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COOPERATIVE SYSTEMS– AN EVOLUTION PERSPECTIVE

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PREFACE

It might be difficult to find a more appropriate topic for research in IIASA than in mastering or, at least alleviating, the problems imposed on us by the *complexity* of various phenomena and/or systems.

The very creation of the Institute can be linked to the problem of complexity. The obvious or suspected failure to comprehend and anticipate (much less than predict) the impacts of modern technology in the industrialized world in a national context led to the idea to study these phenomena in aninternational institute with a cross-cultural environment.

The way of how scientific disciplines managed complexity presents a reliable trail of past development. When old paradigms and concepts seem to be at their limits new principles are the most precious resource needed.

This Paper by Professor Vamos from the Hungarian Academy of Sciences on Cooperative Systems is an example of a new concept, so much needed in systems research, which is devoted to the functioning of very large systems. It shows what important system properties it can accommodate and where it substantially differs from previous, widely used concepts.

It can be developed into an important step in the eternal race between real life posing more and more complicated problems and the ability of science to understand them and to design a blueprint for solutions.

This paper may be of interet to several projects which are being worked on, not only at IIASA but also in collaborating institutes.

Tibor Vasko

Leader, Clearinghouse Activities

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INTRODUCTION

Several coherent trends that originated from different sources can be formalized now as a new and relevant perspective of system philosophy. Even the nomenclature is different—heterarchical, distributed, cooperative--but the profound reasons of this evolution are analogous and contain a significant message for understanding the existing and future design.

In this paper we shall give a historical-phenomenological survey of the roots of this concept. The survey does not aim to be by all means exhaustive, it serves the better understanding of the process only.

The next chapter analyzes the timeliness of the new formulations, why a natural evolution of solutions and ideas are necessary and technologically feasible general methodology just at this period.

The third chapter evaluates some definitions usable for several abstract model buildings, though definitions are always restrictive and just because of this a more pragmatic application is mostly inevitable.

The last chapter surveys those research areas which are related to the concept but an early warning follows concerning handling problems on a not too high abstraction level from the basic considerations about real-life large scale systems.

1. THE ROOTS OF COOPERATION SYSTEMS

The problem of system organization is closely connected with the problems of system building (design) and control (analysis). A simple one-loop feedback control of early technology or a transparent and few-purpose, few-level human organization could easily be modeled (mathematicaly or verbally-conceptually) and suggested an impression of the possibility of extension by the same principles (models) without any major restriction. These models of direct, well-formulated simple controls were transmitted for larger systems, too, by applying more hierarchical levels. The deficiencies of operation were attributed mostly not to the systematic character but to inadequate technical or human realizations.

Against these generally adopted principles of early and simple rationality some systems emerged which were basically different. The first of all these "anti-rational" systems was market (local, national, world), an exchange of goods, without visible control. The next area was international communication: messages and transport. These systems (although being mostly highly centralized and controlled on the national postal, railway, etc., level) could find a mode for international cooperation. This mode does not require any kind of classical high-level hierarchy. The evolution of international power system cooperation provided an additional example for the newborn, not really recognized phenomenon.

Most probably, the idea of heterarchy first appears in W.S. McCullogh's neurophysiological work [1] in 1949. Not incidentally, The neural system is one of the most complex ones ever realized or studied; the impossibility of models, based on last centuries' architectural-mechanical ways of thinking turned out very quickly. The heterarchical was introduced as negative of the hierarchical--by this negation an opening for considerations on new mechanism-models was made. As to how ideas have evolved from that point towards general lessons in computation and human organizations, we refer to a more recent paper of Michael A. Arbib, who started also from neuroscience [2]. The celebrated book of Douglas R. Hofstadter [3] discusses the society of ants comparing the genetic information and neuronal processing capability of the single ant to the complexity of their anthill organization and results in a similar conclusion: the interaction of many different, rather simple but balanced control laws result in a very high-level performance without any explicit "description", "formulation".

