Chapter 1. The Problem

> Today we preach that science is not science unless it is quantitative. We substitute correlation for causal studies, and physical equations for organic reasoning. Measurements and equations are supposed to sharpen thinking, but ... they more often tend to make the thinking non-causal and fuzzy. They tend to become the object of scientific manipulation instead of auxiliary tests of crucial inferences.
>
> Many—perhaps most—of the great issues of science are qualitative, not quantitative, even in physics and chemistry. Equations and measurements are useful when and only when they are related to proof; but proof or disproof comes first and is in fact strongest when it is absolutely convincing without any quantitative measurement.
>
> Or to say it another way, you can catch phenomena in a logical box or in a mathematical box. The logical box is coarse but strong. The mathematical box is fine grained but flimsy. The mathematical box is a beautiful way of wrapping up a problem, but it will not hold the phenomena unless they have been caught in a logical box to begin with. - John R. Platt[1]

The Complexity of the World

> It isn't what we don't know that gives us trouble, it's what we know that ain't so. - Will Rogers

The first step to knowledge is the confession of ignorance. We know far, far less about our world than most of us care to confess. Yet confess we must, for the evidences of our ignorance are beginning to mount, and their scale is too large to be ignored!

If it had been possible to photograph the earth from a satellite 150 or 200 years ago, one of the conspicuous features of the planet would have been a belt of green extending 10 degrees or more north and south of the Equator. This green zone was the wet evergreen tropical forest, more commonly known as the tropical rain forest. Two centuries ago it stretched almost unbroken over the lowlands of the humid Tropics of Central and South America, Africa, Southeast Asia and the islands of Indonesia.

> ... the tropical rain forest is one of the most ancient ecosystems ... it has existed continuously since the Cretaceous period, which ended more than 60 million years ago. Today, however, the rain forest, like most other natural ecosystems, is rapidly changing. ... It is likely that, by the end of this century very little will remain.[2]

This account may be taken as typical of hundreds filling our books, journals, and newspapers. Will the change be for good or evil? Of that, we can say nothing—that is precisely the problem. The problem is not change itself, for change is ubiquitous. Neither is the problem in the man-made origin of the change, for it is in the nature of man to change his environment. Man's reordering of the face of the globe will cease only when man himself ceases.

The ancient history of our planet is brimful of stories of those who have ceased to exist, and many of these stories carry the same plot: Those who live by the sword, die by the sword. The very source of success, when carried past a reasonable point, carries the poison of death. In man, success comes from the power that knowledge gives to alter the environment. The problem is to bring that power under control.

In ages past, the knowledge came very slowly, and one man in his life was not likely to see much change other than that wrought by nature. The controlled incorporation of arsenic into copper to make bronze took several thousand years to develop; the substitution of tin for the more dangerous arsenic took another thousand or two. In our modern age, laboratories turn out an alloy a day, or more, with properties made to order. The alloying of metals led to the rise and fall of civilizations, but the changes were too slow to be appreciated. A truer blade meant victory over the invaders, but changes were local and slow enough to be absorbed by a million tiny adjustments without destroying the species. With an alloy a day, we can no longer be sure.

Science and engineering have been the catalysts for the unprecedented speed and magnitude of change. The physicist shows us how to harness the power of the nucleus; the chemist shows us how to increase the quantity of our food; the geneticist shows us how to improve the quality of our children. But science and engineering have been unable to keep pace with the second-order effects produced by their first-order victories. The excess heat from the nuclear generator alters the spawning pattern of fish, and, before adjustments can be made, other species have produced irreversible changes in the ecology of the river and its borders. The pesticide eliminates one insect only to the advantage of others that may be worse, or the herbicide clears the rain forest for farming, but the resulting soil changes make the land less productive than it was before. And of what we are doing to our progeny, we still have only ghastly hints.

Some have said the general systems movement was born out of the failures of science, but it would be more accurate to say the general systems approach is needed because science has been such a success. Science and technology have colonized the planet, and nothing in our lives is untouched. In this changing, they have revealed a complexity with which they are not prepared to deal. The general systems movement has taken up the task of helping scientists unravel complexity, technologists to master it, and others to learn to live with it.

In this book, we begin the task of introducing general systems thinking to those audiences. Because general systems is a child of science, we shall start by examining science from a general systems point of view. Thus prepared, we shall try to give an overview of what the general systems approach is, in relation to science. Then we begin the task in earnest by devoting ourselves to many questions of observation and experiment in a much wider context. And then, having laboriously purged our minds and hearts of "things we know that ain't so," we shall be ready to map out our future general systems tasks, tasks whose elaboration lies beyond the scope of this small book.

