers

Level $\mathbf{L^1}$ – 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 $\mathbf{L^2}$ – 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 $\mathbf{L^3}$ – trajectory learning- includes for example optimisation methods at supervisory level for process control, robot path planning, etc.

Level $\mathbf{L^4}$ – task learning- includes short-term production planning in process control, autonomous agents (robot) task planning.

Level $\mathbf{L^5}$ – 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 $\mathbf{L^6}$ - learning organizations – including the concepts of medium and long term learning in a multi-system changing organization of agents (systems) with complete autonomy in a dynamic environment.

Actually the levels $\mathbf{L}^1$, $\mathbf{L}^2$, $\mathbf{L}^3$, $\mathbf{L}^4$, are well developed, although still subject of intensive and extensive research. Levels $\mathbf{L}^5$ and $\mathbf{L}^6$ are still in an exploratory phase, particularly in mobile robotics.

5 Definition of control

In the highest levels of learning one meets Artificial Intelligence and Machine Learning. This will be, in the author's opinion, 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 information processing and decision making, as in the proposed following definition:

Definition 4. Control. *Control is 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 involves the three bases of modern science: mass, energy, information. It allows to include all existent approaches for controller synthesis and those to come yet.

6 Conclusion

It is time to develop the third synthesis in Automatic Control history. To maintain Control as a leading discipline, Automatic Control community must look higher that the real-time closed loop and take advantage of the powerful tools of Control Theory to merge them with other tools issued from Artificial Intelligence and Computer Science. Only by this way it will be possible to open perspectives for real high-level autonomous systems. In this paper some definitions were proposed in that direction. They can be adequate if some mental walls will be broken and if one accepts as natural that in each period one must do at least the best the existent technology allows. This puts the accent more in the implementability issues (look for all possible methods and techniques to do it) than in the historical developments or in the formal aspects. A Control Engineer must know the basis of all methods and techniques that exist nowadays to project automatic control systems. This leads naturally to an overall reorganization of this field of knowledge. And in the opinion of the author only in the information space this reorganization can be done.

Acknowledgements:

This work was partially financed by MCT/FCT, contract (Alcine) PRAXIS XXI/EEI/11455/1998 and by POSI Program financed by European Union.

References

[1] Antsaklis, P.(1993), Final Report of task Force in Intelligent Control . Technical Committee on Intelligen Control, IEEE Control Systems Society.

[2] Antsaklis, P. (1997), Intelligent Control, in *Enciclopedia of Electrical and Electronics Engineering*, John Wiley &Sons, Inc.

[3] Bennett, S. (1979), A History of Control Engineering (1800-1930). IEE and Peter Peregrinus.

[4] Bennett, S.(1993), A History of Control Engineering (1930-1955). IEE and Peter Peregrinus.

[5] Aström, K.J. and MacKavoy (92), Intelligent control: and overview and evolution. Handbook on Intelligent Control, in White and Sofge (ed.), Van Nistrand Reinhold .

[6] Dourado, A. (1997). A Proposal for an Information Technology oriented program on Systems and Control , Proceedings of IFAC/IEEE Conf. Advances in Control Education- ACE'97, Istambul, Turky, July 1997, pp. 195-198.

[7] Dourado, A. (2000). About Systems and Control Curricula Centered on Learning Skills. Proceedings of IFAC/IEEE Conf Advances in Control Education, ACE'2000, Goald Coast, Australia, 17-19 December, 2000.

[8] Grupta, M.M. and N. K. Sinha (1996). Intelligent Control Systems. IEEE Press.

[9] Linkens, D.A.(1993), The Role of Intelligence in Systems Engineering, J. of Measurement and Control, vol. 26, pp. 228-234.

[10] MacFarlane, A.G.J.(1993) Information, Knowledge and Control. In Essays on Control: Perspectives in the Theory and its Applications, Trentelman and Willems (Eds), Birkäuser

[11] Mayr, O.(1970), The Origins of Feedback Control. The MIT Press.

[12] Passino, K.M.(93), Bridging the Gap Between Conventional and Intelligent Control.IEEE CSM, June 1993, pp. 12-18.

[13] Samad, T. (1999), IEEE Control Systems Mag, vol. 19, nº 5, p. 2.

