# PROGRESS IN CYBERNETICS AND SYSTEMS RESEARCH

# Volume I

## General Systems
## Engineering Systems
## Biocybernetics and Neural Systems


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WITH INTRODUCTION BY

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# PROGRESS IN CYBERNETICS AND SYSTEMS RESEARCH

## Volume I

General Systems
Engineering Systems
Biocybernetics and Neural Systems

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in cooperation with
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International Association of Cybernetics

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# Contents

# KEYNOTE INTRODUCTION

# On heaping our science together

**STAFFORD BEER**

Just two years ago I should have introduced the first symposium on Cybernetics and Systems Research. Most unfortunately, all I could do on that occasion was to send a telegram from the other side of the world regretting my unavoidable absence. Ten days ago, Professor Hanika summoned me again. And so he has made good the prophecy he may not remember making those two years ago: 'aufgeschoben ist nicht aufgehoben'.

The reason for my defection on the last occasion was in fact an urgent recall to Santiago from the late President Salvador Allende of Chile. We had embarked six months earlier upon a program so ambitious as to have had at least a chance of revolutionizing the form of government on a cybernetic basis that would match the revolutionary political intentions of that democracy. This endeavor took precedence with me for two years, and I emerged from the experience very much changed. I changed in my awareness of myself, of my fellow men and of political realities; but these are not the topics that I shall discuss today. I changed also as a technologist, in terms of confidence. For I now know that it is possible to do what I have advocated for so many years—things which many used to say, and some still do say, are impossible.

But the changes that bear upon the nature of this symposium have to do with cybernetic insights themselves. There is of course no way of changing the laws by which large systems operate; but there can be a change in one's perception, and a change in the depth of understanding of principles we have known about all the time. It is of these matters that I speak today, because I know more clearly now what I am trying to say, and because I also know more about the direct practical relevance of these things to society at large.

We have all found it very difficult, I suspect, to convey the relevance of our kind of science to senior managers and to ministers of government. If this were not so, we should have changed the world by now. After all, we deal in organizational science, and the contemporary world is one in which modes of organization that are at the same time effective and freedom-preserving are virtually inknown. Moreover, the notion of effective management or government has become almost synonymous in people's minds with the idea of tyranny. And there is good reason for this, as one looks around the world. But in my opinion the confusion is leading steadily toward a disastrous error: namely, that everyone concerned to preserve freedom may automatically eschew effectiveness—finding it too dangerous a commodity to approach at all. And then we encounter the opposite fallacy, which is to say that what is ineffective is necessarily free. On the contrary, I believe, confusion and muddle are excellent cloaks for exploitation; and even where there is no

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sinister intent, the instabilities created through organizational deficiencies are everywhere a danger to survival.

The technical concept that we people have which points most surely to a resolution of this dilemma is the concept of a selforganizing system. A self-organizing system is by definition one on which organization is not imposed. And yet it must be designed so that it *is* selforganizing. There is an apparent contradiction in this which caused me a great deal of difficulty inside Chilean politics, and even worse difficulty with hostile critics elsewhere. But the contradiction is not real; and considered as a technical problem in cybernetics the difficulty is easy to resolve. That is, one designs a free, self-organizing system by using a language of logically higher order than that of the system designed; and our mathematical apparatus for doing this leads us to talk of 'metalinguistic' criteria and 'metasystemic' regulators. Now it is perfectly clear that talk of this kind is wholly unacceptable to people who do not really understand it. The message that comes through to them is undoubtedly a confession that everything is being secretly manipulated by shadowy figures in high places. But this is not at all the intention, not at all the reality, and we must find better words with which to explain ourselves. Let me use my first Chilean example.

Consider the workers' committee that is trying to run a factory. What do they need to know? Now of course if our anxiety about effectiveness and freedom is real, the immediate response to this question is: what they need to know is entirely a matter for them—let them find out. Some would say that to give that answer leaves us innocent; I would call it downright oppressive. Who are we to deny to the workers' committee the tools of modern science? So, right from the start, we began an active campaign to explain to the people that science is simply ordered knowledge which can be communicated, and which is part of their cultural inheritance. To make that communication effective, the knowledge obviously must be conveyed in terms that people can understand. And we confront the cultural absurdity that no real attempt has ever been made to do it. When I say 'real', I do not mean the lucrative sale of pot-boiling books nor the patronizing display of miraculous scientific fireworks delivered to an amazed public on television. I mean something founded in the reality of people's own experience, and in this case the factory itself.

