On the Nature of Models: Let Us Now Praise Famous Men and Women, Too (from Warren McCulloch to Candace Pert)[1]

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Centenary Celebration for Warren McCulloch

A Thumbnail Sketch

I had the privilege to know most of the founders of cybernetics, and three in particular I honor as mentors: Norbert Wiener, Ross Ashby, and Warren McCulloch. This year there is special reason to celebrate Warren Sturgis McCulloch, for it is his centenary year. He was born on the 16th of November 1898, in Orange, New Jersey.

Warren was a **philosopher and scientist**. As a freshman at Haverford College he told the Quaker philosopher Rufus Jones that all he wanted to know was: "What is a number that a man may know it; and a man, that he may know a number?" To this the Quaker famously replied: "Friend, thee will be busy as long as thee lives." Warren acknowledged in his last days that the prophecy had been fulfilled, and had helped him to invent cybernetics on the way.

Warren was a **physician and psychiatrist**. He graduated from Yale in 1920, and took in a period of service in the Naval Reserve. Then he went to Columbia University where he qualified as a physician, attaining his M.D. in 1927, and became known for work on experimental epilepsy. You might well ask what he was up to in the early 30s, then, doing graduate work in New York University on mathematical physics. But in a year or two he was back at the alma mater in Yale and working on the central nervous system. Throughout the 1940s, he was professor of psychiatry and clinical professor of physiology at the University of Illinois.

Warren was a **logician and neurophysiologist**. He can properly be called responsible for the field now widely known as neural nets (where for some years he had Walter Pitts as a significant collaborator). Perhaps it now appears more plausible why a psychiatrist in Illinois, should suddenly turn up in 1952 in Cambridge Massachusetts -- running a research laboratory in electronics at MIT! He remained in that small but influential room until his death 17 years later, in 1969. In 1963 he became consultant to the presidential office of President Kennedy.

Warren was a **blacksmith and poet**. He enjoyed physical activity and working as an artisan. He undertook crazy schemes -- from constructing a sizable dam (referred to as a “pond”), to building a quasi-cathedral (referred to as a “barn”), on his estate at Old Lyme, Connecticut, where Einstein was a neighbor. And when the Chicago Literary Society invited him to speak, I am not sure that everyone was entirely prepared for him to spend the entire evening reciting his own poetry.

Philosopher and scientist, physician and psychiatrist, logician and neurophysiologist, blacksmith and poet -- those are a few of the categories that Warren in fact transcended. That is because he was above all a polymath: an all-purpose intellect, and a liver-of-life on a grand (some would say profligate) scale.

In the Small Conference Mode

The notion of meeting in conference as a small group of powerful intellects -- with no outside audience -- had a vogue during the '40s and '50s to which I fervently wish we might return. It was outstandingly successful; but it does however re-

[1] Portions of this article were first presented by the author at the World Multiconference on Systemics, Cybernetics and Informatics held in Orlando, Florida, on July 12-16, 1998

quire substantial funding. The theoretical basis of such an "evolutionary cluster" came from Margaret Mead, and a persistent advocate was Frank Fremont-Smith. Warren McCulloch was a forceful if often manipulative chairman.

The outstanding series of these conferences was sponsored by the **Josiah Macy Jr. Foundation**. Each lasted for two full days. They began in 1946, and continued on an annual basis for ten years. Unfortunately, formal publication did not begin until the sixth year: they were a tremendous boost to those of us who received them as they arrived.

Towards the beginning of this series, in 1948, a cognate conference was held at the New York Academy of Sciences under the heading of **teleological mechanisms** -- again with Warren presiding. It was a favorite topic of his. Teleology comes from the Greek root meaning *end* in the sense of *purpose*. It is concerned with the science that asks how things come to be as they are -- how regulated, shall we say. Or shall we not say this, on the grounds that we might be incriminated by any of a hundred canons of philosophy. The term sounds like an oxymoron, after all, as did Wiener's original definition of cybernetics as being concerned with *the animal and the machine* -- all-in-one-breath as it were. To this day, confusion about the intentions of the founders of cybernetics is widespread, on the part of people who do not refer to original sources. Here is Fremont-Smith introducing the conference of 1948:

> "The concept of teleological mechanisms... may be viewed as an attempt to escape from... older, mechanistic formulations that now appear inadequate, and to provide new and more fruitful conceptions and more effective methodologies for studying self-regulating processes, self-orienting systems and organisms, and self-directing personalities..."

So for those who are prone to reinventing wheels in different sizes, please ruminate over those different sentences -- and the fact that they were written just fifty years ago.

In the Mode of Scientific and Papers

A major collection of seminal papers may be found in Warren's book *Embodiments of Mind*, and there is a complete set of his works available in four volumes. Here, however, we must remain within the scope of the thumbnail sketch.

The first major work that he wrote in the field of cybernetics was surely:

1943: A Logical Calculus of the Ideas Immanent in Nervous Activity

Observing that activities in the nervous system are made up of discrete events, it was proposed that the relations between them could be treated through propositional logic. Using a rather outdated symbolism devised by Carnap, and the ungainly notation of Russell, Warren succeeded in showing that nervous nets could be rigorously represented in mathematical logic. The regenerative activity of constituent circuits so described, however, leaves the brain with no concept of either space or time. This means that fact, sensations and ideas must be generated *within* networks, and are not determined by them. Walter Pitts was the co-author of this paper, and Warren was generous in referring to his improvement of the mathematics.

This brief comment gives the clue to the philosophical importance of these ideas. The extent to which the organization of the brain determines its mental outcomes is not clear to most people even today. The rigorous logic of the *Logical Calculus* began for the first time to elucidate the difference between brain structures and mental contents. The development of this model also made it clear that there must be inhibitors in nervous nets as well as excitors -- a fact not yet conceded in neurophysiology at that time, although later taken for granted.

Many arguments with orthodox psychology were generated by these results, and even more so in psychiatry. Warren was a vigorous opponent of the psycho-analytical schools. Indeed, we had several major disagreements about the importance of Freud himself.

1958: Agathe Tyche of Nervous Nets -- the Lucky Reckoners

Still pursuing the topic of nervous nets, I refer to another formal paper, this time dealing with reliability. The substance of which the brain is made is notoriously unreliable: neurons are extinguished without warning, synapses change their thresholds capriciously, and a single shot of alcohol changes the whole cerebral ecology. And yet we humans continued to operate fairly smoothly through it all. The success of this is due to redundancy -- of a sophisticated kind. I mean that it is not simply a matter of replicating fallible components, until some of them fortuitously work, but of generating complicated logical structures within them. I have written extensively about the redundancy of potential command, for example, which involves just such a strategy. In the present paper, we are presented with an early example of the *formal* treatment whereby unreliable components achieve reliable outcomes.