Philosophers began to think about this unmechanical phenomena much earlier. The dialectic principle of the transition of quantitative changes into quality is still the most general idea on the subject. Gödel's results, the frontiers of classical logics formulated by a rigorous mathematical way, started in 1931--a new epoch in considering the problems. The advent of computers has put the computability issue on a realistic, empirical, tangible form. Polanyi, Dreyfus and several others in their struggle for the renewal of a large scale systems' view began to combine philosophy with computer science, mathematics and psychology. A well-readable survey of these trends can be found in Margaret Boden's book [4] and an exciting, stimulating guidance for this intellectual process in the cited Hofstadter work.

The next impetus came just from the computer field. We can identify the same process--first independently of each other--leading to similar conclusions. The fast growth of hardware availability soon led to hypertrophy problems; it turned out that more distributed-task systems are more powerful than one single giant; operating systems concentrated in one bulk architecture began to show the typical bureaucratic performance requiring more and more of the increased capacity for self-administration. Distributed data processing was the first field where Enslow [5] introduced the *cooperative* nomenclature and gave a still excellent definition for a cooperative system (1976).

Artificial intelligence--intelligent programming, problem solving, by their very nature got to the limits of the conventional approaches and began to open towards the new ones. As usual, exaggerated, superoptimistic forecasts of early results on simple model-examples led to the fast realization of the intrinsic problems previously covered by the thin layer of the simplified paradigms. The history of computer chess was just the same: in the late fifties/early sixties a world-champion's level computer program was predicted within the reach of a very few years. In the seventies this forecast was shifted to the end of the century. Now, having considerably more powerful computers, all predictions are discouraged. Automatic programming had the same carrier. The need for not having structured programs in advance was inevitable in the sixties, the MIT AI group, Minsky, Hewitt, Winograd and others designed the PLANNER, CONNIVER, SHRDLU, etc., devices for *heterarchical* programming where the flow-structure of the program depended on the performance of modes of the program; nodes of the graph could be deliberately either data or procedures. By other nomenclature it was found that in a highly complex task everything cannot be foreseen, a strategy is much more useful than a prefab schedule.

Having reached to even more complex problems and having encountered the vanity of simple hopes in superdevices, the late seventies led to some new perceptions; the HEARSAY-project of recognizing a continuous speech using 1000 words has shown that a simple distributed processing was also inadequate. The cooperative efforts of several different decision making algorithms, procedures, without any hierarchy but organized in a very democratic way are the most feasible ways of solution. Lesser and his colleagues at Carnegie-Mellon [6] reinvented the term: cooperative system. The same conclusion was drawn by people working in the AI solution of the exchange of scientific information [7], in medical diagnosis [8], in computer programming teams [9] and in the psychological experiment of evaluating incomplete information [10]. The latter was an experimental comparison of the performance of a group organized first hierarchically and then by a democratic-cooperative way.

The Stanford-idea of using a virtual "black board", a collection, exchange, evaluation field for several incoming information in their expert systems is based also on the same perception. As Hofstadter concludes Bach's music, Escher's art and Gödel's mathematics crossing all levels: mathematics, neuroscience, psychology, sociology, technology, computer science cross at a certain level of complexity: the failure of predetermined hierarchical structures and a need for a much more adaptive, creative cooperation.

We must emphasize once again that the above survey of this intellectual-perception process is by far not comprehensive or rigorous that would much extend the limitations of a paper--but it serves to illustrate only the evolving ideas.

2. TIMELINESS

2.1 Requirement Conditions

Examining the roots of an idea people frequently consult the Bible or Greek philosophy. We could do the same now and in the first chapter we have shown the need for a new system's philosophy. Now we would like to underline the timeliness and show why this need is so urgent just nowadays and why it is feasible just now. The first answer is the complexity of the systems which is growing much faster than the systems themselves. Any kind of artificial system (technological-manufacturing, electronic-communication, social-servicing, etc.) can be attributed by persuasive examples and data especially about this expansion during the first 30 year period. The complexity growth is not merely a combinatorial one of the increasing number of mathematically homogeneous components--this would be horrifyingly high as well--but the different groups of these components, similar to the Hofstadter's anthills, form different levels where the higher ones are not only simply derivable from the highest features. The complexity is exploded by that transition of quantity to quality. The inhomogenity of these new components (group levels) is wittily illustrated by Wittgenstein: "if a lion could speak, we would not understand him".

