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Could Theory of Complex Multi-Networks Provide a Framework for Holistic Systems Approach? : Fascinating Ideas on Complexity in Complex Networks and Systems Synergies

Georgi M. Dimirovski

Academician of the International Academy of Systems and Cybernetic Sciences, St. Etienne-du-Rouvray, France
Member of the European Academy of Sciences and Arts, Salzburg, F.R. of Austria
Foreign Member of Serbian Academy of Engineering Sciences, Belgrade, R. of Serbia

Presented on behalf of:
Georgi M. Dimirovski,
Foreign Guest Professor, Dogus University, Istanbul, Turkish Republic
Research Professor, St Cyril and St Methodius University, Skopje, R. of Macedonia

A Kind of Prologue First

- ***Uncertainty is immanently inscribed in the very notion of complexity of the social and societal world***. *Uncertainty means incompleteness, unpredictability, openness and non-linearity of an outcome of any social action. Every action taken by an individual is determined by conditions of the social environment and it may turn out that it will deviate from the direction that was originally assigned to it. Therefore, it is necessary to acquire the ability to adjust the direction of action depending on the changing social situations and to develop the strategic vision of the desired and attainable future.*
- **Thus I incline to first to reason and think about complexity phenomenon.**
- *It is shown in the paper that it may well be feasible to derive a holistic systems approach to contemporary conflicting worldwide interconnected societal environments via a set of consistently compatible models that co-exist over a complex dynamic multi-network structure (Dimirovski, IEEE EUROCON 2017, pp. 650-664; Liu, Dimirovski, Zhao, Physica A: Statistical Mechanics & Its Applications, 387, pp. 643-652, 2008). Regrettably so, since the time of Leonardo da Vinci ("There is no much truth in sciences that do not make use of mathematics"), it seems the only crucial societal change is emergence of more or less conflicting alliances and/or states across increasingly inter- and cross-connected planet Earth that replaced conflicting city states across Italy.*

A Kind of Prologue First

- ***This contemporary emerging global societal environment, being largely achieved due to Mankind's technological advances but not accompanied alongside with the relevant cognitive and spiritual advances, also enhances global social environment that hardly has begun to understand its survival needs holistic management strategy modifications.***

- ***Mankind has only begun to understand that actually it is the origin of the relationship of determination, where the boundaries of human freedom ought to accept the survival constraints thus emphasising the underlying structural constraints on our world. Further interaction of Mankind and its societal and social environment with the natural environment seems has become decisive primary instance, which essentially determine each other now and in a foreseeable future. People as conscious actors every societal must transcend from knowledge to wisdom in order to overcome the rising greediness and selfishness so strongly enhanced by the global banking-financial neo-capitalism with its inherent generic uncertainty that may yield further unprecedented consequences.***

- *On the grounds of a kind of synergy of **Dragoslav D. Siljak's dynamic graphs** (Nonlinear Analysis: Hybrid Systems 2, pp. 544-567, 2008) and **Guangrong Chen's enhanced controllability via pining control** (International Journal of Automation & Computing 14, pp. 1-9, 2017) on complex dynamical networks it seems possible to derive an appropriate systems background for a <u>holistic systems approach to contemporary conflicting worldwide interconnected societal environments</u>. At least it seems to be a rather worthy research adventure into holistic re-thinking of uncertain systemics of this world.*

Introduction

- Lets recall here and now what famous ***Henry Poincare'*** had emphasized in his own time:
  - **'The thought must never submit itself nor to a dogma, nor to a party, nor to a passion, nor to a preconceived idea, not to anything that exists if it were not the facts themselves. For, the thought to submit itself, it shall be as to cease to exist'.**
- In addition, since **Whitehead** and **Russell** have had derived the entire mathematical science (1927) on the grounds of Cantor's naïve definition of a set as the fundamental mathematical concept by observing the laws of logic, the here presented discussion also employs the set theory and the logic of natural sciences to its full.
- For, long ago **Leonardo da Vinci** was first to state:
  - 'There is no much truth in sciences that do not use mathematics'.
- Furthermore, much later ***Immanuel Kant*** emphasized
  - 'In every department of physical science there is only so much science, properly so-called, as there is mathematics'.
- And even much more recently Rudolph E. Kalman pointed out:
  - ***'First get the physics right. The rest is mathematics.'***
- *The underlying scientific background here comprises physics, set theory and its special branch on advanced graph theory* [3],

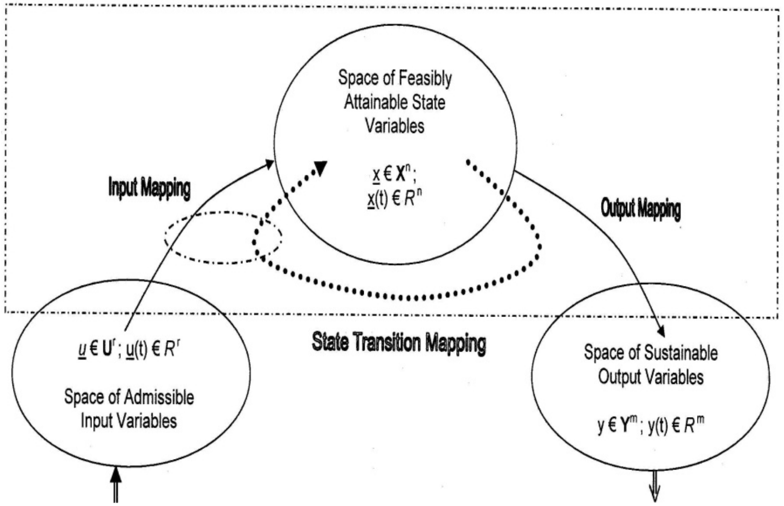

Fig. 1 An illustration of controlled general nonlinear systems in accordance to the fundamental laws of physics (Dimirovski et al., 1977). Although input, state and output spaces in terms of involved classes of functions can be mathematically defined by chosen measuring norm, at any fixed time instant all vector-valued variables become real-valued vectors that may well be the simple Euclidean ones [52]-[54]..