We wanted to show workers how they could themselves make a model of their factory; therefore there is simply no sense in conceiving of the type of model which has to be expressed by differential equations. Instead, we developed a set of rules for devising iconic representations of the dynamics of the business, which we called quantified flowcharts. To set them up in the first place, operational research teams visited all the firms, creating the rules as they went along. The important point was to create a technique that anyone could learn, and that would make the relative importance of different flows and the critical measurements which govern their dynamics instantly recognizable by anyone *who actually knows the business.* So we gave them the rules; we gave them initial flowcharts; we marked initial sets of key indicators; and we explained how to express the numerical quantities in the form of indices.

Why the rules, and why the indices, and why hand over charts and create initial indicators? It is obvious that all these things are specified by the logical design of some metasystem. But in truth this is no more than to specify a language that people are asked to use inside the industrial economy so that everyone can understand everyone else. If every factory were to develop a different set of linguistic conventions, there would be no effective communication. But having made this start, we were careful to say that the quantified flowchart could be elaborated, or totally redrawn, by the workers' committee at any time; that they could add to the list of indicators as they pleased, not even saying what the new daily figures referred to, so long as they were formulated as indices—pure numbers ranging between 0 and 1; and that they could do anything else they wished provided they spoke the language provided.

Now the most interesting point about this is that if they were to find the language itself defective, then obviously they would be able to propose its elaboration too. In this way there is nothing whatever to stop a self-organizing system that is also self-aware from joining in the process of specifying its own metasystem. Indeed, each of us does this as a human individual, insofar as he exercises choice over his environment. Note the word 'insofar'; no individual has the chance *totally* to specify his metasystem, much of which is a genetical inheritance, more of which is socio-economically restrained. For identical reasons, it seems to me, no unit of society—such as a workers' committee—can expect to operate without any constraint from some metasystem. But it can demand maximum freedom within it, and it can claim a democratic share in its specification. To argue for greater freedom than this, seems to me a plea for anarchy; to accept less freedom than this is to abdicate responsibility and embrace dependency.

Let me now complete the example, and reveal —against this background—a feature of the Chilean work which has frightened some observers. We wanted to make science available to that workers' committee, and with it the tools of science—especially the electronic computer. There was no way of purchasing more computers, because of the economic stranglehold in which the entire country was held by the rich world—which cut off its supplies, its spare parts, and its credit. There was no way of training workers in their instant use. So we set out to link up all the factories down the three thousand mile length of Chile to a single computer in Santiago. Again, we could not afford a genuine real-time system, because there was no teleprocessing equipment available. But using Telex and existing microwave links, we had seventy five per cent of the social economy in touch with this computer on a daily basis inside four months. *'Centralization'*, opponents have screamed. Not at all. If there is only one computer available, you have to use it.

Into this computer came a daily flow of indices reported from each factory. What should the computer now do with these data? Add them up? Report them? File them away in a massive data bank? Certainly not. Think of all the work that cybernetics has put in over a quarter of a century to questions of artificial intelligence. Is it not about time that managements and governments used a little human intelligence in deploying computers as the logical engines which men like Leibnitz and Babbage intended them to be, and not as glorified adding machines? This is what we set out to do, in a modest but potent way, and again—for the same reasons as before—it meant specifying a metalanguage. This, in brief, was a computer program that automatically undertook the following examination of every index from every plant every day.

The first question answered by the program suite called Cyberstride was this: has the value arrived, and is it statistically plausible? Secondly, if so, is it to be viewed as a statistically random sample from the population from which it is supposed to be drawn? If it is not, that is to say if there is a strong probability that the inspected value does not lie within the normal limits of variation about the average, then someone must be told. Who must be told? Why, the workers' committee running the factory concerned, of course—AND NO-ONE ELSE. We are making progress, because we are providing people with a service notifying them *immediately* of likely deviations from standard values. Most firms cannot do that on a weekly basis, still less a daily basis; and we were doing it over a three thousand mile long country. But there is more to come.