The understanding of both man and lion would require a superstructure which may be much beyond the general human brain. The difficulties of having common languages were well realized by research in dolphin-communication but the entire history of modern human communication psychology and linguistics machine translation reflects a small light into this bottomless hole. Basic linguistic-understanding-communication problems were well described within a contemporary society of the same language, same nation, same social strata but based on different generations and different educational schemes as the topic of a wide range of novels and plays. The hierarchical levels of systems practically never develop in parallel: the more and more complex entities permit less and less one-to-one mappings.

In that way we reached the second combinatorial explosion: the first one was the number of interrelated components, the second is the number of different-level entities formed by the component-subassemblies.

The next explosion of this complexity derives from the dynamic feature of the whole (components, subgroups, groups, etc.)--the statement of Herakleitos: "we cannot step twice into the same river" gets a relevant new meaning from this aspect. The dynamic processes in real life are mostly very far from being of an ergodic, stationary character. The required observation periods are mostly much longer than the time characteristics of structural changes. The most striking examples for the demonstration of this statement can be cited from economic system's performance but the author had similar experiences in studying steam-generators. We reached the third explosion: unpredictable time-performances of the first two combinatorial galaxies.

A fourth one can be added and this is related to the stochastic-chaotic behavior of rather simple nonlinearities. The realization of this phenomenon is based on the classics of nonlinear mechanics: Poincare and Liapunov but having easy possibilities of computer-experiments was beautifully described recently by Gumowski and Mira [11]. Rather simple nonlinear terms provide a completely chaotic response on simple determinstic signals: the transfer of behavior from one to the other characteristic can be provoked by small perturbations and the oscillatory motion between these "strange attractors" is very much like the unpredictable behavior of a hysteric, psychologically unstable personality. If those random-like, chaotic responsive but determinstically describable simple nonlinearities are coupled in a large scale system which performs all three explosions detailed above: a fourth, nonetheless uncomputable and therefore uncontrollable combinatorial explosion is superimposed!

By the advance of technology the experimental analysis of the natural phenomena dissolved the macroscopic view of nature, too. The easily surveyable picture of a few simple-law-driven-world is over and that is the reason why we could notice the same change of thinking in every field enumerated in the first chapter. The predictable, computable and controllable view of the world which started with the renaissance and led a long, triumphal way of discoveries was disturbed by the deep analysis and the creation of very large scale systems. It is difficult to mark the change by one single milestone, by the revolutions of physics at the turn of the 19th-20th century, by achievements of mathematical logics in the thirties of this century or by reaching some limits of simple control and computation methods and economic models in the last decade. At any rate, we have to realize it, look at the deep reasons and after new answers.

2.2 Technological Conditions

The realization of necessity is combined with the promise of new control technology. This is two-faced, having the same background: information transmission and process-control capabilities.

All the early technological examples of cooperative systems are based on information transmission. This is an essential feature--cooperation is possible by a two-way information exchange only (sending and receiving). According to the hypothesis of some anthropologists, the superiority of human ancestors over any other kind of hominids lay in their palatal development, in the ability of forming consonants and by that articulated signals--a superior communication against any other creatures. Postal, telegraph, telephone communication contained information as their own substance, the development of railway-networks was closely connected with telegraphy, the market in its original form is a joint meeting place of goods and communicating people, the cooperation of power systems was mostly realized by the fact that a basic characteristic of the transmitted current, the frequency is the information-carrier for differences between flow and demand. (Another level was the high voltage-line used as high frequency information carrier.)

It is these information channels that have broadened to such an extent in past years and promised a similar growth in the near future that a new level of *information broadcasting* availability on cooperation need and readiness--is a basic condition for system's cooperation. We consider the quotation of biological analogies as triviality for the reader. Cooperation requires, on the other hand, the local evaluation of the received information and an ability for sending such kind of information that is needed for an understanding between the cooperative partners. If we analyze it deeper, this concept is not as trivial as it seemed in the first minute. We concluded in the above that no central intelligence can solve the problems of complexity--a local intelligence that is needed by cooperation is supposed to scope with the problems of the local level and obey the overall laws of rational cooperation: a double task that should be harmonized both from the local and global points of view (object-functions, stability, etc.). Reasonably priced local computer power--and this is also a new phenomena--combined with a higher level local intelligence (human, software and hardware) are essential requirements, just now when coming on the stage.