Mechanism and Mechanics

> Physics does not endeavor to explain nature. In fact, the great success of physics is due to a restriction of its objectives: it endeavors to explain the regularities in the behavior of objects. This renunciation of the broader aim, and the specification of the domain for which an explanation can be sought, now appears to us an obvious necessity. In fact, the specification of the explainable may have been the greatest discovery of physics so far.
>
> The regularities in the phenomena which physical science endeavors to uncover are called the laws of nature. The name is actually very appropriate. Just as legal laws regulate actions and behavior under certain conditions but do not try to regulate all actions and behavior, the laws of physics also determine the behavior of its objects of interest only under certain well-defined conditions but leave much freedom otherwise.[3] - Eugene P. Wigner

To understand the general systems view of science, we should examine physics—and particularly mechanics—because these sciences are often taken as the ideal of others. The beauty of the mechanical model of the world was well expressed by Karl Deutsch,[4] who said that mechanism

> ... implied the notion of a whole which was completely equal to the sum of its parts; which could be run in reverse; and which would behave in exactly identical fashion no matter how often these parts were disassembled and put together again, and irrespective of the sequence in which the disassembling or reassembling would take place. It implied consequently that the parts were never significantly modified by each other, nor by their own past, and that each part once placed in its appropriate position with its appropriate momentum, would stay exactly there and continue to fulfill its completely and uniquely determined function.

The luster of this description is dulled a bit by the observation that mechanical systems ordinarily have but a handful of identifiable parts—most often 2, sometimes 10, or perhaps as many as 30 or 40 if they are highly constrained, as are the parts of a bridge. If there are too many parts, the physicist may write down equations relating the behaviors of the different parts, but cannot solve the equations, even by approximate methods. True, high-speed computers have extended the range of approximate solutions of mechanical systems, but only by a relatively small amount.

If the formal methods of mechanics are so limited, why is mechanics considered a model for the sciences? We must—if we are to have the answer—consider not the formal methods, but the informal. Complex mechanical systems are always informally reduced to simpler ones. Only then can the formal methods begin to do their work.

Consider, for example, Newton's explanation of the motions of the bodies in the solar system. Rapoport,[5] in speaking about this problem, pointed out that

> Fortunately for the success of the mechanistic method, the solar system ... constituted a special tractable case of several bodies in motion.

Although Rapoport's analysis is correct and to the point as far as it goes, it does not penetrate deeply enough into the heart of Newton's success. The solar system, in the first place, does not consist of "several bodies in motion." We now know that there are thousands upon thousands of celestial bodies in our solar system plus other matter not in "bodies." (See Figure 1.1.)

Figure 1.1. There are thousands upon thousands of celestial bodies ...

Any analysis of planetary motions, however, begins by ignoring most of these bodies. They are said to be "too small" to have a significant effect on the calculations. (See Figure 1.2.) Although this seems a natural step—so natural that texts on mechanics do not ordinarily mention it—it happens to work only in very special circumstances. Any other circumstances are not considered proper systems for mechanistic thinking.