But this time I want to use this example to talk about Warren the man. I had the good fortune to be present on the occasion when he gave his original paper on the *Lucky Reckoners* in 1958. The chairman announced that as usual the paper would be taken as read. Silence fell as Warren arose, clutching a set of manuscript pages. He surveyed the audience with a rather intimidating mien, looking up and down the packed rows. "Who has actually read the paper?" -- the tone of voice suggested that he might well decide to cross-question anyone with the temerity to reply. Half a dozen hands were raised. At

that Warren tossed the whole sheaf of papers high in the air. The pages fluttered down among the front rows.

It was true that without detailed prior study the difficult arguments and complicated diagrams of the paper would have been virtually incomprehensible, and surely the author was correct to abandon the enterprise. However, I have never seen this happen before or since -- whereas hardly a conference passes without listening to some luckless speaker with a similar problem mumbling through incoherently to the end of his allotted span. It was so typical of Warren to be thus direct; but of course it was also typical of Warren to deliver an impromptu speech on some other subject that interested him at the time -- and acquit himself with brilliance.

1959: What the Frog's Eye Tells the Frog's Brain

There is no time to discuss this elaborate research, which elucidated among other things that there are four distinct parallel distribution channels whereby the frog's eye informs his brain about the visual image. Even so, I have picked on this third example for a good reason.

In many ways this work adumbrated an era in which systems thinking would become incorporated into an earlier biology of the old school. A significant early founder of this development was Sommerhoff, who published *Analytical Biology* in the year 1950. It is sufficient, perhaps, to invoke the great cybernetic Ross Ashby, who told me that the whole development of his own work in *Design for a Brain* derived initially from there. *The Frog's Eye*, in turn, became recognized as a milestone.

The authors were, in the order cited, Jerry Lettvin, Humberto Maturana, Warren McCulloch, and Walter Pitts. Notice first that the order is alphabetical. Not every eminent person extends that courtesy. Notice second the name of Maturana, who was at the time a graduate student of McCulloch's; he has since become a world leader in the field of cognition -- and also the originator of autopoiesis.

Some personal memorabilia

When I think of Warren, I think first of my mentor. We met each other first in the mid-'50s, and adopted that relationship from the start. We had no formal connection in academia or in any other milieu -- we were simply friends, but he was thirty years older than I. We had something profound in common; we could joke and argue and hassle as friends do; but underneath he must have been aware of something akin to veneration. We stayed at each other's houses and each other's labs. Especially I relished staying at the estate in Old Lyme Connecticut.

Next I think of his incredible output of writings, which I studied so assiduously, and I became addicted to his whimsical titles. Their style is impossible to resist (at least I have found their imitation irresistible, to the annoyance of some more bibliographically prudent). Two papers published when I first knew him were listed adjacently in the bibliography: *Mysterium Iniquitatis of Sinful Man Aspiring into the Place of God* followed immediately by *Central Effects of Strychnine on Spinal Afferent Fibers* -- this gives some feeling for the effect.

Seized with many of his sayings, I can offer only a few at random -- the first having effected an observable change:

- get your elbows away from your sides, you bloody Englishman
- we must learn to fight fair in our shirt sleeves
- don't bite my finger, look where it's pointing
- all impersonal questions arise from personal reasons and are best understood from their histories

Finally, I frequently have occasion to remember the story that dates from 1959 when Warren was talking to a conference in France about the mathematics of neurology. The discussion was halted by an “antique president”, who thanked him for his obscurity. Added Warren, “The next time they hear it they will say, ‘It is not news,’ and the third time, ‘it is obvious’." I myself was last formally thanked for my obscurity as recently as two years ago, though the location had changed to South Africa. I trust that the rest of the story will follow to Pretoria in due course. In the meantime, no one should ever be disturbed by this kind of reception -- it is a necessary precursor to any change of paradigm.

For the moment this thumbnail sketch ends my celebration for Warren McCulloch on his 100th birthday. He was a man with scant respect for pedigree or academic honors. His personal accolade -- not lightly bestowed -- was to say of someone that s/he was “brighter 'n hell.” He had magnanimity -- but did not suffer fools gladly. I shall present a last and precious word from Warren when I close.

Views from the Bridge

I began by celebrating a man who is a hundred years old, and shall end by celebrating a woman who is still vibrantly alive. Let me take leave to make a bridge between these two extremes, through a number of reflections about my own experiences of cybernetics.

It seemed to me from the start that our field was very weak in an understanding of epistemology. This I fear is true of the whole of science but cybernetics has less excuse than other disciplines -- since, according to Wiener's original definition, it deals with regulation **in the animal and the machine**. This refers us directly to the interaction between brains on the one hand and other kinds of system on the other. What do we

know about systems, and how do we know it? This identifies the cybernetic domain -- and offers a handy definition of epistemology too. I have already said a good deal, through McCulloch's work, about the nature of brain. But how specifically is the bridge to be built between that kind of knowledge and everything else?

About understanding models

The first bridge on which we need to reflect concerns the nature of **models**. Models are mental constructs of what we rather uncritically call "reality". The term reality makes intellectuals uneasy, however, and we often waggle a pair of crooked fingers impotently in mid- air to designate quotation marks -- thereby demonstrating unease if nothing else. When it comes to physical models though, we feel happier. We talk about scale models of buildings for instance, or mathematical models of the stresses that buildings display. And these two kinds of model are surely constructs of *actual* buildings. The truth is, however, that anything at all that comes to our attention is a construct -- and so a model in this sense. Starting from sense data themselves, which are constrained by the physiological apparatus of ears, eyes and so on, our models of reality are only as good as this equipment. (This is a direct consequence of the Conant-Ashby theorem.) Models are not to be confused with the reality of which they are the models -- if indeed there is such a further reality, which is open to question.

If something is illuminated by ultraviolet light, we shall not see it. If a sound occurs at 25,000 cycles, we shall not hear it. These basic limitations of sensation are by definition defective, so any models based upon them will be defective in the same degree. More elaborate constructs are doubly so. Suppose we consider an angel, and define it as a being of higher complexity than ourselves. Then of course we shall not be able to recognize it. So ontology is the slave and victim of epistemology; and our highest achievements are no more than inferences. This makes even the best of scientific judgments less than secure; it makes the best of artistic masterpieces sublime.

A second and inevitable defect of models has its roots in inadequate variety. If we cannot distinguish all the possible states of any supposed reality, we are restricted to model-making using the constructs that we can distinguish. Then all images are restricted to the visible spectrum, and all music is restricted to the spectrum of audible sound. Ratiocination itself is restricted by the neurophysiology of the brain. As to angels as defined, they cannot be recognized in just the same way as you must inevitably fail to tie a knot in a four dimensional piece of string.

Because any subject of our attention is limited in these ways, and because individuals differ in acuity of perception and in pattern penetration, any system is a **subjective** phenomenon. We cannot have an objective system -- which means that no system is ever right or wrong. A system is a model that is more or less useful for some **purpose**. If that purpose is not defined, then there is no criterion of utility.