Introduction

- Indeed, there exist in the literature a number of monographs with ambition to give answers about what the control of complex networks and systems is all about; some of the most important ones are cited in here.
- For instance **Peter Erdi**, the author of one such recent book, which is entitled **Complexity Explained** (Springer, 2008), *also has begun by arguing about the terms 'complexity', 'complex systems' and alike, etc. by citing* **Stephen W. Hawking's statement: *"I think the next century will be the century of complexity."***
- Further, he points out that one aspect of the complexity is related to the structure of a system, and then proceeds so far as to mention underlying facts that all scientists recognize the omnipresent networks and webs.
- And yet *he argues that one aspect of complexity is the structure of a system and further suggests it is the fundamental organizational form of systems despite whether the adopted scientific approach is the holistic or the reductionist one*.
- In contrast, *here we argue that fundamental form pertinent to some entity, object or process, to be considered a system is that of (some) organization in addition to a purpose functionality*
- ***It is further argued in here a proper understanding of the concept of complex systems inevitably requires referring to the reality, including the living systems and the societal systems too* [51].**

Introduction

- The present overview attempts to shed deeper light onto understanding complex systems in a wider setting, including applications, hence via observing physics, in the first place.
- From a certain viewpoint on control and supervision through the general, but physically well-grounded, concepts of systems and control due to Rudolph E. Kalman [123]-[125], as I have illustrated in Figure 1, the present discussion may appear an reincarnation of the statement by Howard H. Rosenbrock '… ***My own conclusion is that engineering is an art rather than science, and by saying this I imply a higher status***…'; see [193].
- In could hardly an opposing argument within the present day prospect of complex dynamic networks and systems. Thus, while it may well be true this Rosenbrock's paradigm of engineering as arts-rather-than-science to lie in the heart of the nowadays conceptual definition known as 'System of systems'[1], dynamic networks and systems per-se do have much deeper scientific foundation.
- *Thus, I do not believe such a pure mechanistic concept of 'System of systems', and the respective methodological approach too, could go beyond the ideas of interconnected and large-scale systems.*
- For, the entire history of natural sciences and of physics, in particular, gives a plethora of evidence that kind of simplistic view cannot be scientifically viable.

Some Preliminaries And Novel Complexity Insight

- It seems ***the idea and issues of complexity*** have been first put forward in the year 1948 on the eve of emergent powerful computing machines as it appeared in the 1964 edited multi-authored book by Edwin F. Beckenbach [24], in which Warren Weaver was cited in the preface to had authored them (American Scientist 36, 1948).
- Though, ***it appears really it was Herbert A. Simon [217] who in 1962 had managed to formulate complexity in scientific terms as well as to promote the concept of complexity and the many facets involved as an outstanding direction of important research prospect*** (*Proceedings of American Philosophical Society*, 106).
- A common belief at that time across all fields of science typically was as pointed out. There exist **two main categories of complexity**: the one of ***organized complexity***, *associated with the applied combinatorial mathematics* (also including graphs, matrix games, and optimal control); and the other one of ***disorganized*** (or unorganized) ***complexity*** *associated with the uncertainty, probabilities, and stochastic processes*.
- *It should be appreciated nowadays that both categories were indeed given sound conceptualizations as well as clearly defined although primarily within the realm of mathematics rather than within the realm of physics.*

Some Preliminaries And Novel Complexity Insight

- *Nonetheless despite this dichotomy-like thinking, it may well be noticed, what appears to follow the illustration in Figure 2 that presents a contemporary telescope snapshot record of some part of the cosmos, which in here conditionally I dare to name the macro-world complexity.*

- There should be clearly noticed: certain elliptic and spiral shaped galaxies versus the vast background of seemingly disorganized ones. Furthermore, a recent insight into the sub-sub-world of the boson discovery by Peter Higs and Fransoa Engler (Figure 3) seems to emphasize over and over again that similarity and symmetry [268] are quite natural properties in physical world [32], [53]; e.g., see both Figure 2 and Figure 3.

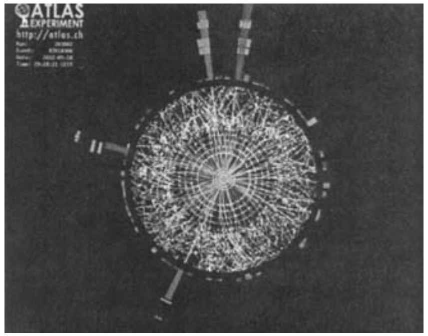

Fig. 3 Reported ***outlook of God's particle – boson of Peter Highs and Francoa Engler***, which explained how other particle acquire mass and yet which may not be the smallest one in the universe, following CERN collider experiment ATLAS: Fascinating properties of symmetry and similarity with respect to and transversal that may partition it into two halves.

Fig. 2 ***A macro-world complexity***: Telescopic snapshot has recorded a cosmic moment in the tumultuous lives of large spiral galaxy NGC 3227 and smaller elliptical NGC 3226 in their close encounter. Spanning about 90,000 light-years and similar in size to the Milky Way, NGC 3227 is recognized as an active Seyfert galaxy with a central super-massive black hole.

Some Preliminaries And Novel Complexity Insight

- Then indeed – Why not ?!? – accept the usage of both similarity and symmetry when developing mathematical representation models and control system designs for of real-world objects and processes. Indeed, considerably early history of the logic of nature has yielded their usage in systems and control studies, both the theoretical ones as well as the ones in engineering applications and technology
- Thereby it appeared that exploiting the similarity and symmetry features have also given rise to results and some sort of trend to seek simplified representation of endowed control problems and then find relevant solutions, a process somewhat opposite to the large-scale systems.
- ***The original Kolmogorov's definition*, which reads "The algorithmic (descriptive) complexity of data sequence is the length of the shortest binary computer program that prints out the sequence and halts",** *is strikingly compatible to the fundamental theorems of computing languages, grammars, and machines*. More importantly in my opinion, however, *is to notice the fact that* **it is compatible with the underlying algorithmic nature of all developments in sciences and engineering of computing, communication networks, and control systems alike.**
- For, what an operating feedback control system in general does always, after any disturbing action from the environment, in a sense, *it is solving over and over again the initial value problem through processing of the control error dynamics of the closed-loop system due to certain newly triggered initial conditions*. It is therefore that ***Kolmogorov's algorithmic understanding of the complexity seems to be the most fundamental one from the viewpoint of the cybernetics of the control and supervision of complex networks and systems.***
- **Though, neither an indication nor a mention of the linearity hypothesis could be encountered, found, or somehow established.**