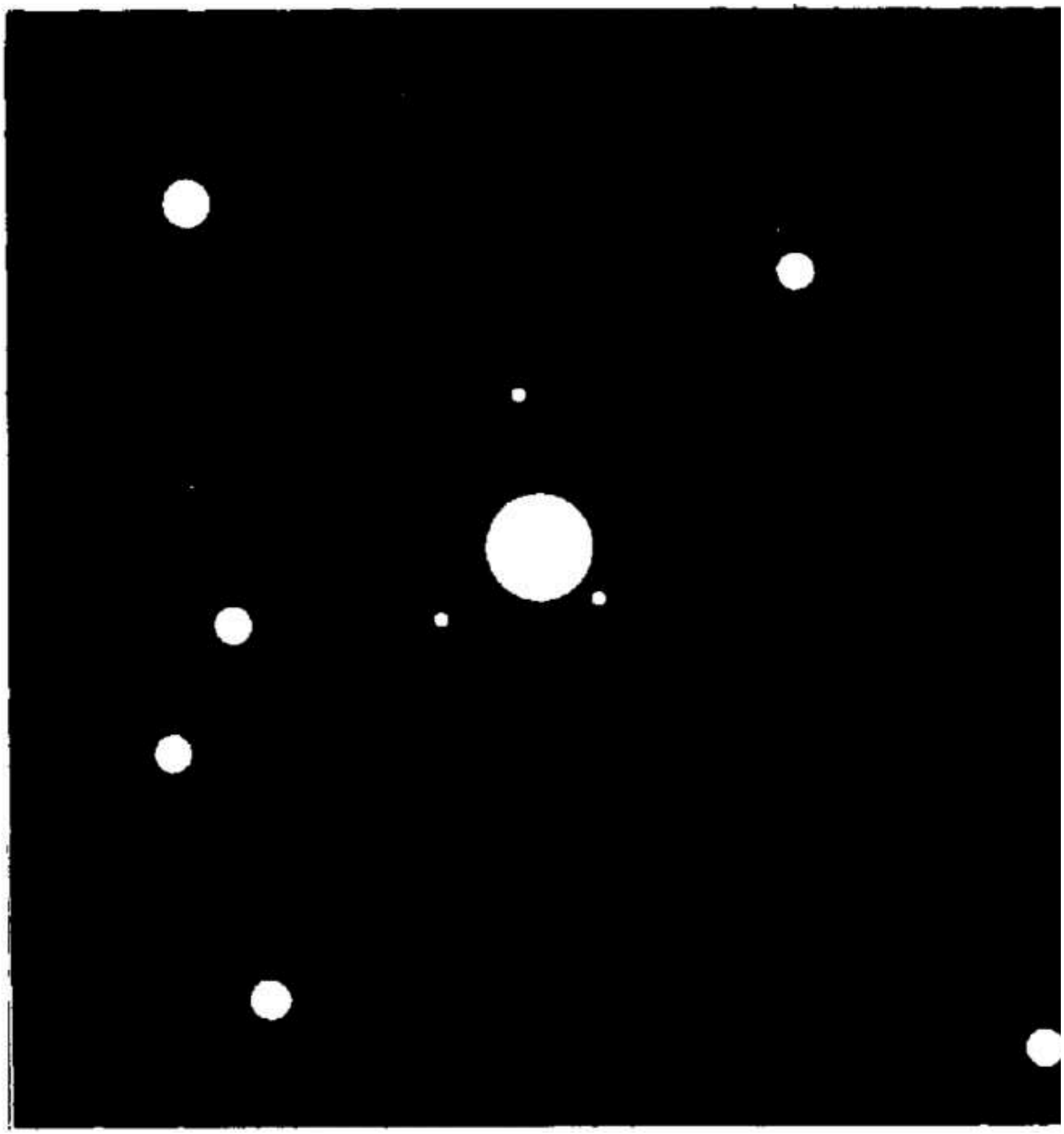


Figure 1.2. The analysis of planetary motions begins by ignoring most of these bodies ...

Consider, for instance, the pineal gland, a tiny piece of tissue in the brain. Can physiologists ignore this body in their attempts to understand the behavior of the human body? Perhaps they can—the question is quite alive —and perhaps they cannot. In any case, no physiologist would think of arguing that because the mass of the pineal gland is small with respect to the mass of the brain, it can be ignored on that account. The DNA in a living cell is a minuscule amount of the cell material, if measured according to mass; but understanding of cellular biology would be impossible without considering its role. The queen bee in a hive is only one of thousands of bees and makes up only a small fraction of the total mass of the hive, but no ethologist dare ignore her.

Mechanics, then, is the study of those systems for which the approximations of mechanics work successfully. It is strictly a matter of empirical evidence, not of theory, that the human body cannot be understood by considering only the gravitational attractions between its parts.

The Square Law of Computation

> Whereas in the past the only resource for dealing with biological systems was to try to minimize the interactions between the parts, thereby often losing the real focus of interest, today nothing but time and money prevent us from treating real biological systems in all their complexity and richness.[6] - W. Ross Ashby

What is the cost of computation, in time and in money? How important was ignoring small bodies (the asteroids, comets, satellites and other pieces of space flotsam) to the economical calculation of planetary orbits?

Consider first the equations needed to describe the most general system of only two objects. We must first describe how each object behaves by itself—the "isolated" behavior. We must also consider how the behavior of each body affects that of the other—the "interaction." Finally, we must consider how things will behave if neither of the bodies is present—the "field" equation. Altogether, the most general two-body system requires four equations: two "isolated" equations, one "interaction" equation, and one "field" equation.

As the number of bodies increases, there remains but a single "field" equation, and only one "isolated" equation per body. The number of "interaction" equations, however, grows magnificently, with the result that for n bodies we would need 2^n relationships! (See the Appendix, under "Scientific Notation," for an explanation of these exponential numbers.)

To be more concrete, for 10 bodies we would need $2^{10} = 1024$ equations and for 100,000 bodies, about $10^{30,000}$. By "ignoring small masses," then, the number of equations is reduced from perhaps $10^{30,000}$ to approximately 1000. At least it would now be possible to write down the equations, even if we still could not afford to solve them.

How much effort is involved in solving equations, and why are we so interested in the question? In Newton's day, the impact of mechanics on philosophical thought was pervasive. Many philosophers thought, with Laplace, that given precise observations on the position and velocity of every particle of matter, one could calculate the entire future of the universe. Although they realized that they would need a large computing machine, they lacked even the smallest computers. How could they possibly put a measure on the required computation?

Only in our lifetime have the dreams of the mechanists been realized, but with the realization came a revolution in philosophical thought. One aspect of this revolution was the more realistic concern for the question of computational cost, a question raised by the systems thinkers, but most notably and consistently by Ashby. This annoying question—how much "time and money"?—lies at the very foundation of the general systems movement.

We do not need exact measures. Instead, we merely want to estimate how the amount of computation increases as the size of the problem increases. Experience has shown that unless some simplifications can be made, the amount of computation involved increases at least as fast as the square of the number of equations. This we call the "Square Law of Computation." Thus, if we double the number of equations, we shall have to find a computer four times as powerful to solve them in the same amount of time. Naturally, the time often goes up faster than this—particularly if some technical difficulty arises, such as a decrease in the precision of results. For our present arguments, however, we may conservatively use the Square Law of Computation to estimate how much more computing is required for one general set of equations than for another.