It is time perhaps to lighten the atmosphere of these weighty considerations by choosing a more jocular example of the range of variety as a restraint on model-making. Suppose that you want to understand the nature of music. Unfortunately, because of low variety in your repertoire the only basis for model-making available is an experience of Wagner's *Parsifal* and another of a rock-and-roll concert. Can you construct a useful model of music on that basis? If so, what would it look like? Let us first ask what these two experiences share. Three things, perhaps: they are both too long, both too loud, and you cannot understand the words of either. If these things were all that mattered, and you yourself had made the judgments, it is easy to see that you might have created a valid because it is a useful model. The models we use can be as arbitrary as that -- and I did say that all models are subjective!

About not understanding jokes

That example made its point legitimately -- but it turned out to be funny. That is because of the context in which it was put forward, and because the variety admitted to the system of music was absurdly low. Here are a few selected examples that are not in the least funny, because the context is different. As to the variety, a strange embedment will be discerned...

- For every dollar of aid vouchsafed to the poor world by the rich, eleven dollars is exacted from them in interest.
- Forty thousand children in the poor world die every day from easily alleviated illnesses, notably those of malnutrition and contaminated water, while 600,000 women die as a result of complications arising from pregnancy and childbirth.
- In poor countries one in ten pregnant women in do not survive -- it is one in five thousand in Britain.
- Year after year the model of Canadian society is held up as a cynosure by the United Nations as the best in the world. The Prime Minister continually refers to this with pride -- but 21 percent of Canadian children live in poverty.
- In Britain, much exercised as it is by the abuse of animal rights, the percentage is much higher -- more like a third of children live in poverty there.
- Indeed, on the United Nations poverty index Britain ranks almost the worst among the world's industrial nations. But the top slice of the wealthy grows significantly richer every year.

I stumbled on these examples by happenstance, and I hope that you find them outrageous. They do not happen because they are willed by vicious policies. They happen because the

models that uphold them do not have requisite variety to discriminate between the policies that generate such results. When a large system is recursively embedded in a smaller system, the large system often includes entailments that constrain discrimination of variety at the lower level. We saw this happening in each of those examples. In general, the model of Western capitalism includes entailments of the model at lower levels of recursivity that are not in practice susceptible to dispute -- because to call them in question would deny the paradigm obtaining at a higher level. Here is an example: the dogma of privatization is an instance of a policy that belongs to the paradigm. It is also a policy that generally fails. Instances abound, here are a couple from Britain:

- The private ownership of water was a disaster of scandalous proportions. Management emoluments skyrocketed, while water quality went down -- in some cases even the provision of piped water failed, and supplies were transported by truck.
- Following the privatization of the national railway system, complaints showed an increase of 103 per cent -- topping a million last year.
- Timetables and fares were in disarray, thanks to the carving up of franchises, and the unwillingness of newly competitive entities to talk to each other. The Consumers' Consultative Committee referred to appalling delays and cancellations.

But although this policy of privatization in the public domain is a manifest failure, there is no requisite variety within accepted politico-economic theory to argue the point. It is an intrinsic component of the macro-model and must therefore be pre-judged a success. It would take a new paradigm within which either to assert or deny any of the statements relating to actual events such as the examples mentioned. In the meantime, would-be rebuttals constitute undecidable (Godelian) sentences. This is not to say that the previous system did not require overhauling. It is to say that privatization expressed as the raw exploitation of greed within the robber-baronies is not the best way to do it.

I said at the start of this section that science is weak in epistemology. The great Isaac Newton famously alleged *Hypotheses non fingo* -- I do not form hypotheses. He simply did not recognize that he did so. Yet his dictum has certainly survived, and latter day scientists continue not to recognize the point. Science is supposed to amass "the facts", and then to form hypotheses based on those facts. But the hypothesis is already covertly implicit in the selection of the facts, and further selection of a less than overt nature occurs during the process of elaborating the hypothesis further. The continuing operation is circular. That is why cybernetics takes *ouroboros*, the snake that bites its own tail as a suitable logo, and talks about **circular causality**.

It is from within the circular model of Western capitalism that monstrous results are generated at lower recursive levels of variety that are inevitably undecidable. Attention to this kind of absurdity is often dissipated by changes of terminology so that contradictions are accommodated. Witness for example the more than twenty changes made by the British government to the definition of unemployment during the '70s and later -- until the definition matched its paradigmatic expectations. A more fundamental circularity concerns a truly tenaciously held belief, which means that contradictory evidence will be attributed to quite different causes. Witness the contention that market forces in free competition can be expected successfully to regulate an economy. This policy is inherently unstable, and can cybernetically be guaranteed not to work. But if we are assured by authority that it does work, instability will be put down to other factors. Because of the underlying instability, there will be many contenders.

The hardening of the categories

Various taxonomies have been used to classify human knowledge, the most general based upon the practical needs of libraries (-- or possibly librarians). The library is organized by subjects. As new knowledge accrued, it was allocated to the "correct" subject in the shelves. The past tense is important: those judgments were written in stone, although later knowledge makes the categories less than optimal. So here is another illustration of circular causality: a book is allocated to a subject, which is defined as a university department, which determines what books will be allocated. The growth of knowledge so defined is an accretion of past decisions about the categories to which books belong. This raises problems when hitherto separate topics become multidisciplinary: biophysics, for example, or socio-economics. These problems are not always satisfactorily solved. In the case of a new subject that is *multi*disciplinary, such as cybernetics, no satisfactory solution is found.

Research papers feed and exacerbate the system. Under a university regime in which the number of publications is the only criterion of success, and more important to advancement than quality, or careful teaching, or the nurture of human potential, a predictable system develops. It involves the circular causality of publication, fresh submission, journal editor, anonymous referees (but guess who), reinforcement of the topic and of its kind of handling, and publication. The character of the journal consolidates. Before long, everyone knows the pecking order of journal prestige. If you are getting used to circular causality by now, you will instantly recognize who will review a new book, and why it is that an innovative book will not be reviewed in a journal whose reader would gain most from it. By the same token, a new author is lucky to publish an innovative book in the first place.

If the learned taxonomies we use have had the dire consequences so briefly indicated, it behooves us to ask whether there could be an alternative approach. It would be idle to imagine for an instant that the whole rationale of knowledge as now organized could be supplanted. But I am arguing for something more subtle -- an augmentation of the existing practice by taking account of whatsoever insights we may draw from the theory of models. It would seem (judging from the jocular example) that any system would serve as a model of any other system, if precise conditions as to purpose were specified. Suppose that we look at a managerial situation that is reminiscent of a system already understood in scientific terms. That might then suggest that a useful purpose might be served by pursuing such a metaphor -- the hot flow of metal through a steel works, say, as referred to the blood coursing through the body.

This metaphor was actually deployed in a steel works in Sheffield 50 years ago. The common ground of energy -- expressed in one model as latent heat, and in the other as dormant cash flow -- led to some interesting ideas. Think of the distinction between arteries and veins for example. But those ideas reposed on insight, on the metaphor, even though they were elaborated by further similarities. The air soon became dense with similes. I recall a manager who said at some point that he felt like a piano that was playing in the wrong key. It seems likely that by now the word **analogy** has come to your mind. And if it has, the threat of false analogy will not be far behind. Then comes the well-known phrase: "you have pushed the analogy too far." Yet the approach through model-building was opening exciting possibilities, and in particular liberating creative alternatives in both policy and practice. Could a more rigorous treatment of models embracing models be devised?