Some Preliminaries And Novel Complexity Insight

- System properties of structural symmetry and/or similarity have been well exploited in to the investigation of various kinds of interconnected and large-scale system representations, which have yielded an outstanding plethora of developments and discoveries.
- For instance, the works by Dragoslav D. Siljak have discovered most of structural features of decentralized control of such complex systems in the presence of information constraints and structural perturbations as well as of uncertainty.
- Systems and control theories, in particular those concerning the linear systems and linear-quadratic optimal control (as well as their applications) have had a blossom of developments following the fundamental discoveries by Rudolph E. Kalman on theory of systems and control.
- A very much similar impact have had the fundamental discoveries of Vladimir A. Yakubovich on matrix inequalities, S-procedure, and the celebrated Kalman-Popov-Yakubovich Lemma.
- Practically, all these developments later have been extended to both large-scale systems and nonlinear systems in various ways by a number of authors (e.g., some are found the references given in here). Yet, the ideas and issues as well as concepts about control of complex systems continue to get enriched and to evolve up to nowadays, most recently within the paradigm of complex networks and networked systems.
- ***Evolution happened somewhat gradually beginning with exploiting the natural features of similarities and symmetries in both of the real worlds, the dead ones and the living ones.***

Some Preliminaries And Novel Complexity Insight

- In order to return back to the issue of primary concern in this discussion notice that there exist *considerable knowledge about astrophysics perception of the cosmic complexity and birth, life and death of celestial objects and galaxies* (seen via Figures 2 and 3).
- Yet, *the journey into the discovering the essence of life via studying its manifested features (for instance, see Pavlov, 1927) has started progressing not so long ago* and it was largely due ***to various visionary perceptions of what complexity and complex system dynamics may be all about*** .
- On the other hand, *our real-world experience via human perception of natural ones as well as of man-made dynamic processes demonstrates the existence of variation "sheds" of complexity in between those categories*. Nonetheless, it is within this context precisely ***where*** **Heinz von Foerester,** ***within his thinking about cybernetics and systems in the wider setting of nature and society,*** **seems to have highlighted considerable deeper roots** ***involving not only the interplay of energy and matter with information, but also the cognition process too*****.**
- It appears, his emphasis on cognition has emerged to be considerable crucial in the contemporary developments of systems engineering design and automation technology.
- *The cognition process, however, also implies some anticipation and maybe consciousness within the evolution dynamics in the nature.* ***But can it indeed be so, then?*** **There is no clear cut answer as yet, and it does not seem one will appear in the near future.**
- *Perhaps it is beyond von Foerester's 'Understanding of Understanding'.*

Some Preliminaries And Novel Complexity Insight

- Indeed, most of the consulted source literature suggested for quite long time there have existed considerable endeavors to **explore the life itself**. It is a strikingly old idea that actually has led to a deeper understanding of the issues of complexity and complex systems, as a matter of fact.
- *This shift has taken place due to the crucial impact of discoveries in genetic research within biological systems leading to the idea of systems biology. Indeed,* ***considerably many aspects of complex systems on the way towards complex dynamic networks have been evolved into an innovated insight since the works by Darwin, Bogdanov, Pavlov, Dobzhinsky and Radcliffe-Brown.***
- Moreover, it appeared transcending these ideas onto life evolution and societal dynamics have had even greater stimulating impact towards the development of the science of complex dynamic networks and systems have in turn induced another insight into the issues of complexity and complex systems as well as their control strategies.
- **The evidence in the literature, during the past couple of decades towards, also suggests that** ***the general trend towards an ever increasing interconnection and cross coupling in all societal and human based activities*** **has caused a definite shift towards** ***certain unified comprehension of complex dynamic systems and complex dynamic networks in various realization forms*****.**
- *Muscolesi and Mascolo (2009) noted, the unprecedented recent advances in computer networks, communications, and information technologies as well as the world-wide expansion of mutually interconnected economies have only reinforced this major trend.*
- Furthermore, this major trend is to expand even further in all domains of societal and human activities and thus nowadays (Barbasi, 2002) is becoming the overwhelming one. It seems however, ***the life itself plays more essential role in the collective adaptability and the evolution dynamics than it has been admitted in so far****, nonetheless.*

Results Based On Novel Insights To Complexity

- A common belief at that time across all fields of science typically was: there exist two main categories of complexity: the ones of organized complexity, associated with the applied combinatorial mathematics and the other ones of disorganized (or unorganized) complexity associated with the uncertainty, probabilities, and stochastic processes.
- It should be appreciated that both categories were indeed well conceptualized and clearly defined.
- *As already pointed above, the dichotomy-like thinking appears to follow the illustration in Figure 2 that presents a contemporary telescope snapshot record of some part of the cosmos, which in here is conditionally named the macro-world complexity involving simplicities.*
- *There should be clearly noticed: certain elliptic and spiral shaped galaxies versus the vast background of seemingly disorganized ones an yet possessing similarity and symmetry. Precisely so suggest Peter Higs and Fransoa Engler sub-sub-world of bosons that emphasizing the natural presence of similarity and symmetry. So it does suggest both the Big-Bang (Figure 4) and theory as well as the Gravitational Waves (Figure 5) theories.* These justify best the deep physical foundation of Rudolph E. Kalman's generalization of systems theory.

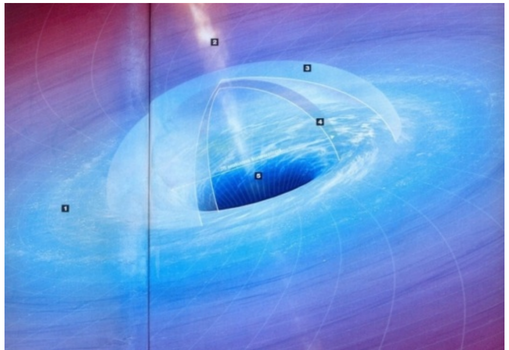

Fig. 4 In the centre of Milky Way: Artistic perception by author M. A. Garlick of the phenomenology of black hole SgrA*, weighting 4 million times more than Sun and radiating powerful radio-waves(National Geographic 102(4);

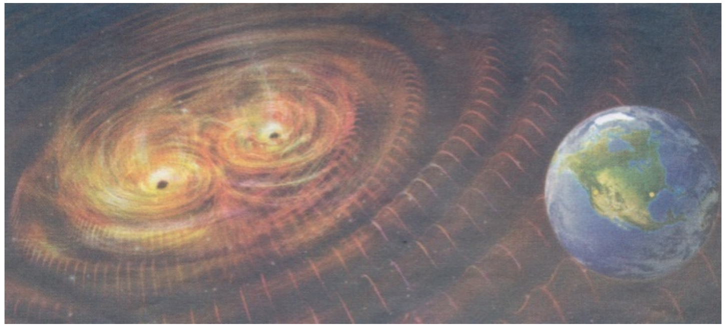

Fig. 5 An artistic vision of Eiensten's gravitational waves as embracing Earth. Albert Einstein: "I would like to know God's thought. I would like to know how God created this world." (brothers Bogdanov Igor and Grishka, 2012).