Even immediate notification that something may have gone wrong is too late for corrective action to be taken: I mean that yesterday lies as much in the past as does last year. What intelligent machinery ought to do is to use the information it has to predict that something may go wrong in the future. And this is just what the Cyberstride program went on to do. It would inspect every index against the background of the time series of which it was a part, and assign probability to the likelihood that whatever this index was measuring was changing. To be precise: it calculated four probabilities: that the new point showed no change, that it showed a transient pulse in the time series, that the series was developing a slope, and that the new point indicated a step change. In the latter two cases the computer would automatically notify the plant concerned, thereby (I feel entitled to say) breaking the time barrier and showing some intelligent anticipation of events. All this analysis was done using Bayesian probability theory. [1]

So there, in the shape of the Cyberstride program, was a metasystemic brain-like activity which the workers' committee had no chance to modify. In fact, this is just like my saying that I have a brain whose basic functions are determined by the genetic code of my own DNA. But my brain is a service to me; and I do not think of it as being oppressive—although there are ways of discussing this matter which surely make it so. In the Chilean example, I think the only way in which this service to the workers' committee could possibly have become oppressive would have been if the closed loop flowing from the factory through the computer program back to the workers' committee was subject to invigilation by some 'higher authority'. The system laid down that this would not happen; but I do not for a moment pretend that this system—like any other system whatsoever—could not have been perverted by a malevolent régime. Then, say the anarchists, do not instal it. And to this I reply: there is no way of building freedom into a system of government that oppression backed by force cannot overthrow in any case.

I will leave the Chilean experience there for the time being, with the remark that if one can devise a self-organizing system in this sense for every firm that belongs to the economy, then one can presumably do it for other social units as well. These are of two kinds. First of all there are other social units than firms, such as neighbourhoods. And this way of looking at society will create a total system, called the country, which contains many sub-systems of similar size and evincing a fairly similar degree of organization, which are sub-systems of the total-system—all interconnected, all adjusting to each other in a self-organizing way. For example, we may expect neighbourhoods of a city to be supplied with quite a high proportion of their consumer requirements from factories also located in the city. The second kind of development we should expect is hierarchical. Factories belong in some sense to an industry of which they see themselves as representatives. Industries in turn become larger sections of the economy—whereby, we speak, for example, of light and heavy industry. It is to this problem of hierarchy that I next turn attention, because I think it has been left in a very, very confused state in our literature.

If we take any viable system we shall certainly find that it is broken down into sub-systems, and that these sub-systems are in turn broken down into sub-sub-systems, and so on. I am describing the primitive notion of hierarchy, and do not take your time to attempt extremely formal definitions because this has been done so well by other cyberneticians—notably, in their different ways, by Mesarovic and Pask. May we please take their work as given. I do not seek to criticise it: on the contrary, it provides us all with extremely powerful theoretic foundations for hierarchical analysis. The confusion to which I refer in this case has nothing to do with theoretical cybernetics, but with the domain of social applications. In this area we inherit a long-standing tradition of analysis by use of the tool called the organization chart. It is very easy to make fun of this device, and I often do so myself, on the grounds that it does not at all depict a dynamic self-organizing system, but a machine for apportioning blame. If something goes wrong, you can consult the organization chart to discover whose fault it is. Now that is the kind of complaint that I make to business men and to civil servants, on the ground that we need a better account of what is dynamic, what is self-regulatory, what is self-organizing, what is adaptive and evolutionary, than this kind of chart can possibly provide. But in speaking to you as cyberneticians and systems scientists, I have something very much more fundamental to say. In saying it, I wish to use the technical term, due to our greatly missed teacher Ross Ashby—the term 'Variety', meaning precisely the possible number of states of a system.

When we address ourselves to the analysis of any real social system, we are confronted with gigantic variety at the level of humanity itself. Vast numbers of men, women and children live on the territory of our social system, their feet on the ground, their arms outstretched in love and hate, in need and aggression, their heads anywhere between firm implantation in the sand and the clouds above. They proliferate variety on a scale that I think we cannot possibly imagine, although—thanks to logarithmic functions—we may be able to put some sensible numbers to it. If, as before, we demand a base in people's own reality, here it is that we must start. And if we develop a hierarchical analysis we shall agglomerate these people, by some criterion, into units, which we shall then aggregate into larger units, and so forth. If we are being at all meticulous about this, we shall not—in any real social situation, whether a firm or a whole country—make a very useful hierarchical classification having less than seven levels. There is no proof for the assertion of this number seven: I can only say that in practice a lesser number conceals too much, while a larger number probably exceeds the brain's discriminatory capacity to tell them apart or to hold them together synoptically.