Science is supposed to amass "the facts", and then to form hypotheses based on those facts.

But the hypothesis is already *covertly implicit* in the selection of the facts, and further selection of a less than overt nature occurs during the process of elaborating the hypothesis further.

Attention to this kind of absurdity is often dissipated by changes of terminology so that contradictions are accommodated.

I re-read the earlier work of Victorian logicians such as John Stuart Mill, who had made noble efforts to import rigor into analogy, but they seemed to be not rigorous enough. The answer I eventually proposed came in 1965, with an epistemology based on the theory of groups. The mathematical treatment was published in the journal *Nature* (Beer, 1965), and was transposed as usual into a diagram (published in *Decision and Control* (Beer, 1966)). This later passed into the general literature as the **Yo-yo Model**. (See Figure 1 The Yo-yo Model: an epistemological approach.)

Here we see an insight or a metaphor connecting some fairly well understood scientific situation to a managerial situation less well understood. The two situations are each reduced to conceptual models, providing a carefully argued comparison of the kind Mill had in mind, and taking care to stop short of false analogy. The two conceptual models are then reduced to a rigorous formulation, involving homomorphic transforms -- a many-one reduction to one-one that sacrifices variety in the cause of rigor, please note. The original two models are now isomorphic with each other, and can therefore be generalized into a scientific model. This must by now be expressed in a *lingua franca*, probably mathematics. At this stage, we may ask whether the scientific model, developed from this particular pair of perceptions, represents a generally applicable systemic behavior. That is where the yo-yo comes in. On the central line of the diagram, extra samples of the class being considered are tested for validity and utility. We might look in the original case, for instance for other flow systems that store kinetic energy. Always assuming that the model formulations

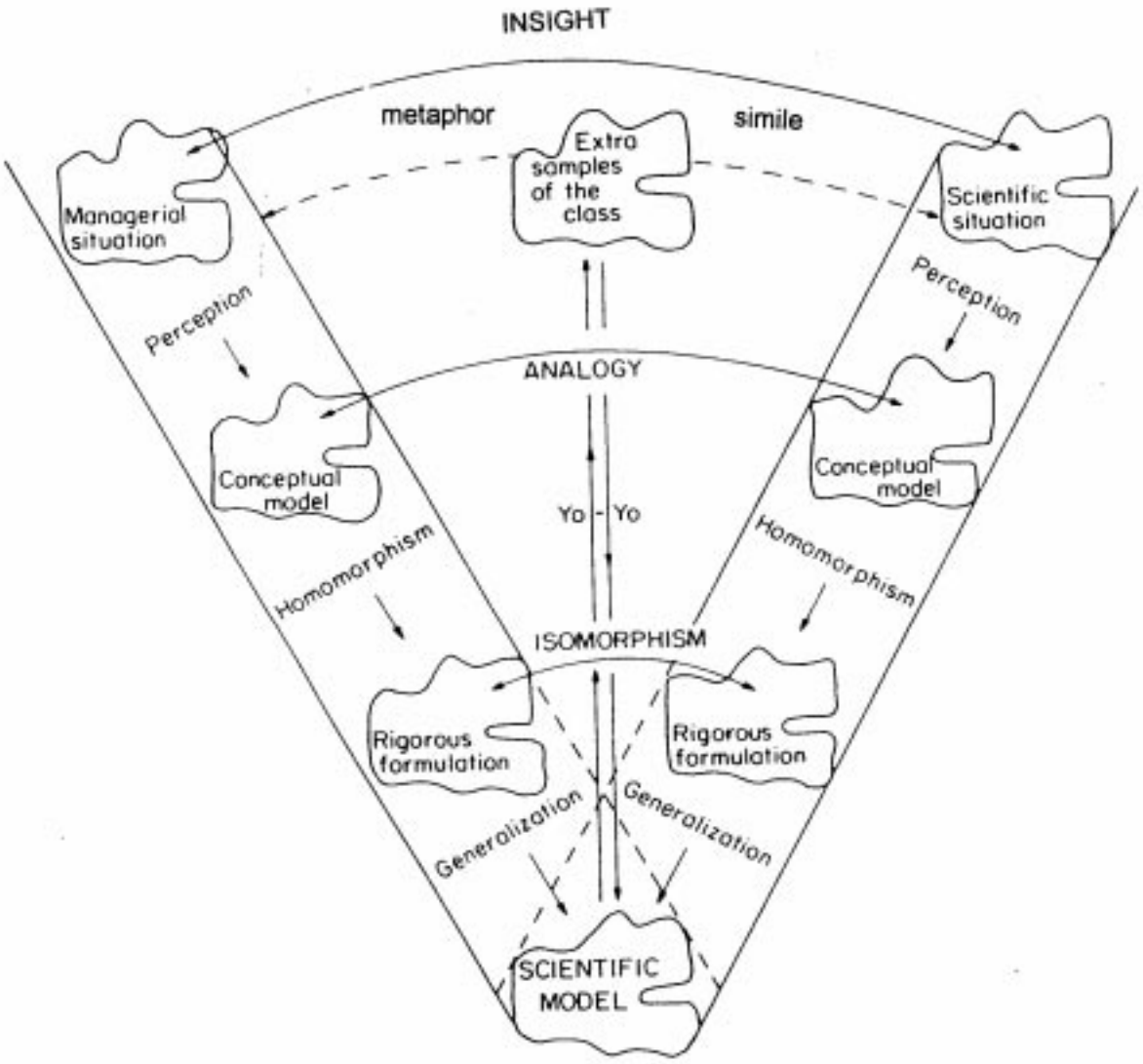

Figure 1 -- yo-yo

are rigorously maintained in each throw of the yo-yo, value in the model will grow.

Let us call this **systemic invariance**. Scientific progress has always depended upon recognizing the invariant properties of systems. They used to be called *laws of nature*, but to use such a useful term nowadays would be a postmodernist solecism. The yo-yo model builds an inductive case of mounting confirmations of the model concerned in action. As it does so, it will gradually trim irrelevancies and find the essence of the invariance. For example, we have encountered the systemic invariance of gravitation so often that that we now take it for granted -- these irrelevancies have disappeared. If I drop my glass on the floor we all except that it will shatter. No one will warn me that my name is not Newton and the glass is not an apple. Systemic invariance works in gravitation within a defined purpose -- give or take the perihelion of Mercury for instance. Remember "models are neither true nor false only useful for a purpose." We are not purposing planetary travel on this particular afternoon.

On the potency of invariance

Systemic invariance is widespread in cybernetics, and a most potent tool. The topic ought to be central to any course in cybernetics -- but it seems not to figure in that cohesive way. Instead of a course on systemic invariance, teachers seem to be content with pointing out mere instances of an idea that proved to be relevant to some case history.