Results Based On Novel Insights Into Complexity

- *Yet, the journey into the discovering the essence of life via studying its manifested features (for instance, see Pavlov, 1927) has started progressing not so long ago and it was due largely to various visionary perceptions of what complexity and complex system dynamics may be all about.*
- On the other hand, our real-world experience via human perception of natural ones as well as of man-made dynamic processes demonstrates existence of variation "sheds" of complexity in between those categories.
- Nonetheless, **it is within this context precisely where Heinz von Foerester, within his thinking about cybernetics and systems in the wider setting of nature and society, to have highlighted considerable deeper roots involving not only *the interplay of energy and matter with information* but also the *cognition* too.**
- It appears, his emphasis on cognition has emerged to be considerable crucial in contemporary developments of systems engineering design, automation technology and wider systems science applications to societal and non-technical systems.
- *The human cognition process, however, **also implies certain anticipation and it maybe some consciousness within the evolution dynamics in the nature***. **But can it indeed be so, then?** There is no clear cut answer as yet, and it does not seem one will appear in the near future.

Some Results Due To Novel Complexity Insight

- ***One of main exploration trends nowadays are complex dynamic networks that comprise a set of nodes possessing locally controlled or uncontrolled dynamic systems (various classes) and a finite graph structure having finite capacity communications as well as interactions among those node systems*.**
- These have already gained not only growing attention by scientists and engineers worldwide but also research momentum. Nowadays, a dynamic network is commonly understood to be a large-scale systemic structure consisting of a graph that contains enumerable set of dynamic systems as its nodes and a finite set of signal-flow interconnections among them.
- ***Thus, I do believe complex dynamical networks and systems, the roots of which can be traced back to Mikhail A. Aizerman and his collaborators as well as to Ford and Fulkerson, in their very essence can be completely described by the dynamic graphs of Dragoslav D. Siljak, as he proposed in [216]. During the last couple of decades research activities in exploring synchronous evolution or motion dynamics has been steadily growing, and* the emergence of both spontaneous and controlled synchronization has been extensively addressed in a number of works.**
- *Though, the importance of synchronized evolution or motion does not lie only in those situations in which synchronization can be found, but also where synchronous motion can be induced to ensure the proper functioning of particular collective devices such as multiple machine ensembles and/or controlled formation of collectives of (sub)systems* .
- **It should be noted some of those works have supplied feasible control methods for enforcing and reinforcing stable synchronization in a few fairly wide classes of dynamic networks with regard to their topology**.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- The investigation of the aspects and issues related to the controlled dynamical networks has become a rather attractive research area at least for two main reasons.
  - Firstly, dynamical networks appear in various worlds of the nature and of the human societies on Earth as well as many events and processes in the real world can be modeled by dynamical networks.
  - Secondly, there can be identified a large number of important applications of dynamical networks in various disciplines, which include astrophysics biology, economics, engineering, life science, neuroscience, and sociology too.
- ***In the sequel, there is attempted building an argument in favor of observing Darwin's evolutional dynamics, as a point of centrality in the quest for a consistent theory of controlled complex networks and systems via the theory of Siljak's dynamic graphs as an adequate tool from applied mathematics and the physics behind systems science [56] is attempted.***
- *The crucial point of departure to notice is the unique integrity of the interplay of energy and matter with information in the universe (Hawking, 2014) hence on Earth's nature too.*
- Furthermore, an interactive process of mutual adjustment and co-evolution matching up the structural coupling (Dobzhansky, 1937; Rosen, 1991) while the organization remains an '*autopoietic*' class identity "living organism", which emanates out of organization possessing a certain structure determinism.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- It should be noted that **reference to biology, life science, and sociology inevitably puts a special emphasis onto the conceptually *fundamental category of organization* and its feasible evolution, and not solely onto the structure as such**. For, *Darwin's evolutional dynamics of species [49] involves interactive process of mutual adjustment and co-evolution that is matching the structural coupling up while the organization of an '**autopoietic'** (i.e. a self-reproducing circular nature) of the class identity "living organism" comes out from the feature of the organization possessing a certain structure determinism.*
- In turn, *reference to the living points out to essentially another but deeper understanding of complex dynamic network and systems that often exhibit goal seeking behavior in addition to decentralized feedback (self)control.*
- It is in this regard that *I do believe complex dynamic networks and systems, which employ combined control, coordination and supervision to enforce their organized integration, ought to be viewed as a kind of approximates to biological systems.*
- In particular, *the (my) intuition suggests the supervisory level ought to have some properties of controlling cognition within the broader view on evolution process dynamics that is associated with the entire phenomenon of living biological systems.* **It is therefore that supervisory function should be sought to have implemented *certain mentalist activities hence cognition within the wider set of decision and control activities***.

Some Results Due To Novel Complexity Insight

- As such these *natural real-world systems must be compatible with and coherent to set of:* *decision and control activities within the complex networks and systems so as to guarantee* ***not only the system integrity and stability but also the goal-seeking behavior are simultaneously reinforced by drive to certain rewarding optimum.***
- Indeed these aspects may well open a new prospect but they also pose some tremendous complicated analytical problems both mathematically as well as from the viewpoint of systems and control sciences.
- Though, the established insight that all complex networks and systems are indeed characterized with the feature of inseparable twin of structure determinism and structural coupling, due to extensive internal communications of information, in addition to evolution capacity.
- A comparison analysis of technologies and science of dynamic networks, systems and of their control at the times of the classics of engineering cybernetics with the nowadays ones readily yields not only too many but rather most important changes to notice.
- These changes I believe can be summarized in two entities: *incredibly powerful computational* technologies, on one hand, and *unprecedented pervasive fast communication* and *transportation* networks, on the other. Of course, along with these technologies, the underlying scientific knowledge of highest quality and in enormous quantity has been acquired too. ***It is therefore that the real-world systems are abundant in all sorts of nonlinear and time-varying processes, which as such may not be not amenable entirely to mathematical representation.***