Type of control	Information processing	Source of Knowledge	Dominant discipline
Intelligent Control	Super-Microcomputer	Computation Science Artificial Intelligence	Information Engineering
Adaptive Control On-line identificatio	Digital Microcomputer	Recursive Estimation Real Time Operating Syst.	Computer Engineering
State Space Theory	Digital Computer	Numerical methods	Electrical/Comp. Engineering
Classical Theory (Transfer Function)	Electronic Valve and Analog Computer	Laplace Transform and Cables	Electrical Engineering
Empirism and art	Mechanical parts	Levers, Hammer and Screw-driver	Mechanical Engineering

Table 1. Overview of the historical relation between-technology and control

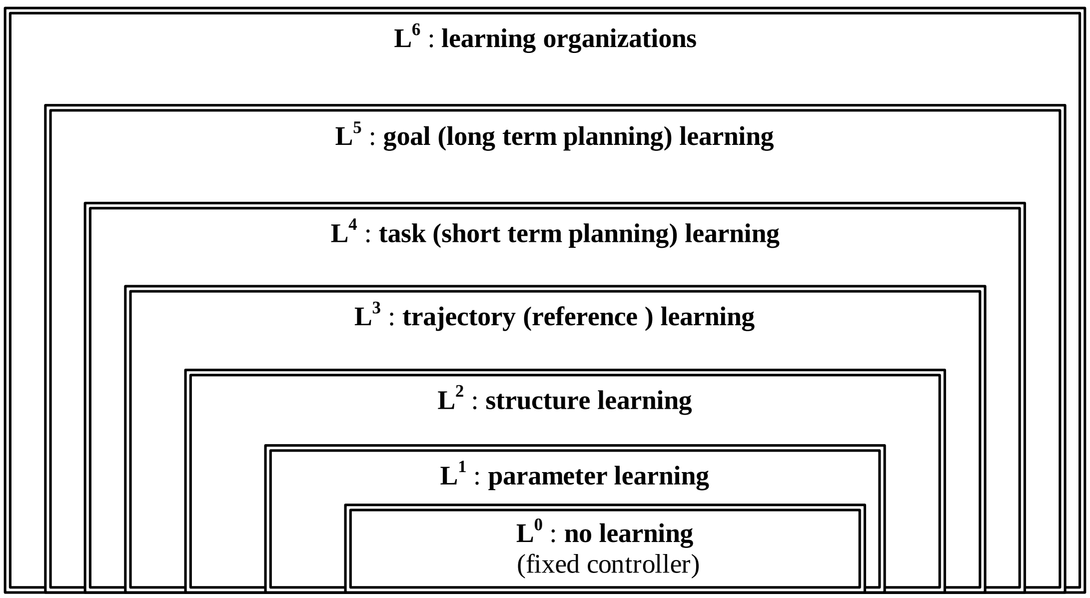

Figure 3. The proposel levels of increasing learning abilities.

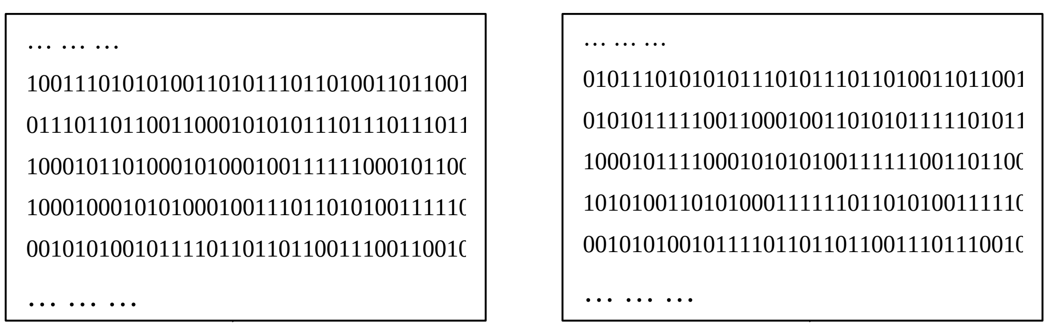

Figure 2. A model is a piece of binary machine code to be executed. In a) it comes (hypothetically) from a set of differential equations (integral-differential paradigm (Dourado(97)). In b) it comes (hypothetically) from a fuzzy rule (linguistic paradigm). But at the end the difference is in just some 0’s and 1’s. One model is not more legitime than the other. They just process information with different granularity.