Historically, the systemic invariance first noted by the founders of cybernetics was the ubiquity of **feedback mechanisms** -- in particular the role of error controlled negative feedback. That kind of terminology has led many people to the conclusion that cybernetics is fundamentally deterministic in character, just as if we knew nothing about stochastic processes, fuzzy logic, or any other way of handling outcomes that are not determinate. In particular, many have been led to ignore this feature in societary systems, far from “mechanistic” though they be. An instance: high-gain error-controlled negative feedback systems rapidly become dominated by the error signal. (See *Brain of the Firm* (Beer, 1972 and new edition 1981) pages 34-37.) Evidently the model used derives from servo-mechanics. But the methodology of the yo-yo has been used in multiple applications to generalize it. The relevance of this high-gain error signal to the domination of societary agenda by the media is then inescapable. The model that demonstrates this, together with many other features of societary invariance, is to be found in the paper *The Will of the People* (Beer, 1983a).

High on the importance scale of systemic invariance comes **homeostasis**. The origin of this term goes back to 1927 and Walter Cannon's *Wisdom of the Body* -- although as long ago as 1865 Claude Bernard wrote about the "constance du milieu interieur." Both authors have always been recognized as a precursor of cybernetics. To this should be added Sommerhoff's 1950 book *Analytical Biology*, which I mentioned earlier. But Ashby himself was the man who most importantly formalized homeostatic theory, and recognized the self-vetoing homeostatic. Out of his work, which included a famous experimental machine, grew his understanding of the **Law of Requisite Variety**. In my opinion, this law has the same stature in the world of affairs as the law of gravity has in the world of physics. It is not recognized as such, because people do not apply the yo-yo methodology. As soon as anyone tests Requisite Variety in any real system at all, s/he perceives its relevance -- and is also likely to discover something important.

Let us pause for a moment here to remark on the current fashion to misrepresent Ashby. It has been suggested that because he discovered how to measure variety, he thought it was an *absolute* measure. He knew perfectly well -- none better in fact -- that any nominated system depends upon its definition, so the variety measured must depend on the arbitrary selection of factors included in it. Do those people imagine that because it is possible to divide folk into male and female, that Ashby would thereupon declare “objectively” that humanity has only two states? Again, have people who say that he did not understand that the observer is part of the observed system failed altogether to understand his notion of the self-vetoing homeostat? Before he wrote about that, I was myself using the cognate term "implicit control". That was because each of us knew from Heisenberg's principle of indeterminacy that the intrinsic and ultimately decisive role in any observation is that of the observer.

The universal validity of the examples I have just been using of systemic invariance is well encapsulated by the food web and its intricacies. Consider the cabbage aphis. That is the tiny bug that feeds on cabbage leaves. It weighs very little indeed. The New York Academy of Sciences many years ago quoted some research that calculated what weight of aphides would accrue in one season if this single aphis (s/he is hermaphroditic) was supplied with unlimited quantities of cabbage -- and no predators assaulted either population. The answer was 822 million tons, about five times the human population. We do not expect that to happen, and know in principle why. The principle is properly called the self-vetoing homeostat, and it operates through complex systemic interaction according to the law of requisite variety.

Yo-yo-ing through the world of affairs, and reflecting on similar problems to do with the environment, we rapidly find out what to do about many problems (but no one will believe it). And we may reflect on how managers would typically deal with the explosion of aphides. Overwhelmed by variety, they would first divide the country into hundreds of amenable zones, and appoint zone commanders with supporting staff, consultative committees, and so on. That's the appropriate way to deal with high variety. Research would be started at great expense to examine the feasibility of contraception among hermaphrodites -- hm... better double the research grants. That's the appropriate way to deal with intractable technological problems. The legal department would have its own feasibility study to look at the licensing situation... There are bound to be appalling pitfalls, but fortunately there are enough lawyers to go round to study each of them. Meanwhile, inadequate insight is likely to render the aphis extinct. I shall not go on with this analysis, although it is fun, because that situation cannot actually arise. In any case, nature already knows the answer. The serious point, however, is that managers and ministers behave all the time as if that is exactly what they would do. They do not understand cybernetics; they unilaterally attempt to repeal the law of requisite variety without knowing that it exists; they act in accord with the received managerial paradigm.

The next critical idea that I mention links with homeostasis, and it is **closure**. Much of systemic invariance features closure, and we have already seen that circularity -- which is a form of closure -- is a cybernetic phenomenon. When I first studied philosophy, circularity was anathema: it was the name of a logical fallacy, or it was a kind of argumentation that got nowhere. Through cybernetics, however, came the realization that circularity properly understood is a critically valuable building block of system. This perception is not limited to cybernetics. The latest candidate as the basic and smallest