Another warning is indispensable at the end of this chapter, too: the complexity problem cannot be solved at all, either by global (central) or by local (distributed, cooperative) control. The latter can provide a reasonable approximation, a much more adaptive, survivable system by reducing the predetermination and recognizing the uncomputable by handling it as random events. This is equivalent by reducing the problem complexity of one step from global optimization to a continuous iterative approximation by local suboptimums. Thus we do not possess the solution or either any hope of having it in the future but a way for a reasonable compromise!

3. SOME DEFINITIONS

3.1 Concepts

For a more conceivable treatment let us see the basic concepts what we intend to use (Figure 1). A cooperative system's graph is a *net* (and not a tree). The nodes of net are *sources* and/or *drains* of *flow*. Flow can be anything as the subject of cooperation: material in continuous or discrete flow, energy and information. The flow-character information is conceptually different from the information used for the cooperation itself, although these two kinds of information can be combined, mixed physically and in the transmission way but somehow separable (envelope and letter, different codes of a digital data transmission package, etc.,--the letter is the flow). The nodes can have *storage* capacities, too.

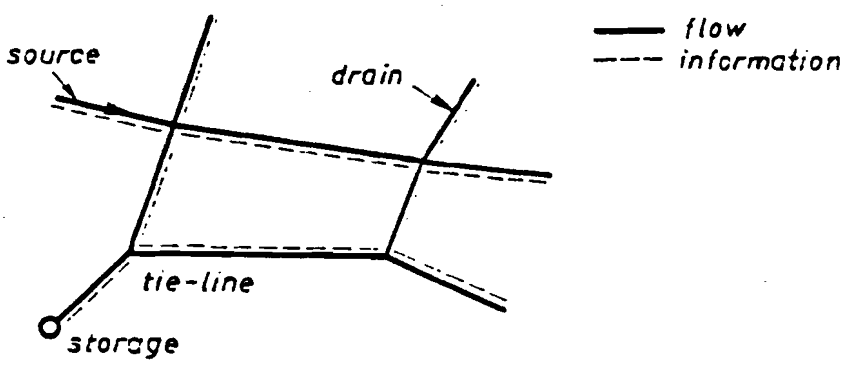

Figure 1.

The source emits information on availability for *supply* of flow, the drain on the *demand* of flow. The emission mode of information is not restricted anyway, this is an optimization-agreement procedure, can be realized by continuous and unlimited broadcast, by asynchronous or synchronous operation, any kind of handshaking, unlimited in the extension of the system or somehow oriented by distances or specialities of flow, etc. Let us call this kind of information--containing messages on addresses, routing, on parameters of the flow and terms of demand and supply-- *administrative information*. The flow uses *tie- lines* (power, telecommunication cables, any kind of radio-links, railways, motor-routes, pipelines, etc.). Typical characteristics of tie-lines are their *capacity*, *delivery time- delay*, *cost of operation*. The cooperative system has no central control in the conventional sense, especially not in normal operation. The control is of distributed, adaptive type based on *agreements* (standards, protocols) *of interface* (the systems' components, nodes' responses on administrative information). The interior control of the nodes (system components) is not restricted, it can be a cooperative one, too, or any kind of conventional control depending on the node's complexity and on other local circumstances. The basic condition of participation in the cooperation system is the standard *interface* (in the broad sense, as outlined here and later).

The system should be prepared for extraordinary regimes, too, i.e., several stages of *emergency*. All these controls should be designed, i.e., the design (agreement) procedure takes over a part of conventional direct control. This covers the interface, the short range *schedules*, the long range *forecasts*, all measures of emergency (and adjustment logic beyond the limits of schedule, conditions of central direct controls, voluntary or compulsory detach operations, etc.).