Some Results Due To Novel Complexity Insight

- Still, as argued by Rosenbrock [193] in 1977, *indeed both mathematics and physics are indispensable in systems and control sciences*, and therefore I believe a special attention should be paid to an important feature in modern physics.
- **Namely, *modern quantum theory* [63], [99] *has abandoned to deal with strict causal determination for elementary atomic processes and has turned more towards statistical anticipation about those processes*.**
- Should we now take a closer insight into the network control-theoretic developments and practical designs, *no special imagination is needed to see that such network systemic structures have parallels with the worlds of atoms and sub-atomic processes as well as the molecular world.*
- I do believe the sub-system processes in networked control systems, and even more so, in complex dynamic networks are to a certain extent analogous to those elementary atomic processes, and indeed to various macro- and micro-worlds on Earth.
- Thus, it occurred to me, **indeed we ought try hard to transcend some of modern quantum theory onto the general framework of reasoning about the systems and control science [51] *hence complex dynamic networks systems too*.**
- For the time being, let leave off this issue and address what specific features can be recognized about control systems over communication networks as implementations, which represent pervasive existence nowadays. But notice nonetheless, these are by and large computer controlled hence computer science is indispensable too.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- In my opinion, **the features of primary importance are the known kinds of *complexities* and of *uncertainties*, *information constraint* as well as *connecting/ disconnecting sustainability and survivability*.**
- *The latter is being directly related to all variants of pertinent systems stability problems,* **now largely tractably by LMI based techniques originally due to original discoveries of Vladimir A. Yakubovich in the fundamental theory of control [255]-[257] as well as in sorts of applications [75], [258].**
- Though, no doubts, *adaptation and re-organization also play rather important roles. And even more so do adaptation and re-organizing adaptation and re-organization on a massive scale, not necessary collective unless induced by some consensus strategy.*
- For, by and large these all are control driven and reinforced too ta the same time.
- However, I do believe adaptation and re-organization come only second next to the previously pointed complexities.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- Upon noting several kinds of complexities, *let first take into consideration the* ***organized*** *ones, because it is the control infrastructure precisely that can convert unorganized complexities and uncertainties into the organized ones*.
- It should be noted, however, **solely the mathematical hence the computer science too, complexities are the one precisely defined**.
- These are referred to as NP-completeness and NP-tractability, usually.
- However, ***it has become apparent in the present day encountered complex dynamic networks there appear architectural, structural, and topological system complexities in addition to the computational one. Yet, it is true none of them is either completely or precisely defined as it is the NP-completeness in computer science and ICT-technologies.***
- It should be noted further, the last couple of decades have yielded considerable advances in various issues about Complex Dynamic Networks and Systems, *one of which is that an improved understanding of topological complexity versus network sustainability seems to be instrumental for the further developments*.
- However, it appeared much more deeply involved nonetheless for the present day existing knowledge and understanding of complex networks and systems.
- *Nonetheless, some of the recently reported research has indicated that enormous control effort is needed in order to reinforce controlled synchronization, in general, and also to ensure connective sustainability, in particular.*

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- The feature of information constraint is considerably well understood thanks to the advances in large-scale systems theory and decentralized controls for large-scale systems.
- Following the Springer's monograph [264] entitled ***Control of Complex Systems: Structural Constraints and Uncertainties by A. I. Zcevic and D. D. Siljak (2010), there still remain open issues in this regards as well as about the decentralized control of complex networks and systems – in Siljak's words –*** **beyond the decentralized feedback** ***(Figure 6), in general.***
- In particular, ***despite the existing knowledge on connective stability, this knowledge still remains to be transcended in the wider setting of connecting/disconnecting sustainability and survivability***.
- One rather important pathway forward to be pointed out, I do believe, is the one via dynamic graphs of Siljak precisely [214].
- In other words, *complex dynamic networks are systemic structures do possess features of dynamics requiring control mechanisms that transcend beyond the nowadays knowledge on decentralized feedback control and supervision in functional synergy.*

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- The issues of the uncertainty have been subject to study from the very beginnings of information theory as part of the theoretical studies in Cybernetics and its applications.
- However, as with complexities, there appear various kinds of uncertainties albeit in systems and control most often the parametric and structural uncertainties are being accounted for.
- *Should we recognize the unavoidable need for some integrative organizational strategy imposed even in largely decentralized complex dynamic networks, then the uncertainty too becomes as multi-faceted one as the complexity is.*
- At this point, it should notice the largely neglected need for developing sophisticated theory on supervisory control strategies that can guarantee survivability of the complex dynamic network under various ad-hock topological circumstances via some controlled reinforcement of system integration (see Figure 6).
- In my opinion, much too long time the issues of supervisory controls have been left over to more empirical investigations rather than theoretical studies.
- It is in this regard that I believe Siljak's concept of dynamic graphs does provide an innovated and sound path forward.

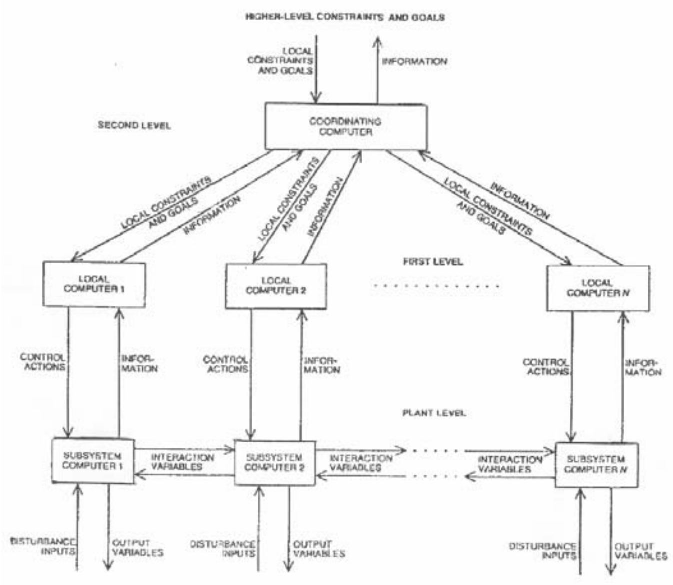

Fig. 6 The well-known hierarchical, computer control based, implementation of integrated control and supervision [214] for complex dynamic networks and systems in terms of dynamic sub-networks of nonlinear dynamic nodes, which in compliance with Siljak's concept of dynamic graphs (2008).

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- At this point in here, *now I would like to infer the issue of exploiting some hints from modern quantum theory, which seems to have been foreseen by Einstein his fellow-friends.* Namely, I think that *sooner or later we have the place our main focus on how to mitigate consequences of strict usage of the causality principle in systems and control science.*
- I incline to believe *no major breakthrough is feasible without endowing the integrative supervisory control with some capacity for anticipation*; for, only then combined control and supervision could deliver far beyond the present day knowledge on various predictive controls.
- *It is therefore that I believe the IPDI principle [198] due to George N. Saridis, i.e., the analytical formulation of* ***the principle of increasing precision with decreasing intelligence*** *(Automatica, 25, 461-467, 1989).* This I do believe in despite primarily it was driven for the needs in robotics; it has been underestimated and left aside unjustified for that matter.
- In here and for the purpose of complex dynamic networks and systems, **I would dare to re-interpret it in terms of *increasing intelligence with decreasing precision* hence and, on the grounds of entropy theory, come up with *supervisory control processing* albeit with some *incomplete anticipatory properties*.**
- **However, such coordinating supervisory controls cannot be achieved without employing *computational intelligence* techniques. Hence exploiting the *cognitive approach* in control imitating human intelligence capacities, which we may dare to envisage in terms of *evolving computational intelligence*, becomes as necessary as mathematics and physics are.**
- It is within this context that the technological implementation of integrated control and supervision, which is illustrated in Figure 7, seems to gain its full systems engineering value as emanated from control system theoretical endeavors of large-scale systems theory.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