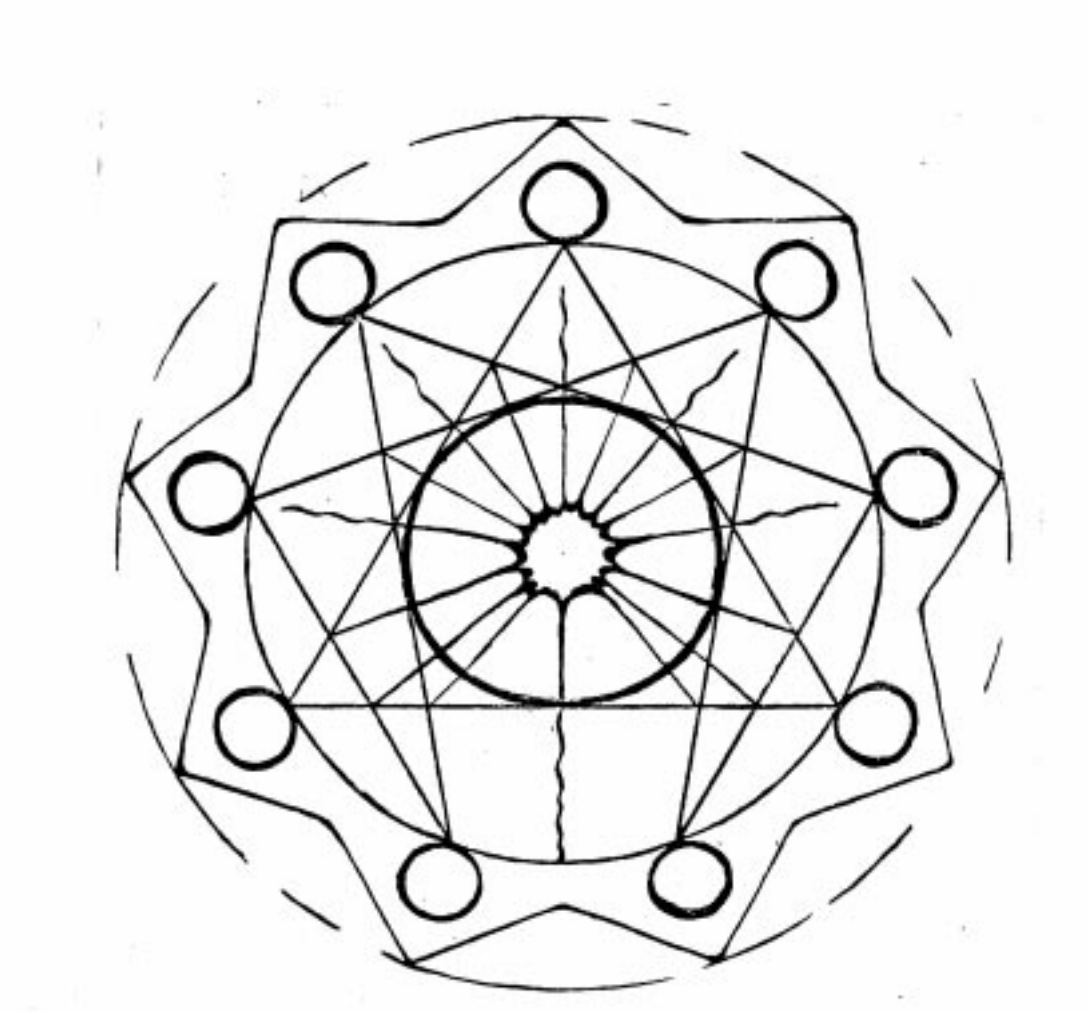

Figure 2 -- Sunburst

building block of all matter is not the atom, not the electron, not the quark. It is the eleven-dimensional superstring, conceived as a vibrating *loop*. This may be too small an entity to contemplate; the perception of closure of which we are intuitively aware is our own knowledge of **selfhood**. This is the notion of a defined entity thought of as self-contained, and in principle bounded by that containment. On examination, this will never proved to be absolute but rather a convenient convention, but convenient it certainly is. (See Figure 2: The Sunburst Model of Selfhood: an enneagram with discriminate varieties.)

The Sunburst model began by describing the selfhood of a human being. The blob in the center of the diagram stands for the autonomous nervous system. The inner circle is the envelope of skin -- within which the radial lines take in the rest of the nervous system. The larger complete circle outside the inner circle is the rest of the conscious individual. The radial lines now do not always reach where they looked as if they were going... these are the goals of life, the strategies of attainment. The final circle, which is incomplete, is (what Aristotle called) entelechy, which nowadays might be spoken of as human potential. The model is set in an enneagram -- the nine-pointed star that has held much spiritual significance in many cultures from the Sufis down. There is no time to say much more about this here, although you should not find it difficult to discern resonances of everything so far mentioned in this talk. All the radial lines represent discriminate varieties as the circle expands: we know the law of requisite variety, we know the Conant-Ashby theorem, we know about closure, implicit control, and so on. The nine small circles represent loops... recall the superstrings.

The reason for quoting the Sunburst model here is simply to emphasize the importance of systemic invariance. As far as human selfhood goes, I have used this same model (with different emphasis) to discuss the central nervous system with students of neurophysiology on the one hand, and the spiritual path with Jesuit seminarians on the other. With philosophers, the Sunburst model was extended to examine Leibnizian monadology. But the notion of selfhood does not end with personal selfhood. I defined the notion earlier as an entity thought of as self-contained, relatively bounded. It has been used to talk about Gaia, the planet Earth, and its survival. It was used to examine the politics of the nation state in Mexico. It was extensively developed in working on the planning system of a major city in Ontario. I hope very much that delegates here will accept the challenge to build significant university courses based on systemic invariance. I have made dozens of models in my life as a consultant, many of which could not be published for commercial reasons. Never mind them. These have served their purposes well. What matters is the search for invariance.

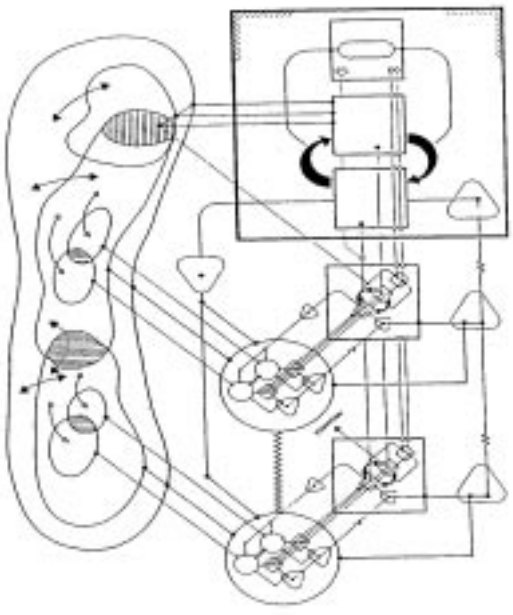

Figure 3 -- VSM

The viable system model -- VSM

There are three whole books (Beer 1972 and 1981,1979,1985) and many other writings about the VSM, and I cannot begin to describe them here. This occasion is devoted to the basis of cybernetics and the voyage of discovery it invites. What follows is something about motivation, something about development, one new principle of systemic invariance, and an unpublished application. To make this possible, the complete diagram of the VSM is appended -- not so that the newcomer could possibly understand much of what is going on, s/he will find it virtually incomprehensible. I hope it will remind those who already know, but the real purpose is to demonstrate the new principle. (See Figure 3: The Viable System Model: to illustrate only included recursivity.)

The model of the brain that I developed throughout the 1950s, is a closed system. There is no way of knowing what is owed to my three mentors in this respect, since discussion was volatile. However, I believe I was the first to set down a formal closed model of the brain: it used a topological algebra derived from Bourbakian set-theory. (Two of those mentors were present when the paper (Beer, 1962) was presented in 1960; and did not demur.)

This closed model was neurophysiological. I used the yo-yo model as far as ever I could, and tested other biological systems against it. The conclusion was that I could never find anything that was inconsistent with what the neurophysiology was saying about regulation -- in particular what was newly becoming known of ecological systems was supportive. But

this was a weak outcome in terms of the inductive power of the yo-yo. It worried me deeply that other major systems of the body's regulatory processes could not successfully be mapped, especially the endocrine system. To a holist, it was self-evidently reductive to be modeling even so large a system as the neural brain in isolation, when there were so many biochemical pointers left un- accounted for. This was surely because too little was known about the internal interactions of the definable components. I knew about neurons and their nervous processes. As to the rest -- even at the cytological level there were mysteries. To this day, I feel convinced that too little is known about the glial cells for instance.

I spent much time, covering the decade of the '50s and beyond, in trying to develop a systemic model of the endocrine system. But little progress was made, and I have since found out that the questions I was posing were unanswerable at that time. I had to be content with the fact that at least new things were being discovered: for instance, when I was a student in 1943 nobody knew that the pituitary gland was innervated -- or at least they wouldn't tell me if they did! You do not need convincing that this gland is all-important, and withal a large structure, so the omission seems incomprehensible. But then we recall the hardening of the categories. Why in the '40s would endocrinologists be hunting nerves? Well, I was working with an authoritative book on endocrinology that began, "The endocrine balance of most people is probably about normal." I have never forgotten this pearl. It was some kind of solace.