The cooperation is interest-driven, i.e., the nodes (system elements) are concerned in participation, and exclusion or restriction is a penalty for them. This well-defined interest-system (short and long range, harmonized) is the basis of *operational strategies*. This contains the rules of the game for bargaining and competition between sources and drains. In some special cases a tie-line, too, can be an active element.

The reader can easily discover that most of our concepts are borrowed from power system and telecommunication field some of them, furthermore from economics, sometimes from sociology. This is not done by change: the first chapter indicated that these are the most advanced models of cooperative systems.

3.2 Definitions

Having clarified the basic concepts we can deal with the definition of the cooperative system. Although Enslow [12] referred to distributed data processing only, his definitions are so pioneering that we feel a more detailed quotation to be useful: "A distributed data processing system must be designated so that the operations of all components or resources, both physical and logical, are very highly autonomous. At the physical level, this may be accomplished by the use of network transmission protocol in which the transmission of a message requires cooperative actions by both the sender and the receiver. At the logical level, between processes, the same degree of cooperation must exist. Further, any resource must be able to refuse a request for service, even after it has accepted the physical message. This is a result of the fact that there is no hierarchy of control within the system.

This is *not* anarchy. All components follow a "master plan", which is reflected in the philosophy of the high-level operating system. This mode of operation should be described as cooperative autonomy rather than simply autonomy. A high degree of autonomy between all components is essential to attain many of the benefits listed in the table and this characteristic of system operation and component interaction will result only from meeting all of the five criteria of the definition which are as follows:

- "A *multiplicity* of general-purpose resource components, including both physical and logical resources that can be assigned to specific tasks on a dynamic basis. Homogenity of physical resource is not essential.
- A *physical* distribution of these physical and logical components of the system interacting through a communication network. (A network uses a two-party cooperative protocol to control the transfers of information.)
- *A high- level operating system* that unifies and integrates the control of the distributed components. Individual processors each have their own local operating system, and these may be unique.

- *System transparency*, permitting services to be requested by name only. The server does not have to be identified.
- *Cooperative autonomy*, characterizing the operation and interaction of both physical and logical resources."

Our definitions are based on all enumerated precedents. The cooperation system is

(1) a free coalition of systems;

(2) a system where no complete knowledge is available on the system as a whole;

(3) a system that operates by exchange of information.

We have to add several important comments.

(a) In definition (1) the word ***free*** means that (co)operation is decided at the component system's (*node* as defined in this chapter) level, and not by any kind of hierarchically superior command. If cooperation is decided, it must obey the laws of *interface*.

(b) The cooperative system is also free, because it can be augmented, reduced or dissolved according to the actual demand. During ordinary operation (emergency can be an exception, but also strictly defined restricted) these decisions, too, are taken by each cooperative component system (node).

(c) The cooperative system is supposed to be either infinite (or approximately infinite) in the sense that looking from one component system (node) it is irrelevant how many other nodes are available; or composed of component systems (nodes) which can survive in stand-alone (detached) operation mode, too. This detached mode can be very disadvantageous against the cooperative mode but (temporarily) feasible.

(d) Definition (2) is relevant because the necessity of cooperation and the superior performance to any kind of hierarchy is derived from the consequences of complexity. The exponential explosion of internal relations, the variety of subsystem levels and formations, the dynamic and stochastic behavior of the system increases the overall control problem beyond the practical computability.

(e) The cooperative system is not a decentralized one what is only a reorganization of the centralized structure by introducing more distributed but hierarchically organized local controls. The decentralized system's graph is a tree, the cooperative one is a net. The cooperative system is an advanced distributed one but much more rigorously anti-hierarchical according to our definition.

(f) The exchange of information is multidirectional (not unidirectional), the basic forms of exchange are:
   - broadcast on demand;
   - broadcast on supply readiness;
   - bargaining, competing, broadcast on terms;
   - contracting (conclusion of the previous phase, scheduling, forecasting).

(g) An unlimited broadcasting of all administrative information is ***not*** a necessary condition.