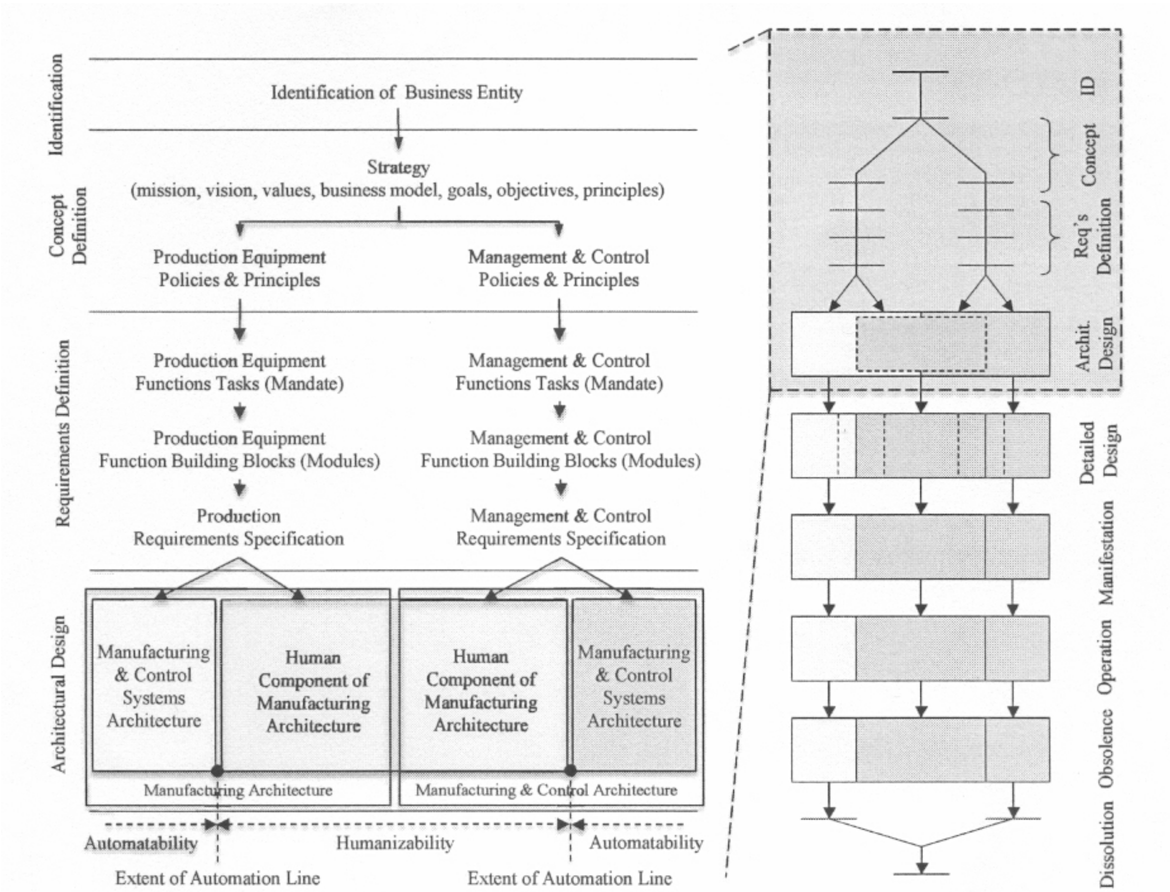

Fig. 7 An overview of the current state-of-arts of developments in human-automation symbiosis (Romero et al., 2015) within design variants human-centred automation systems (Fast-Berglund and Stahre, 2013) in terms of the Purdue Enterprise Reference Architecture; the segment on the right points the ongoing research tasks [192].

Some Results Due To Novel Complexity Insight

- *The IPDI principle of Saridis [198], in my opinion, has made a rather stimulating impact towards exploiting computational intelligence methods for solving complicated tasks of control, coordination and supervision for nonlinear and complex systems as well as for complex dynamic networks.*
- These methods, along with the respective techniques for representation modeling of processes to be controlled, *include* ***theories and methodological techniques of fuzzy systems, neural networks, fuzzy-neural or neuro-fuzzy systems, and fuzzy-Petri nets*** *as well as learning machines and systems in a broader sense*.
- Furthermore, some of the most recent studies have clearly demonstrated *how many mingling and mutually influencing are the nonlinear theories of systems and control interacting with fuzzy-system and neural-network theories*; in particular, from the viewpoint of stability. In this regard, the interested reader is suggested, for instance, to consult recent articles.
- **For, it is interesting to notice that *computational intelligence techniques appear*, *by and large, as yet another alternative methodology* to tackle mathematically complex nonlinear problems, where analytical techniques fail to deliver technologically tangible results.**

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- As known from the literature, *indeed synchronization is a collective behavior of dynamical networks, of course.*
- **But it is one of the crucial issues in studying potential behavior of complex dynamical networks as well.**
- **For, it does have direct relevance to and certain relations with the logic of life itself (Dennett, 1995; Kauffman, 1993; Nowak, 2006; Rosen, 1987).**
- ***And the life itself indeed is the best teacher of both organization and self-organization in the universe (Dennett, 1995; Kauffman, 1995; Maturana and Varela, 1987).***
- ***The main issue of concern seems to appear in terms of how to accommodate within complex networks setting the need to employ some techniques of game theories and some anticipation features (Rosen, 1985). Because they too are crucial in comprehending the real-world living, ecology, and societal systems in their mutual interactive couplings.***

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- The ideas about engineering implementation of *integrating the control, coordination and supervision of man-made complex industrial plants* too deserve to an appropriate but brief address in this essay tractate.
- It should be noted here, in the first place, *the heritage from control developments aimed at interconnected and large-scale system complexes in terms of hierarchically organized computer control system architecture and the respective applications software technology.*
- For, these were precisely the technologies that enabled the modern days automated factories, power plants as well as communication, power, and transportation systems, and even further stimulate exploration of the paradigm 'factories of the future'.
- *For this purpose, form Romero et al. (2015) and the related works [192], [204], [235], respectively, in here there is only given the borrowed Figure 7 as presented above [192].*