In *Brain of the Firm* (1972) I expounded what I had earned from the VSM in terms that the manager might understand. First of all, there was closure. And in order to re-open that bounded concept, I had drawn on mathematics again. Number theory supplied definition by recursion: the bounded system could be re-opened by including recursive models of itself inside itself. The image of Russian dolls was a help. So the diagram of the VSM contained icons of itself. Next, using the yo-yo methodology, the VSM was shorn of its neurophysiological connotations. The *Heart of Enterprise* (1979) re-created the work to yield a model of any viable system. The diagrammatic version was enhanced so that the included recursions were no longer icons, but faithful copies. However, it was not until *Diagnosing the System for Organizations* (1985) was written that I finally solved the problem of diagrammatic recursion with a degree of elegance. This is what you see in figure 3. The model is complete but, as mentioned before, it is included without further explanation simply to illustrate the new principle of included recursivity, like this.

By focusing on the two included circles, and turning them through 45 degrees, you will see that small-scale but exact reproductions of the total model are presented. A very large circle to match the very large square in the upper right hand corner is omitted as too ungainly to draw, but no internal connections attached to it. Otherwise the topology is exact. Moreover, a lower recursion still is implied, just as a higher recursion is implied by the large square -- making four levels of recursion visible on the diagram, two of them complete. So please note this dictum:

> Every viable system contains and is contained in a viable system.

The recursions of the VSM are indefinitely extensible -- there were eleven recursions in the VSM of the socioeconomic model of Chile developed in 1971 to '73 for President Allende (see *Brain of the Firm*). Much emphasis is placed upon the faithful reproduction of the VSM at every recursion, because these are mathematical theorems reproduced topologically. They are not arbitrary illustrations. The validity of the methodology -- especially its recursive features -- depends on them. It follows that attempts to represent the. VSM to make it "easier", sadly lead to invalidity.

Applications of the VSM have been made over the last forty years all over the world, and they have ranged from the eukaryote cell and a bee colony to the nation state and the globe. They have included every conceivable enterprise both public and private in between. Sometimes applications have amounted to little more than creating pretty pictures and writing names in the boxes. But so much more can be done, in particular via the quantification of variety. The VSM constitutes profoundly interlocking networks of five subsystems, to which the balance of variety is central. It hinges on the maintenance of homeostasis between the horizontal and vertical axes of the model.

> Let me draw on advanced thinking here for the benefit of VSM adepts. According to the VSM's First Axiom of Management, the sum of horizontal variety disclosed by the operational elements (System One) must equal the sum of vertical variety disclosed on the six vertical components of corporate cohesion. The Law of Cohesion itself relates rather similar equalities for each pair of multiple recursions. (See *The Heart of Enterprise*)

Here now is the promised application. About 15 years ago I was commissioned to re-design the Canadian Red Cross, with the support of a leading company of management consultants who made available staff to carry out investigations on a national basis from their provincial offices. This involved a very extensive study, and incorporated a large number of recommendations, which were adopted -- with one exception. The most dramatic of the visible changes made meant moving the main office from Toronto to the national capital, Ottawa. Evidently, the study was comprehensive: it was built on the VSM, but it took account of sociopolitical factors too -- as is essential in the practice of consultancy. However, the one recommendation that failed was a casualty of that sort.

Most unusually, the Canadian Red Cross “owned” the national blood supply. In most countries blood is treated independently of any institution. Here it was one of the many operations

(System One) of the Red Cross -- alongside all the others, ranging from First Aid through to appeals in support of international emergencies. Now, the organization required to administer most of these activities is quite different from that required to administer blood supply. Everything else is based on voluntary effort, with whatever is involved by way of philanthropy and the committee structure required to organize on the part of "the great and the good". The blood supply conversely is science-intensive. It also requires administration of technology of a high order. You might think that these activities would make strange bedfellows. But Canada did not think that, and the reason was this. Blood is a serious economic commodity. In the Red Cross, it accounted for much more than half the budget -- on the credit side. To put it bluntly, the Red Cross made a great deal of money out of blood. Talking to committed Red Cross people, one could see that most thought it entirely appropriate that the lucrative activity should support the altruistic. The argument is highly debatable -- until you consult the variety equations of the VSM, and discover it to be a matter of assessing varieties.

The First Axiom of Management simply does not hold. The horizontal variety committed to regulating blood is *vastly* incommensurable with the horizontal variety that is based on voluntary regulation. Moreover, collecting blood on a decentralized basis (there is no alternative) means that the incommensurability of variety crosses metasystens for every pair of recursions in a way that denies the Law of Cohesion itself. In the circumstances it was idle to engage in semantics. The cybernetics left me no option but to recommend the complete withdrawal from the Red Cross of the responsibility for the blood supply of the nation.

The recommendation was denied -- not as you might think because no one could understand the argument, which in context I had the time to explain. The matter hinged entirely on the economic consideration. The senior consultants vehemently opposed the plan. They were partners in a famous firm of accountants -- and felt that l threatened to destroy the financial viability of the Red Cross. The Canadian Secretary-General seemed torn, but in the end was constrained to support "prudence". It is by now well known that the blood supply in Canada eventually turned into a tainted blood scandal, and recently led to a Royal Commission. As I give this address today (July 1998) there is talk of potential liabilities amounting to more than five billion dollars in lawsuits, and of seeking bankruptcy protection for the Red Cross. "Prudence"? The replacement agency, Canadian Blood Services, starts its independent existence on September 1, 1998. There have of course been problems in other countries with tainted blood supplies, and I do not know how they were organized or what led to their difficulties. Long before any of these difficulties in Canada surfaced, in fact quite soon after the re-organization, which were in other respects successful, the Canadian General Secretary went to Geneva to head the International Red Cross. The two accountants who had been assisting me at the consulting company resigned to start an independent firm of their own.

Celebration for Candace Pert

I have never had the honor to meet Dr. Pert. When I asked from the hall who had heard of Candace Pert -- the name was printed in huge letters on the screen beside the podium -- two small knots of a few people in an audience of hundreds raised their hands. Then followed a little laughter as each knot was observed to center on two well-known professors, each of whom is my friend -- and some of their students. Well, we had the celebration for Warren McCulloch, and here is another celebration -- for Candace Pert. Why?

Some twenty-five years ago she discovered the opiate receptor. This is a site in the cell that can recognize an opiate, typically a protein molecule, which is then anchored in the outer cell membrane to bind with substances such as neurotransmitters. There was confusion and disagreement at the time, as to whether the biochemical components even existed in the body naturally to create such outcomes.

The search to find the opiate receptor was one of dogged endurance reminiscent of the search for radium. Other scientists were searching too, but it was she who discovered a pair of amino acids constituting the critical peptide. This in itself was a discovery of major importance -- significant people in the field expected Candace Pert to be awarded the Nobel Prize. The non- story of that, and of how the hardly less significant Lasker Award for medical research (often endorsed by a later Nobel Prize) was awarded to three *men* -- men heavily underlined -- will appall but not surprise egalitarian scientists, especially if they remember the shocking events surrounding Rosalind Franklin and the discovery of the DNA molecule. You may read about all this in Pert's book *Molecules of Emotion* (1997), and very entertaining and exciting you will find it.