In practice, then, there is an upper limit to the size of the system of equations that can be solved. Clearly, $10^{30,000}$ equations are far beyond that limit. And in Newton's day, without computers at all, the practical limit of computations was well below 1000 second-order differential equations, especially since Newton had just invented differential equations. Newton needed all the simplifying assumptions, explicit or implicit, he could get away with, just as physiologists and psychologists do today. We may note, in this regard, that old-time physicists now say that the "youngsters" no longer do "real physics." These young upstarts use the computer to solve large sets of equations, rather than applying physical "intuition" to reduce the equations so they can be solved with a pencil on the back of the proverbial envelope.

The Simplification of Science and the Science of Simplification

> I do not know how it is with you, but for myself I generally give up at the outset. The simplest problems which come up from day to day seem to me quite unanswerable as soon as I try to get below the surface. - Justice Learned Hand

Thinking about the practical problem of computation, then, can give us a new point of view about what mechanics, or any science, is. Since practical computation demands that implicit assumptions be brought out into the open, it is no coincidence that computer programmers are attracted to an approach devoted to studying how people make assumptions. As an example of such computing experience, consider another assumption already made in our reduction of the solar system problem to 1000 equations.

We have assumed—as one always assumes in mechanics—that only certain kinds of interactions are important. In this case, the only important interaction was gravitational, which meant that each relationship gave only one equation. How do we know that only gravitational attraction is important in this system? How do we know that we can ignore magnetic effects, electrostatic forces, light pressure, force of personality, and so forth? One answer is that this problem would not be a problem in mechanics if other kinds of forces were important; but that answer is merely begging the question. How do we know it is a problem in mechanics?

As before, we know it is a problem in mechanics because when we try these approximations, they give us satisfactory answers—that is, answers that match observational data. If we had a problem for which they did not work, it would never make its way into the mechanics textbook. Our practical computing example of this quandary is the calculations that were made of the orbit of the Echo satellite, which was a large inflated Mylar sphere. The classical solution of the gravitational equations was not doing a satisfactory job of predicting Echo's orbit. After much perplexing labor, the programmers realized that because of its small density, Echo was much larger than any "normal" solar body of the same mass. Consequently, the pressure of the sun's light radiating upon its surface could not be implicitly ignored, as it is in all "ordinary" orbital calculations. No, mechanics does not tell us which systems are "mechanical."

And yet, even having reduced the number of equations to 1000—by applying deeply buried assumptions—we still may not be able to say we have solved this mechanical system. The equations may still prove intractable, even for a large computer. We need further simplifications. Newton supplied an important one in his Law of Universal Gravitation, which has been called "the greatest generalization achieved by the human mind.'"

The law states that the force of attraction (F) between two (point) masses was given by the equation:

$$F = GMm/r^2$$

where M is the mass of the first, m is the mass of the second, r is the distance between them, and G is a universal constant. From the viewpoint of simplification, this equation says more implicitly than explicitly. Why? Because it states that no other equation is needed. It says, for instance, that the force of attraction between two bodies is in no way dependent on the presence of a third body, so that only pairs of bodies need be considered in turn, and then all of their effects may be added up (Figure 1.3).

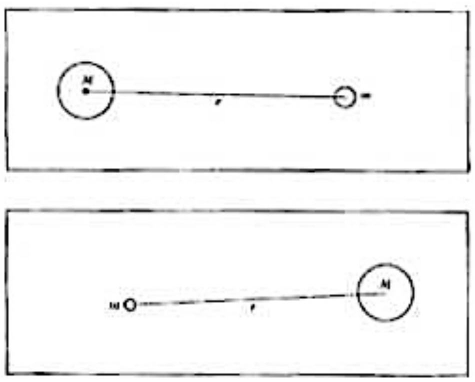


Figure 1.3. Only pairs need be considered in turn ...

A psychologist, for one, would be tickled pink if she could consider only summed pair interactions. This simplification would mean that, to understand the behavior of a family of three, she would study the behavior of the father and mother together, the father and son together, and the mother and son together. When all three interacted at the same time, their behavior could be predicted by summing their pairwise behaviors. Unfortunately for the psychologist, it is only in mechanics and a few other sciences that superposition of pairwise interactions can produce successful predictions.

In the case of the solar system, pairwise superposition reduces 1000 equations to about 45, that being the number of ways 10 things can be taken in pairs. From the point of view of the Square Law of Computation, we have reduced the size of our task by the square of 1000/45 or about 100 times, at least. We might be willing to stop at this point, although Newton went still further—perhaps because he did not have the computers we have.