I am entirely convinced that a hierarchical model based on this approach, using any of the scientific techniques that I know to be available, will not work. The problem is this. If we start at the top of such a structure, we specify (at least) a seventh order metalanguage and metasystem. By the time that the rules have been elaborated through the remaining six orders of hierarchy, the total system cannot possibly operate effectively—because it has seized up; and those actual living people at the bottom cannot possibly be free—because everything about their behaviour will by now be totally constrained. The fact is that every hierarchical level on the way up the pyramid is, because it must be under this model, a variety attenuator; whereas, on the way down, the whole apparatus is a kind of megaphone, the amplifications of which will flood the people with sheer noise. As I said, I know of no scientific approach to this monstrosity that would predict a society that is both free and effective. Perhaps the most obvious model to employ would be an electrical model. Given that we are dealing with a high variety network, rather than with the idealization proposed by the hierarchic tree laid down in the representation, then it seems fairly clear that the impedance of the system would be such as to close it down altogether.

Quite apart from the models that reveal to us the impossibility of tackling the societary problem in this way, I myself consider that theoretical analysis poses an insoluble problem. In 1960, I propounded a model of the brain (in which the variety-handling difficulties seem to be of similar order to the societary problem) which postulated a law that I called 'the indeterminacy of configuration structure'. [2] This declared that in a very complex hierarchical network of the kind we are considering in a social system (as in the brain) the configuration of the network would be indeterminate. That is, if it retained its identity through time, then it could not be denoted by a general algebraic function; whereas if it could be so denoted it would not retain its identity. In the fifteen years since I proposed this law, no-one has either assented to it or denied it: as for me, I still believe it. But if the law is true, we must expect not to be able to handle the variety of a system of this kind by hierarchical formalizations on their own. Indeed Mesarovic [3] himself has not concealed this limitation of his work. Most of it considers optimizing systems, whereas I do not consider that society—even in the shape of a business concern—much concerns itself with optimization. He also says 'we found it convenient to assume that the decision problems of the sub-systems are relatively well defined and simple; otherwise, we might have been bogged down with the intricacy of individual unit behaviour and not have the chance to study the proper hierarchical questions at all'. We must take this disclaimer seriously, because the high variety, which he calls 'the intricacy of individual unit behaviour', is exactly the problem with which any societary system has to deal; its sub-systems are not relatively well defined—and certainly not simple; and as far as I can see they put the intention to survive in front of optimization every time. In fact, optimization is an extremely precarious strategy for any viable system to adopt, because the maximal value of any complex objective functional turns out typically to be unstable. Any sensible manager would rather sit securely on a plateau of reasonable profit than to climb a further two per cent in payoff, only to perch on the brink of a precipice leading to bankruptcy.

So here is our second dilemma. It is clear that all complex viable systems do have an hierarchical structure; but it is equally clear that some kind of pyramid involving an endless succession (or even merely seven) levels of sub-system and sub-sub-system will not serve as an analytical device for resolving the cybernetics of any such organization.

My answer to this problem lies in the concept of recursion, not of hierarchy. I base my use of the term 'recursion' in the mathematical usage of recursive number theory—not merely in the loose and idiomatic usage of ordinary language. Recursive number theory is interested in examining the process of *counting*; and indeed we are counting when we look at a society through various levels of aggregation. Then, at each level, we are looking at some kind of collection; this being admitted, the counting process explicitly 'consists in overlooking the individual idiocyncracies of the elements of the collection and regarding them as being all alike (but not identical) for the purpose in hand'. [4] In expressly mathematical terms, 'a function $f(n)$ is said to be defined by recursion if, instead of being defined explicitly (that is, as an abbreviation for some other expression), only the value of $f(0)$ is given, and $f(n+1)$ is expressed as a function of $f(n)$',

The argument, then, is that we have to define exceedingly complex probabilistic systems, such as societies, by recursion rather than by hierarchy. You may have noticed that I have been using the words 'viable system' rather a lot. It is possible to define a viable system, namely a coherent whole that is capable of independent survival, at only *two* levels of hierarchy. The lower level has a sub-system consisting of any number of viable systems. The upper level is metasystemic to that set of sub-systems, and itself consists of four sub-systems. Because the lower level sub-system consists of viable systems, we now have a recursive definition that we can handle.

It took me more than twnety years to validate in practice, that is to say in application to societary systems, this model of a viable system. I have found that there is no limit to the number of levels of recursion that can be accommodated in a societary model. And I firmly believe that because the nest of systems that results is connected together only by the process of nesting itself, which is specified in the metalanguage of the whole, the *operational* freedom of each viable system can be totally preserved. And so I have stated a Recursive System Theorem, which says: 'If a viable system contains a viable system then the organizational structure must be recursive'. [5] I might better have said: 'If we decide to define a social system by recursion, we shall find that every viable system contains a viable system'.