Informational substances

However, I do not expect a cybernetic conference to celebrate this discovery with particular enthusiasm. Please bear with me as I follow the peptide story a little further. All sorts of peptides were shortly discovered, and a whole new era was to begin. I suggest that we focus what was to happen on Candace Pert's own comments. Where about in the body would you expect to find opiate receptors? Obviously you would look in the brain itself -- the hypothalamus perhaps. Alternatively you would look in the limbic system. But when she looked comprehensively for “her” peptides, she found them all over the place in the body. Think of finding concentrations of such peptides in the colon, as she did... so *that's* where "gut feelings" come from!

We move to the early '80s. The neuropeptides, it had reasonably been assumed, communicated across synapses in the nervous system. The assumption proved untenable. Many of the neuronal receptors were inches away from the neuropeptides: how were they communicating, if not across the synaptic gap? A co-worker named Miles Herkenham found that, counter to the assumption of people working in the neurosciences, less than two percent of neuronal communication actually occurs at the synapse. This seems so absurd that for several years the result was ignored, and put down to errors of one sort or another. But Miles Herkenham was right all the time. He reckoned that the connection did not reside in the synapse-brain cells, but was determined by the specificity of the receptors. Candace Pert wrote: "the way in which peptides circulate through the body, finding their target receptors in regions far more distant than had ever previously been thought possible, made the brain communication system resemble the endocrine system, whose hormones can travel the length and breadth of our bodies. The brain is like a bag of hormones!"

At about this time, Francis Schmitt, who had originated the neuroscience research program at MIT, introduced the terminology of "information substances" to describe “a variety of transmitters, hormones, factors, and protein ligands.” Ligands are various small molecules that specifically bind to a cellular receptor, such as the opiate receptor, thereby transmitting an informational message to the cell. This was exactly the concept that Candace Pert needed to advance her own work, and she embraced it enthusiastically.

Now there are three classically separated areas of medical biology:

- **Neuroscience** -- dealing with the brain and central nervous system,
- **Endocrinology** -- dealing with the glands,
- **Immunology** -- dealing with the spleen, bone marrow, and lymph nodes.

If you have taken my homily about the hardening of the categories to heart, and recall my long battle in the '50s to incorporate the endocrine system into my brain model, you will understand the excitement with which I received the discoveries that *Molecules of Emotion* unfolded. Instead of those three sciences demarcated by their library shelves and dedicated journals, and following them into separate laboratories, we have a unified system. It consists of a multi- directional network of communication, linked by informational carriers at the *molecular level*. It is surely delightful to contemplate the continuous molecular busy-ness that achieves wonders of intricate homeostasis -- while quite indifferent to the pompous definitions of academe.

And quo *do you think you're* vadis*?*

May I urge you to read the book? At any rate, I do not have the effrontery to dissertate at greater length, thereby spoiling the author's own account -- and a thoroughly good read. Instead, I return once more to the bridges that I have been trying to construct all the way through this address, which began by celebrating Warren McCulloch.

In speaking of him, I referred to rather serious quarrels with him about Freud. He contended that the unconscious mind was not only illusory, but a delusion -- there was no neurophysiological basis for it, and he accused Freud of deliberate duplicity. For my part, I had found the notion so useful in the practice of clinical psychology that I was happy to accept it as a model. Please imagine my squeal of joy to read Candace Pert write that the unconscious mind of Freud is no less than the body! Perhaps we could both have settled for that.

Many of the discoveries made by Candace Pert are pointing to the kind of holistic emphasis on the unity of being that is familiar in eastern philosophy. I see her helping to cross that East-West divide -- and that other chasm existing between science and philosophy. Surely these are matters for high celebration. By the end of her book she is openly hypothesizing about connections not only between body and mind, but also between body, mind, soul and spirit. Predictably, she will have a rough ride, as do all holists. I should like to wish her well in those endeavors, and that she continue with the same brave-heartedness with which she confronted so much prejudice in the past. Meanwhile, her scientific demonstration of the molecular reality of informational substances -- the neuropeptides -- in continual interaction between body and mind is, at least in my view, a great **cybernetic** triumph.

But hardly anyone in this audience knew of Candace Pert, still less of the cybernetic triumph, when I started this talk. How can this be? Surely it is because each of us here is pursuing the next step in the agenda s/he has elaborated within the confines of the paradigms that are already understood. This comment is not meant offensively. The research we are all doing, the development of the thinking we so far understand, are all worthy pursuits -- the backbone of scientific advance indeed. But as system scientists, are we constantly in search of systemic invariance? Do we ever consider taking time off to play the creative yo-yo? If not, we are tacitly accepting the established paradigms of system, tacitly resisting change and the hope of new visions. I doubt if anyone present actively want to appear in that role.

That is my reason for linking this second celebration of Candace with the original one for my old mentor and cybernetic founding father, Warren. They look well together. What they had in common was a holistic sense of system, being *brighter'n hell*, and the fortitude to challenge existing para-

digms and win. I close as I promised with some final words of closure about Warren.

Centenary Valedictory for Warren McCulloch

Although this is a valedictory for his centenary, it applies to this year alone: there will never be a last goodbye -- not for me, not anyone who preserves his words.

The last recorded words I know of were printed by Kathie Bateson, I think. They occurred during a session in Austria during 1968, in a meeting presided over by her father Gregory Bateson. Warren was speaking :

> "The difficulty is that we, who are not single-cell organisms, cannot simply divide and pass on our programs. We have to couple, and there is behind this a second requirement." Warren began to weep. "We learn... that there's a utility in death because... the world goes on changing and we can't keep up with it. If I have any disciples, you can say this of every one of them, they think for themselves."
>
> Very softly Gregory said, "sure, Warren."

As in many other matters, I have tried to adhere to Warren's attitude towards people coming behind. They are surely precious words of advice.

I intend to conclude with a piece of poetry written by Warren but never (as far as I know) published. First of all, here is a Sonnet from me to him. It was written to celebrate his sixty-fifth birthday in 1963:

Sonnet for Warren on his sixty-fifth birthday

Days that are cherished, moments that persist,
reverberate in neural circuits, catch
in the throat of recollective calm, attach
to sensory recall. And so enlist:
the lobsters at Old Lyme; and English mist;
the snap of seminars; nocturnal scratch
of pen on paper; your disdain to match
the paltriness of an antagonist.

The stature and the public awe exist --
while secretly the twinkling friendships hatch.
Warren, the neurons crackling in his head,
parks fire at nature. Others may insist
that science is serious. But we shall snatch
our laughter from the universal dread.

Stafford Beer (1983b)

And here as promised is what Warren had earlier handwritten to me, in the flyleaf of his own poems, *The Natural Fit*, published in 1959:

Since of that loveliness I know is you
which in quick having holds me quite content
love could not gather what could not have grown
or what from my poor gardening never grew

I to the frenzied and immortal few
turn hungry home

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