As it happens, the solar system has one body (the sun) whose mass is much larger than any of the other masses, larger, in fact, than the mass of all of the other bodies together. Because of this dominant mass, the pair equations not involving the sun's mass yield forces small enough to be ignored, at least considering the accuracy of the data Newton was trying to explain. (Discrepancies in this assumption led to the discovery of at least one planet that Newton did not know.) This simplification, which is made possible by the special reality of the solar system, rather than by mechanics, reduces the number of equations to about 10, instead of 45, giving an estimated 20 times reduction in computation.

But Newton went even further than this, for he observed that the dominant mass of the sun enabled him to consider each planet together with the sun as a separate system from each of the others. Such a separation of a system into noninteracting subsystems is an extremely important technique known to all developed sciences—and to systems theorists as well. To understand the power of such a separation, we need only recall the Square Law of Computation. If solving a system of n equations takes n^2 units of computation, n separate single equations taken one at a time will take only n of the same units (Figure 1.4).

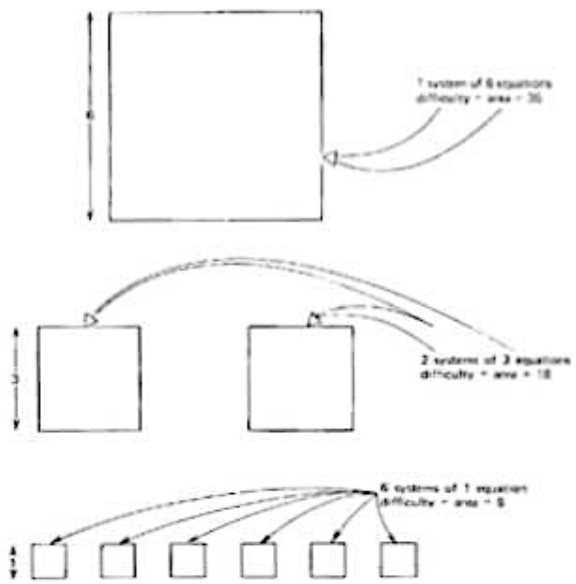


Figure 1.4. The power of separation. Each square represents a set of equations. The side of the square represents the number of equations n. The area of the square then represents the difficulty of computation n^2. By dividing the 6 equations into 2 sets of 3, we reduce the area of the squares from 36 to 18. By dividing the 6 equations into 6 sets of 1, we reduce the area of the squares from 36 to 6.

At this point, Newton stopped simplifying and solved the equations analytically. He had actually made numerous other simplifications, such as his consideration of each of the solar bodies as point masses. In each of these cases, he and his contemporaries were generally more aware of—and more concerned about—the simplifying assumptions than are many present-day physics professors who lecture about Newton's calculations. Students, consequently, find it hard to understand why Newton's calculation of planetary orbits is ranked as one of the highest achievements of the human mind.

But the general systems thinker understands. He understands because it is his chosen task to understand the simplifying assumptions of a science—in Wigner's words, those "objects of interest" and "well-defined conditions" that delimit its domain of application and magnify its power of prediction. He wants to go right to the beginning of the process by which a scientist forms his models of the world, and to follow that process just as far as it will help him in suggesting useful models for other sciences.

Why is the general systems thinker interested in the simplifications of science—in the science of simplifications? For exactly the same reason as Newton was. The systems theorist knows that the Square Law of Computation puts a limit on the power of any computing device. Moreover, he believes that the human brain is in some sense a computing device. Thus he knows that, if we are to survive in this complex world, we need all the help we can get. Newton was a genius, but not because of the superior computational power of his brain. Newton's genius was, on the contrary, his ability to simplify, idealize, and streamline the world so that it became, in some measure, tractable to the brains of perfectly ordinary men. By studying the methods of simplification that have succeeded and failed in the past, we hope to make the progress of human knowledge a little less dependent on genius.

Statistical Mechanics and the Law of Large Numbers

> In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Silurian Period, just a million years ago next November, the Lower Mississippi River was upward of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three-quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding along under a single mayor and mutual board of aldermen. There is something fascinating about science. One gets such wholesome returns of conjecture out of such a trifling investment of fact. - Mark Twain, Life on the Mississippi

Newton's achievement was in describing the behavior of a system of perhaps 10^5 objects, of which he found 10 of interest. By the nineteenth century, however, physicists wanted to tackle other systems, simple little systems such as the molecules in a bottle of air.

The molecules in a bottle of air differ from the solar system in several ways. First of all, there are not 10^5 of them, but 10^{23}. Second, the nineteenth-century physicists were not interested in just 10 of the molecules, but in all of them. Third, had they been interested in only 10, they would still have had to study all 10^{23}, since the molecules were pretty much identical in mass and were, furthermore, in close interaction (Figure 1.5).