Warning for this chapter: Definitions are not prohibitory signs for action. They are useful for clarifying concepts and create more easily treatable models. A real system is never an orthodox realization of any pure model but always a pragmatic compromise among ideal concepts. Thus all the above said can be useful as an aid only, and not as a rule.

4. NEW AREAS OF RESEARCH AND DEVELOPMENT

4.1 An Outlook for Generalization

The fast expansion of similar ideas, necessity and availability extends the various fields of application and, the realization raises several unclarified problems for research. An amazing example was the cooperative control of an operating airfleet [13]. The essence and an excellent illustration of the above principles is well-summarized in the following citation: "The planner requiring assistance does not dictate a particular, favored plan. Rather, the planning aircraft (A) broadcasts its set of potential plans to all aircraft in the conflict set (B, C, etc.) but sets no constraints concerning what assumption they must adapt regarding A's or the other's patches." This kind of application looks, nevertheless, much more extreme than the area, where the most revolutionary effecting phenomenon is evolving: the local networks. Ethernet, the various other further local network systems making use of the same basic principles, the standardization effort concentrated in the IEEE 802 committee are not only new formations of inhouse communication but the heralds of new working organizations. Office automation (what should not be the automation of the conventional office work of our days) is only one dimension of this trend--flexible manufacturing, CAD-CAM systems are another question. Recent trends in process control, the future of the control systems--which could be nowadays called distributed ones only with some concern--indicate the same directions.

Our main thesis in this paper is that the cooperative-nature organization is very generally distributed and is a basic trend for the future. This involves that letting a much higher freedom for local realizations (controls) a very sophisticated high-level agreement should serve this unbelievable expanding future. It is not an exaggeration that the mentioned 802 standard proposals contain a 32 bit address-space! We have to remember the example of telephone and power networks started about 100 years ago when nobody could foresee the application-services spectrum that had to be integrated into the early conceptual frame!

A second relevant consequence of our considerations is that--due to the generality and convergence of several, mostly autonomous trends--we have to face the challenge of new organizational methods--a research field not only for engineering but for sociology, urban planning, education, ergonomy, management, politology, etc., as well. Cooperative technology provides a higher level of possible democracy, individual and local development, coexistence than any technology previously--if it is used appropriately.

4.2 Modeling Problems

Approaching to more technical problems, cooperative systems apply mainly similar mathematical-system science methodologies than any other system research did before, but the emphasis is shifted and much relevant details must be clarified. One major shift in emphasis is the role of protocols that in some sense and to some extent (by far not completely) take over the role of conventional control algorithms. That means that logics has a major role than the differential equations, description is done more by linguistic methods than by algebraic ones. Modeling of the systems will be in most cases a combination of the logical and the analytical, that fits well into the mentioned direction of heterarchical program structures: a net of intrinsically controlled programs containing data and procedures in the nodes--the procedures are partly analytical model components, partly decision schemes.

The heterarchical program-model raises new aspects of stability investigations: stability of the component systems (nodes), stability of the system, stability under various conditions, e.g., dynamically changing system architecture (see Chapter 3, definition 1., comment (b)).

Several simulation languages are used for modeling of analogous systems. Most probably the features of SIMULA or developments based on SIMULA philosophy are apt solutions, but this is also an undecided question, we have to compare the SIMULA features with some Artificial Intelligence languages.

4.3 Information Transmission

Many results of communication networking can be used and further developed. These are architecture-configuration problems both for flow and administrative information, the formulation of protocols, protocol levels, the safety, recovery, concurrence, privacy, equal user opportunity (or priority) issues. A comprehensive literature can be referred to, these are now those research areas which are in the focus of major interest.

Cooperative systems which are not exclusively information systems raise a decisive additional problem to the aspects of information networks: the inhomogenity of delivery (flow of any kind and information) has very different requirements (safety, economy, etc.). Even information network problems for process control and office automation--that should be integrated somehow for a company plant--have such different features that no agreement could be reached until now in spite of great efforts.