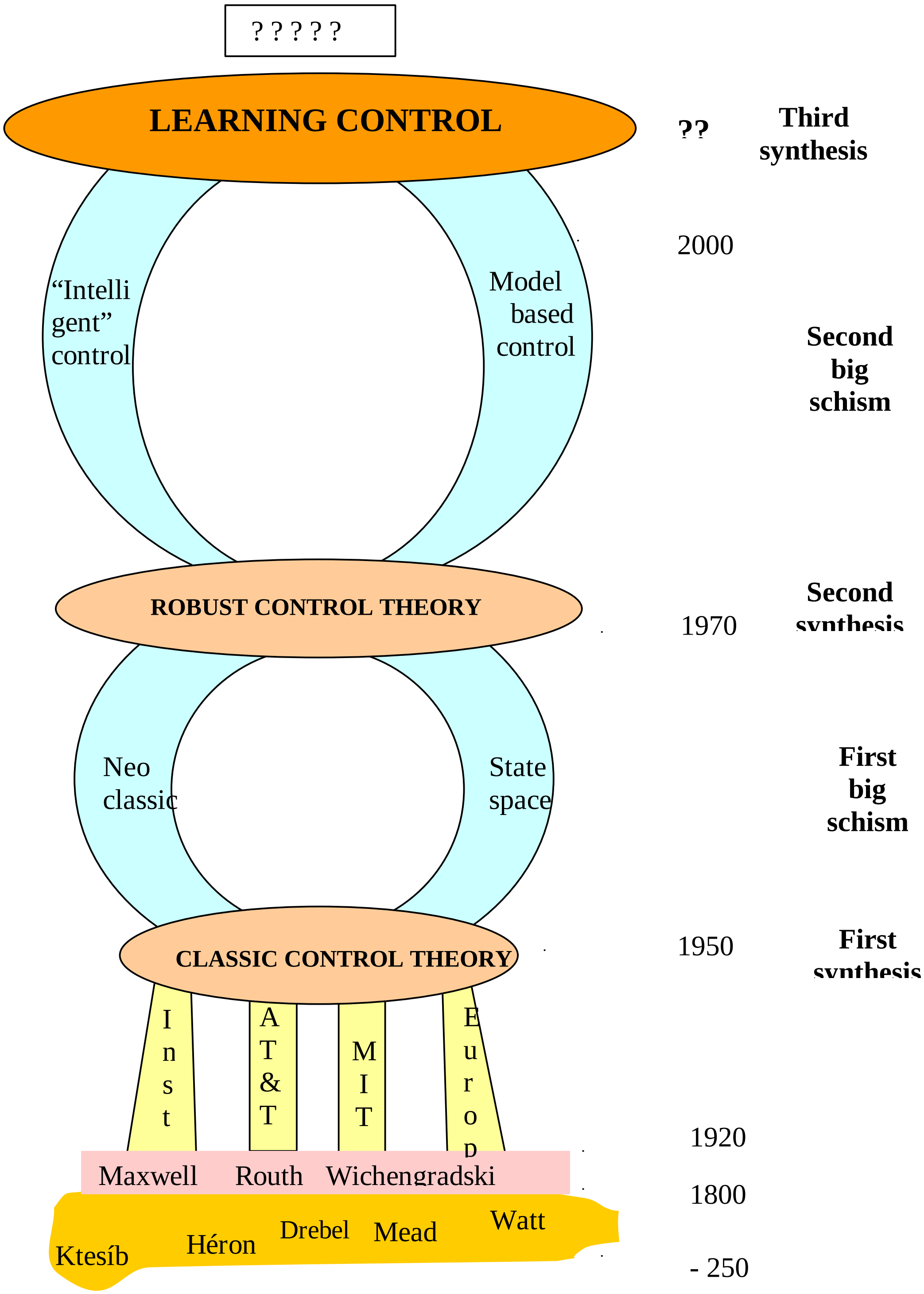

Figure 2. Review of the Automartic Control History. The situation today indiciates already the coming of a new synthesis, the third one in Control History. This synthesis will be the Learning Control Theory (or Theory of Control and Learning).