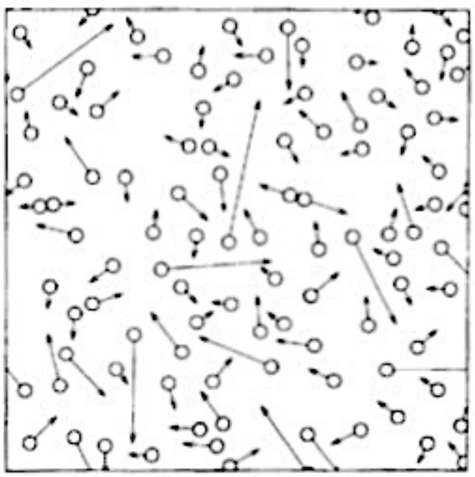


Figure 1.5. There were 10^{23}molecules, identical in mass, and in close interaction.

These nineteenth-century physicists already knew from Newton that they only had to consider pair relations, but this merely reduced the number of equations from about $2^{1023}$to 10^{46}. Although this is undoubtedly a substantial reduction, the prospects of further reduction of that 10^{46} looked rather grim. After a few fruitless tries at the job, these physicists must have felt much like the fox in Aesop's fable who just could not quite reach the grapes. We know they must have felt that way because they solved their problem the same way the fox did: They decided that they did not really want to know about the individual molecules anyway.

Actually, of course, the matter was not entirely one of sour molecules. We might more realistically describe the position of these physicists (such as Gibbs, Boltzmann, and Maxwell) by saying that they were lucky not to be interested in things for which they could not solve their equations. They had inherited a set of observed laws (such as Boyle's Law) about the behavior of certain measurable properties of gases (such as pressure, temperature, and volume). They believed that gases were made of molecules, but they had to bridge the gap between that belief and the observed properties of gases. They bridged that gap by postulating that the interesting measurements were a few average properties of the molecules, rather than the exact properties of any one molecule (Figure 1.6).

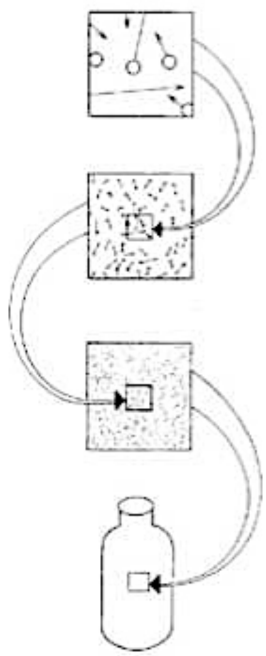
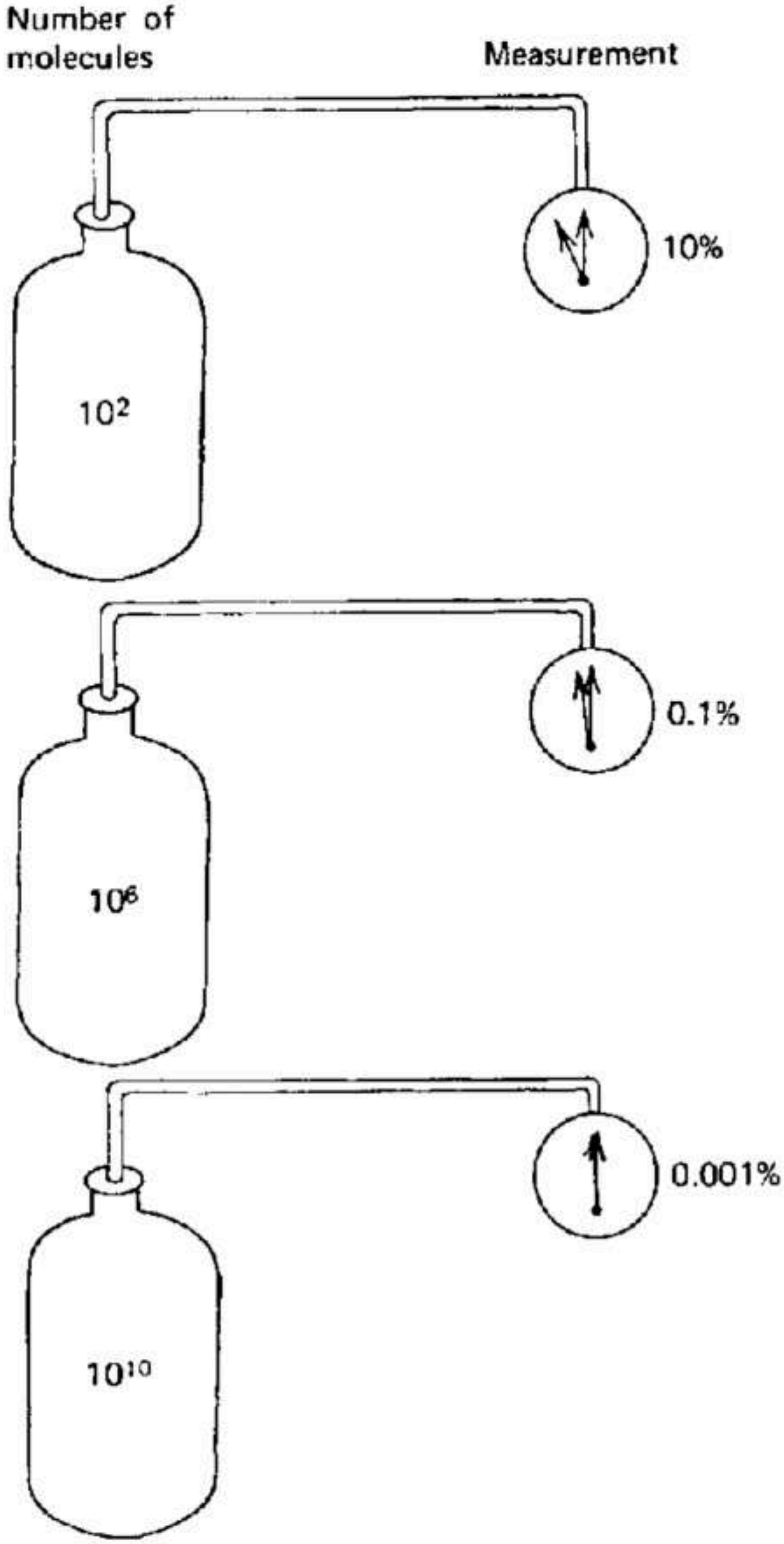