What all this adds up to is a way of modelling a society, not as a hierarchy looking like a family tree with so many branches that all the cousins could not possibly know each other's names, never mind interact, but as a series of Chinese boxes. Every box is a viable system containing a viable system; every box is contained within a viable system. Continuity is given by the boxiness of the boxes, rather than by their explicit contents—for as we have read recursion regards the collections as being all alike, but not identical, for the purpose in hand. The purpose in hand is the design of a metasystem that can be both effective and free at the same time. To be free, each box is its own viable system—untrammelled. To be effective, each box is enclosed in its metasystemic box, which is also a viable system. And to maintain freedom, ultimately, we shall take note of the endowment that every box is entitled to participate in the specification of the metalanguage used by its enclosing box.

To bring this theoretical disquisition back to reality, I turn to my second Chilean example. You may remember that I said that the firms using the system I earlier described could be aggregated into industries—or, as the Chileans called them, sectors. Then the firm is a viable system, and so is the sector. This means we need a model of the sector. And if we adhere to our rules about the language that is spoken within this total system, then the sector must be describable in terms of a quantified flowchart, and must be quantified in terms of indicators relating not to the firm but to the sector—yet still expressed as indices. Then if you can tolerate the notion of this second Chinese box, a viable system enclosing a set of firms that are themselves viable systems, you will see that both the model of the sector and the quantification of its indicators will be given at a *higher level of recursion* than the elementary data themselves define. This leads to a process of aggregation of models and of data, which is quite unlike the process of aggregation familiar in economic controls throughout the world.

The systemic model of the sector looks exactly the same as the systemic model of the firm: both are viable systems. But the quantified flowchart of the sector looks nothing like any one of the flowcharts of the firms; obviously not, we are looking at a different (though still viable) animal altogether. But when we come to quantify the model of the sector, we shall want to use the basic data of the firms—not as totals or as averages, but as defining whatever functions are necessary for us to define in the *meta*-systemic model. Then once again freedom is preserved, because the data available at the sector level reveal nothing of the individual idiocyncracies obtaining at the level of recursion below. Because the mathematical concept of recursion is not violated, the political concept of freedom is not violated either—and this is what so many critics have totally failed to understand.

Having set up a sector model, at a second level of recursion which is not to be confused with a second level of hierarchy, we observe how the agglomerated data—agglomerated (not totalled, not averaged)—become susceptible to treatment through the Cyberstride computer program for the artificially-intelligent handling of facts. Because each sector model is expressed as a quantified flowchart, and because its indicators are expressed as indices, there is no difficulty whatsoever in channelling daily *agglomerated* information through the same suite of programs. And whatever signals emanate from that daily process are fed back to the committee of workers responsible for the sector, in exactly the same way as indicators belonging to the lower level of recursion were fed back to the factory. Please note that this does not make itemized information about factory performance available to the sector committee. Each level of recursion is its own self-organizing system; they are linked by recursive transformations of data founded (where else should they be founded?) in shop floor reality.

Now to continue with this second Chilean example, what applied to the second level of recursion—the sector—also applied to the third level of recursion, which is a branch of the industrial economy. In the case of Chile, these were categorized as light industry, heavy industry, consumer industry and 'materials' industry—which in round terms meant 'the rest'. And everything I have said about modelling and quantifying the second level of recursion, applies at this third level; as indeed it does at the fourth level of recursion—total industry itself. This means that when the President's economic committee came to consider the performance of the total industrial economy in the social area, it would be looking at quantified flowcharts linking together the elements of the next level of recursion downwards, quantified by variables appropriate to that level, *but processed through Cyberstride just the same.* So here is the massive variety reduction that of course we must have to obey Ashby's Law. The machinery designed to apply artificial intelligence to sensory inputs works identically at every level or recursion.

I wish to emphasize this point. As long as we have organization-chart models of societary systems, and as long as we insist on treating them as multi-level hierarchies, so long shall we compel ourselves to devise data-handling routines that are specific to every separate cell of this beehive. Then no wonder that all we have so far managed to do with our computers is cybernetically trivial, and no wonder it is done at prodigious expense.

Let us now turn to the next fundamental cybernetic concept, so often debated among us, which I believe to have been illuminated in the context of