Some Results Due To Novel Complexity Insight

- It may well be considerably stimulating, and possibly instructive to, if a few more words more in this context are pointed out. Then this discussion inevitably involves the issues of operating symbiosis of human(s) and automation system (Kaber et al., 2001).
- It is therefore that also man-machine interactions as well as features of humans in the role of control operator ought to be placed within the scene and scenarios of control and supervision of complex dynamic networks and systems.
- It is in this regard that the supervisory level ought to have some properties of controlling cognition as a broader evaluation of controlled processes within the automated complex plant.
- *Therefore that supervisory control level is to be designed so as to have implemented certain mentalist activities hence cognition within the wider set of decision and control activities.*
- As such they must be coherent to entire feasible set of decision and control activities within the complex networks and systems in order to guarantee not only the system integrity and stability but also overall adaptability and goal-seeking evolution.
- *Furthermore, following a recent study [235] by Tzafestas (2006), this conceptualization seems to transcend beyond the technological complex system since it does reflect upon the society hence the nature at large too.*

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- **Finally, within this discussion about complex dynamic networks and systems integrated via their control and supervision infrastructure, to issues of stability ought to be addressed because these are sine-qua-non in systems and control sciences from the time of Poincare' (1890) and classic analytical mechanics.**
- For, indeed it is so since days of developments in the theory and engineering of linear dynamic systems and their control; for instance, Anderson (1966 a, b), Barnett (1971), Bernusou and Titli (1982), Dimirovski et al. (1977), Kalman (1960 a, 1963 b), A. A. Krasovskii and Pospelov (1962), Mesarovic and Takahara (1975), Rosenbrock (1977), Siljak (1973, 1978), Tsien (1954).
- *True, these aspects are considerably more difficult and more involved within this context of complex dynamic networks and systems. Moreover, there are much more involved than in studies of nonlinear dynamic systems at the time of Liapunov (1907) and Poincare' (1890) within the realm of classic analytical mechanics.*
- ***It is the extension towards the control of nonlinear dynamic systems and its optimization that made essential difference; for instance, see Anderson (1966 a), Emelyanov (1957), Filippov and Arscott (1988), Isidori (1995), Moylan (1980), Kalman (1957), Krasovskii (1959), Lurye (1951), Pontraygin et al. (1961), Siljak (1975, 1978,1991).***
- **These developments have given considerable understanding of the nature of Lyapunov functions and Lyapunov-Krasovskii functionals to the extent to became fundamental tools for explorations in the realm of complex dynamic networks and systems.**

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- It should be noted first of all, the first considerable extensions of Lyapunov stability theory have been made rather early by A. I. Lurye (1951) and N. N. Krasovskii (1959).
- These extensions have paved the way towards a deep and far reaching study of the original conceptualization of Lyapunov function that yielded innovated modifications up to nowadays to various Lyapunov-like functions in the search of constructing Lyapunov that are suitable for specific but nonlinear and/or time-delay phenomena; for instance, see Antsaklis (2000), Basar and Bernhard (1995), Fomin et al. (1981), Fridman and Shaked (2003), Ikeda and Siljak (1985), Kalman (1963 a), Kozyakin (1990), Lee and Jiang (2005), Liberzon et al. (2014), Liu and Fridman (20112), Long and Zhao (2014), Tee et al. (2009, 2012), Zhang et al. (2015), J. Zhao and Dimirovski (2004), J. Zhao and Hill (2008), Zhao et al. (2015).
- However, as recently pointed out by Ahamdi et al. (2013) a kind of complexity of Lyapunov functions for switched linear systems exists if these are sought in the tradition of quadratic stability, due to the underlying linear algebra [120], [121], [142] that seems even the set-theoretic methods in control [28] could not be overcome.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- Indeed, during the last couple of decades very many new and/or innovated exiting stability results complex dynamic networks and systems and for network controlled systems, all based on the ideas about Lyapunov functions and Laypunov-Krasovskii functionals, have emerged; for instance, see [13], [25], [27], [43], [52], [81], [82], [106], [107], [143], [149]-[152], [182], [187], [216], [232], [273]-[278]. Furthermore, even computational intelligence [46], [61], [93], [106], [132], [191], based on either fuzzy-systems or neural-networks, recently have been handled as complex nonlinear systems by means of novel developments of either Lyapunov functions or Lyapunov-Krasovskii functionals [13], [53], [81], [106], [107], [156], [182], [187], [229], [230], [259], [266].
- *In the view of these works it may well be inferred the derivation of sophisticated Lyapunov functions and/or Lyapunov-Krasovskii functionals in combination with* <u>*the dynamic graphs and the principle of increasing precision with decreasing intelligence*</u> *appear to be the building blocks for future exploration of complex dynamic networks and systems under integrated supervision and control.*
- However, as shown by Filippov and Arscott (1988) and by Siljak (1978, 1991), the stability problem shall require constructive usage of techniques based on the theory of differential inclusions [74], [211], [214], e.g. see Aubin and Cellina [18], and on the theory of functional differential equations, e.g. see Hale and Lumel [91], For, the stability problem in such systems is by far much more involved and subtle to handle in a clear-cut way.

SOME RESULTS DUE TO NOVEL COMPLEXITY INSIGHT

- It should be noted further, in addition, during the last couple of decades significant scientific advances have been achieved in the theories of both the *complex dynamic networks* as well as the *switched systems and switching-based controls*. Such dynamic networks and systems largely occur due to combined event-driven, state-driven and time-driven control and supervision in man-made technologies [13], [16], [39], [40], [77], [83], [97], [110], [146], [149]-[156], [237], [238], [270]-[278]. It seems more than just coherent that these theoretical developments are also well coherent with technological implementation scheme that was presented in Figure 6.

- Nonetheless, as far as the complex dynamic networks involving switched topologies and switching base controls, I do believe, appeal for essentially modified conceptualizations on how we perceive processes that evolve due to the combined time-, event- and state-driven dynamics. In fact, these two areas have opened a whole of new prospects towards networked systems engineering creations of the future.

- It should be noted, although being at infancy now, some encouraging results on the synergy of complex dynamic networks and dynamical systems. It also yields the obvious result that in this case no switching sequence exists to stabilize the system at all, thus complying with the intuitive conclusion.