Figure 1.6. The interesting measurements were only a few average properties.

Since the number of different average properties was small, this simplification brought down the amount of computation in one fell swoop. Furthermore, the precision of prediction obtained for the averages was excellent, because the number of molecules was very, very large, and therefore the so-called "Law of Large Numbers" could be invoked. What this law says, in essence, is that the larger the population, the more likely we are to observe values that are close to the predicted average values.

More precise statements of the Law of Large Numbers enable us to say just how close we may expect observed and predicted values to be, depending on the size of the population. The most useful rule of thumb (or general systems law) in this context is Schrodinger's "Square Root of N Law":

> If I tell you that a certain gas under certain conditions of pressure and temperature has a certain density, and if I expressed this by saying that within a certain volume (of a size relevant for some experiment) there are under these conditions just n molecules of the gas, then you might be sure that if you could test my statement in a particular moment of time, you would find it inaccurate, the departure being of the order of the square root of n. Hence if the number n = 100, you would find a departure of about 10, thus relative error = 10%. But if n = 1 million, you would be likely to find a departure of about 1000, thus relative error = 1/10%. Now, roughly speaking, this statistical law is quite general. The laws of physics and physical chemistry are inaccurate within a probable relative error of the order of 1 divided by the square root of n, where n is the number of molecules that co-operate to bring about that law—to produce its validity within such regions of space or time (or both) that matter, for some considerations or for some particular experiment.
>
> You see from this again that an organism must have a comparatively gross structure in order to enjoy the benefit of fairly accurate laws, both for its internal life and for its interplay with the external world. For otherwise the number of co-operating particles would be too small, the "law" too inaccurate. The particularly exigent demand is the square root. For though a million is a reasonably large number, an accuracy of just 1 in 1000 is not overwhelmingly good, if a thing claims the dignity of being a "Law of Nature."[8] (See Figure 1.7.)



Number of molecules
Measurement
10^2
10%
10^6
0.1%
10^{10}
0.001%

Figure 1.7. The departure is of the order of the square root of the number of molecules.

In this vivid passage, Schrodinger not only explains why the laws of physics and physical chemistry work so well; but he goes on to explain a design principle that organisms should follow if they too are to "enjoy the benefit of fairly accurate laws." For now, however, we are only interested in the usefulness and limitations of the statistical approach to problems in other fields of science and technology.