4.4 Operation Strategies

Most of the less elaborated questions are connected with operation strategies and growth--especially not only concerning dimensions but the variety of flow and administrative information. The latter raises the reasonable bandwidth problem and here lies the emphasis on comment (g) in Chapter 3— and ideally free cooperation would suppose an unlimited (and therefore untransmittable and unprocessable) broadcast of information. The design of directories, local and regional data-bases, limitations on basis of distance and application area, etc., are the practical conditions of any larger realization: a two-building software factory in Japan has fast outgrown the proposed international bandwidth for local networks: the 10 Mb/s rate, Bell Labs is working on a 100 MB/s system [14].

The strategies for ordinary, auxiliary and emergency operations, methodology for the competing of sources and drains (resources and users), bargaining, contracting are major new areas where we can apply some previously developed principles (the fair play, the randomization, etc., strategies) but the real systems raise much more complex problems than they can solve by simple ideas used for simple models. We refer only to the long way of network communication standards especially of the ISO Open Systems Interconnection's levels.

4.5 Resolution of Some Contradictions

Having an attractive scheme, the cooperative system, we must not forget contradictory trends and considerations. The first reference should be oriented to the fact that in spite of all problems with very large scale systems, systems are still growing and largeness is required in several cases for those organizations which could exist as small ones earlier. We think (and this is a conjecture statement) that even the cooperative organization can dissolve the contradiction between the growing need in resources (both dimensions and variety) and the absurdity of controls. We cannot sufficiently emphasize that this cooperative way is much more highly disciplined (with respect to cooperation only) than any other previous ones, the transient is a laboring process containing all the symptoms of acromegaly, conflicts, sometimes disorder. The second contradiction that we would specially mention here, excepted from the whole problem context, is related to the different level complexity treated under paragraph 2.1.

Not only different system components have different goals (optima) but the different levels, too. This means that the overall goal (optimum) of a system is mostly distinct from those of the components (this is trivial). The difference is hidden not only in parameters but also in time-behavior (long range, short range), some goals can not even be formulized, derived, estimated on the lower, component levels but are essential for the long range survival of itself. Straight technical systems can be quoted as examples (vehicle guidance in similar instantaneous but different environmental situations, steam generator pressure control depending on the nature of disturbance, control of a combined cold and hot strip mill operation, etc.) but human operator problems, social systems are even more typical.

The conventional answer was always a paternal solution of a higher level (more wise) central control which superimposes its "benevolent" will on the less intelligent, deviant lower level control. The cooperative solution is different: the component control is made more intelligent, able to receive and process all relevant external signals. (This remark is relevant also in the case of a human operator's educational level.) A specially dedicated overall estimator--which issues information signals for individual local controllers--is not an excluded version either. Several methods were elaborated, helping this process, we refer here only to a typical one of Borkar and Varaiya [15] on asymptotic agreement in distributed estimation. The mostly conflicting field in this respect is the human-social one, no wonder that this area has the broadest literature [16-40]. Concerning man-machine systems, semi-autonomous network models, an MIT group led by Sheridan [41, 42] examines the basic problems of common resource allocation and risk taking:

(1) "each individual entity (person, family, village, company, nation) must allocate limited resources of personal attention to select among alternative

(2) risky but hopefully cooperative games to acquire information on a probabilistic information value basis so then to be able to

(3) exert some control over accessible variables to satisfy with respect to the local objective function.

This makes for a three tiered complexity:

(1) select among "information games" to play, based on a prior expectation and costs of one's time, communication and energy,

(2) engage in each such game to maximimize useful information gain, based on criteria of relevance of expectations of what others will do in providing information in return for information,

(3) use the information to (automatically) control, based on time, energy and other attributes of objective function(s)."

5. CONCLUSION

This can be drawn from the first and last points in Chapter 4. Starting from various technologies, needs, evolution trends and realization possibilities a new perspective of system architecture is evolving that feeds back its revolutionary effects, not only to technology but to a broad spectrum of human activity. The new levels of complexity force this process inevitably.

On the other hand, the complexity problem cannot be solved in toto--and that is the supreme lesson. A new and more appropriate approximation raises new questions but it is more adequate to the complexity levels of the present than the earlier models of the past, that were more or less workable under past conditions.

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