CONCLUDING REMARKS

- In this overview an attempt was made to bring up to date the many facets of complexity and complex systems.
- It is only up to the interested readership to evaluate whether and to what extent it has been accomplished.
- To this author's belief, the concept of organization is the most fundamental one into the further quest for deeper comprehension of complex dynamic networks and systems if a theoretically sound, systematic, and yet reasonably pragmatic engineering design creativity is to be achieved.
- This seems to be an appropriate one-step ahead perception for the future, which was largely argued for in the preceding sections.
- Furthermore, recently it was well illustrated by L. Y. Wang and P. Zhao have rightly entitled their article "Evolution of the feedback mechanism in information era" in AASC 2 (1), 70-76 (2014); see Figure 7 and Figure 8.
- It is by the special permission by Prof Ji-Feng Zhang, the Editor-in-Chief of AASC journal, that I selected and included in here these two original figures from article [245] presented further below.

CONCLUDING REMARKS

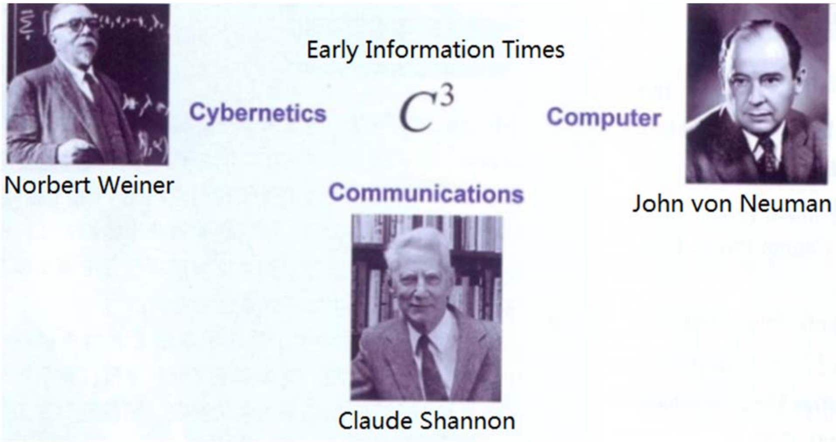

Fig. 7 The Eraly Cybernetics and the C^3 paradigm – Cybernetics-Computing-Communications – to all of which the feedback feature plays a crucial role for their very existence; also, notice the monograph by Tsien, Hsue-Sen [231].

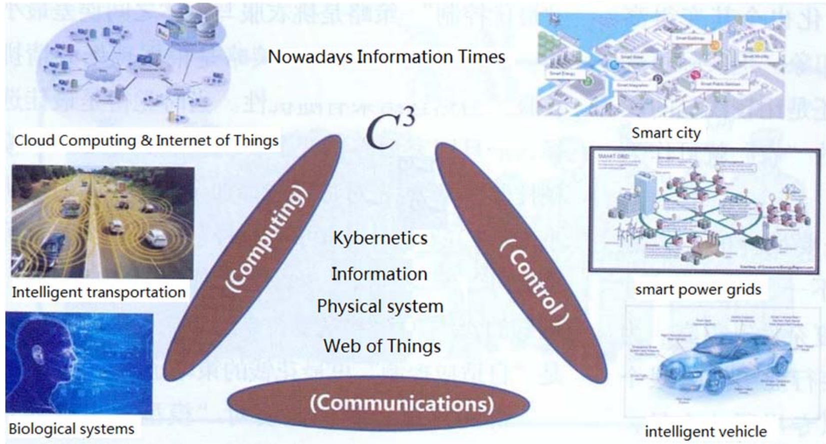

Fig. 8 Notice these are propagated through space and time on planet Earth more half-a-century: The information induced C^3-paradigm demonstrate well Control-Computing-Communications, to all of which the feedback feature plays a crucial role for their very existence; all three enclosed within Cybernetics or Kybernetics; see also Engineering Cybernetics by Hsue-Sen Tsien (1956), Academician of the CAS.

CONCLUDING REMARKS

- **Indeed, it may well be argued in favor of what Chinese colleagues promote the paradigm Control-Computing-Communication (C^3):**
  - **Dynamically evolving entity that, being integrated by means of control functions, decision and supervision, essentially remains a simultaneous systemic information processing, communication and *feedback control* mechanism beyond decentralized feedback.**
- This survey paper is based on the foreword to a 2016 monograph [51] , which I have edited for Springer International AG, that indeed has enabled me to gain considerable new knowledge, and for which *I am profoundly grateful to one rather remarkable international group of contributing authors*.
- ***However, in that foreword as well as in this paper,* I dared to present only my own perceptions, reasoning, and beliefs about complex networks and systems from a control perspective.**
- ***Furthermore,* I dared to place these on a prospect with regard wider knowledge on fundamental natural sciences, physics in particular, and advanced engineering technologies available nowadays.**
- **Therefore the responsibility is solely mine for all the here expressed views.**

CONCLUDING REMARKS

- Though these views are expressed via a kind of symbiotic 'Look back - Look forward' reasoning primarily on the background of physics – to cite again words of late Prof. Howard H. Rosenbrock – "… mathematics is indispensable..." [189].
- Hence mathematics is a sine-qua-non tool in systems and control sciences.
- Though, in this control intellectual effort I did observed verbally the background mathematics of sets, set relations, and sets of sets as well as graphs and graphs, nonetheless, following the pigeonhole principle of Church-Turing hypothesis [131], [175], [230], 241] in the first place.
- For, up to nowadays only the computational complexity and the undecided-ability issue are formally and rigorously explained via the NP completeness or non-completeness [131] to the full.
- For, within the same context, also the potential emergence of paradoxes [63], [66], [95], [195], [252] has been made a legitimate outcome mathematical event too.
- In the view of these facts, one may argue that some paradoxes existing in the system-theoretic sense could make legitimate outcome events as well if these are looked upon and kept as questionable conjectures [195], [252].

CONCLUDING REMARKS

- Finally, at this point I would like to emphasize again the famous remark put forward by late Prof. Rudolf E. Kalman in one of his many plenary lectures:
- **"First get the physics of considered problem right. The rest is mathematics."**
- For, indeed [123] I do appreciate deeply Kalman's advice despite my arguments favoring the necessity to involve cognitive and computational intelligence sciences as well into our perception and exploration of complex networks and systems.
- *It should be widely noticed for that matter, without a proper understanding of the physics behind any investigated phenomenon in theories and applications of systems science, decision science, and control science, solely the usage of sophisticated mathematical methods and models is bound to remain an academic exercise only.*
- In any case, my own conclusion is that **the build-up of an all-encompassing science of complex networks and systems is bound to remain an ever-open, lasting quest that appears to be correct precisely because of very many facets of complexity**.

My beloved and most respected teacher as well as a friend,

Professor Dragoslav D. Siljak at Santa Clara University,

California – USA; photo a couple of years ago at the time of his final retirement, when I received his friendly letter of information.