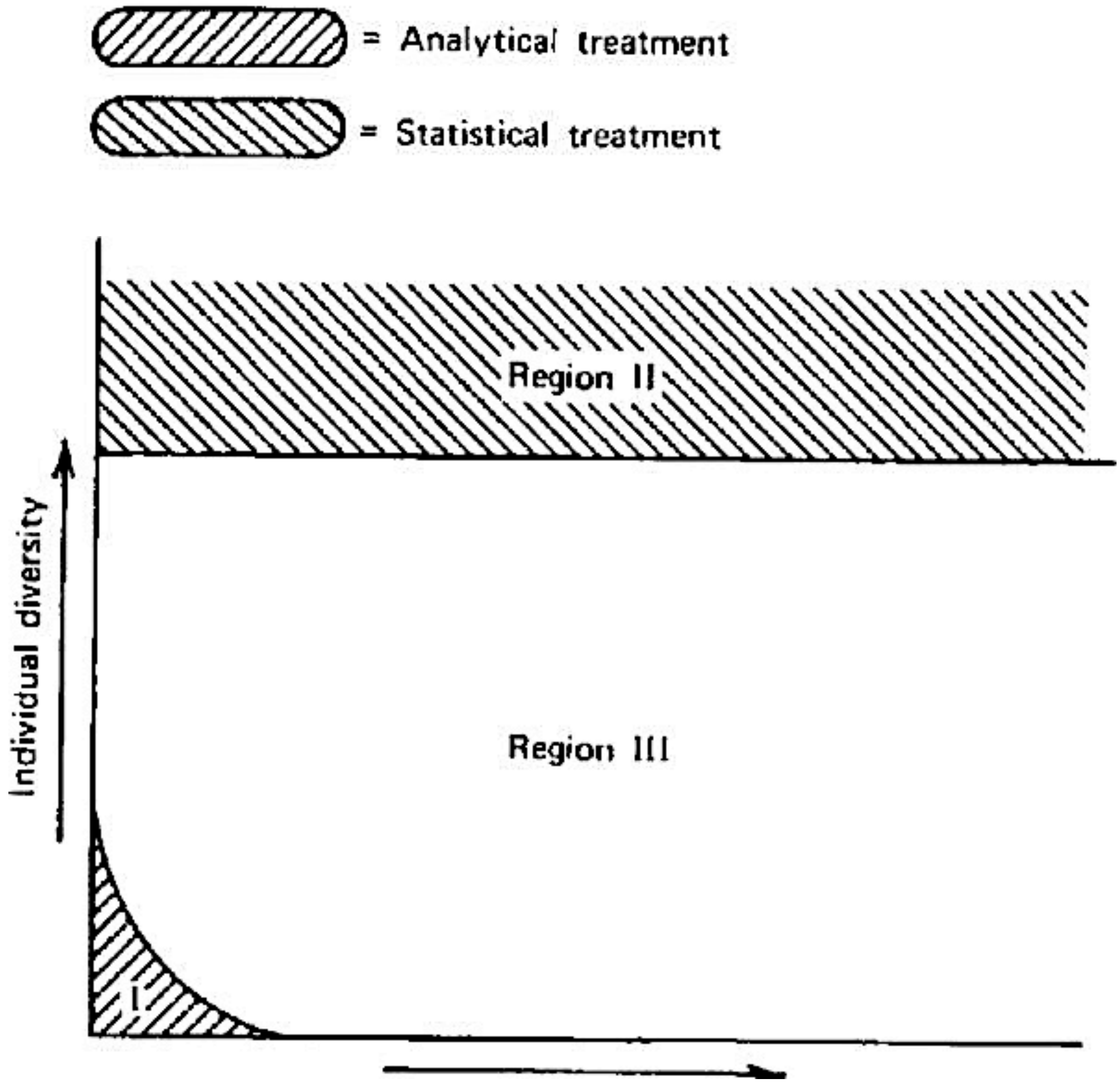
What is the scope of the statistical approach? How does it relate to the scope of the purely mechanical? One suggestive phrase is that statistical mechanics deals with "unorganized complexity"—that is, systems that are complex, but yet sufficiently random in their behavior so that they are sufficiently regular to be studied statistically.

The concept of "randomness" is most important for systems thinking, though randomness often leads to properties quite contrary to our intuition. We do not have such a problem in understanding the success of mechanics, for although "simplicity" will prove to be as slippery a concept as "randomness," to a first approximation we were able to use the number of objects as a measure of complexity—the complement of simplicity.

Intuitively, randomness is the property that makes statistical calculations come out right. Although this definition is patently circular, it does help us to understand the scope of statistical methods. Consider a typical statistical problem. There is a flu epidemic and we want to know how it will spread through the population so that we may plan for the distribution of vaccine. If every person is just as likely to get the disease as any other, we can calculate the expected number of cases and the effect of vaccination strategies with great precision. If, on the other hand, there is some sort of non-randomness in the population, our simple calculations will begin to deviate from the experienced epidemic.

What could be a source of such non-randomness? To take one case, people are not randomly distributed around the countryside, so that the chances of exposure are not the same for everyone. If it were a simple (small) population, we could calculate the exact exposures for every member, but we use a statistical approach just because the population is not small. In a small population, the very knowledge of the precise nature of the interactions would be what we needed in order to calculate the pattern of infection. On the other hand, in the large population, we have already given up hope of calculating the exact pattern and want to calculate averages, which are deranged by underlying structure. Thus the very type of structure that helped us in one approach hinders us in the other.

It may assist in understanding the situation to conceptualize it as shown in Figure 1.8.



Number of people

Figure 1.8. Types of populations in the prediction of epidemics.

There we consider the size of each possible population as the X-axis of a plot and the "diversity" as the Y-axis (up). In the lower left corner (Region I) are small populations with a great deal of structure, which, as the figure shows, could be treated analytically. At the top, above the straight line in Region II, we have sufficient diversity or randomness to achieve some desired precision of prediction. In Region III, in between, lie all the populations that are too diverse for analysis and too structured (perhaps because they are too small) for statistics.

Passing from this specific example to a more general case, we may obtain the chart shown in Figure 1.9, which is a relabeled version of Figure 1.8. "Number of people" has been generalized to "complexity," and "individual diversity" has been generalized to "randomness." In keeping with the very rough nature of the arguments, we do not put any numbers on the chart, but only concern ourselves with its general characteristics.

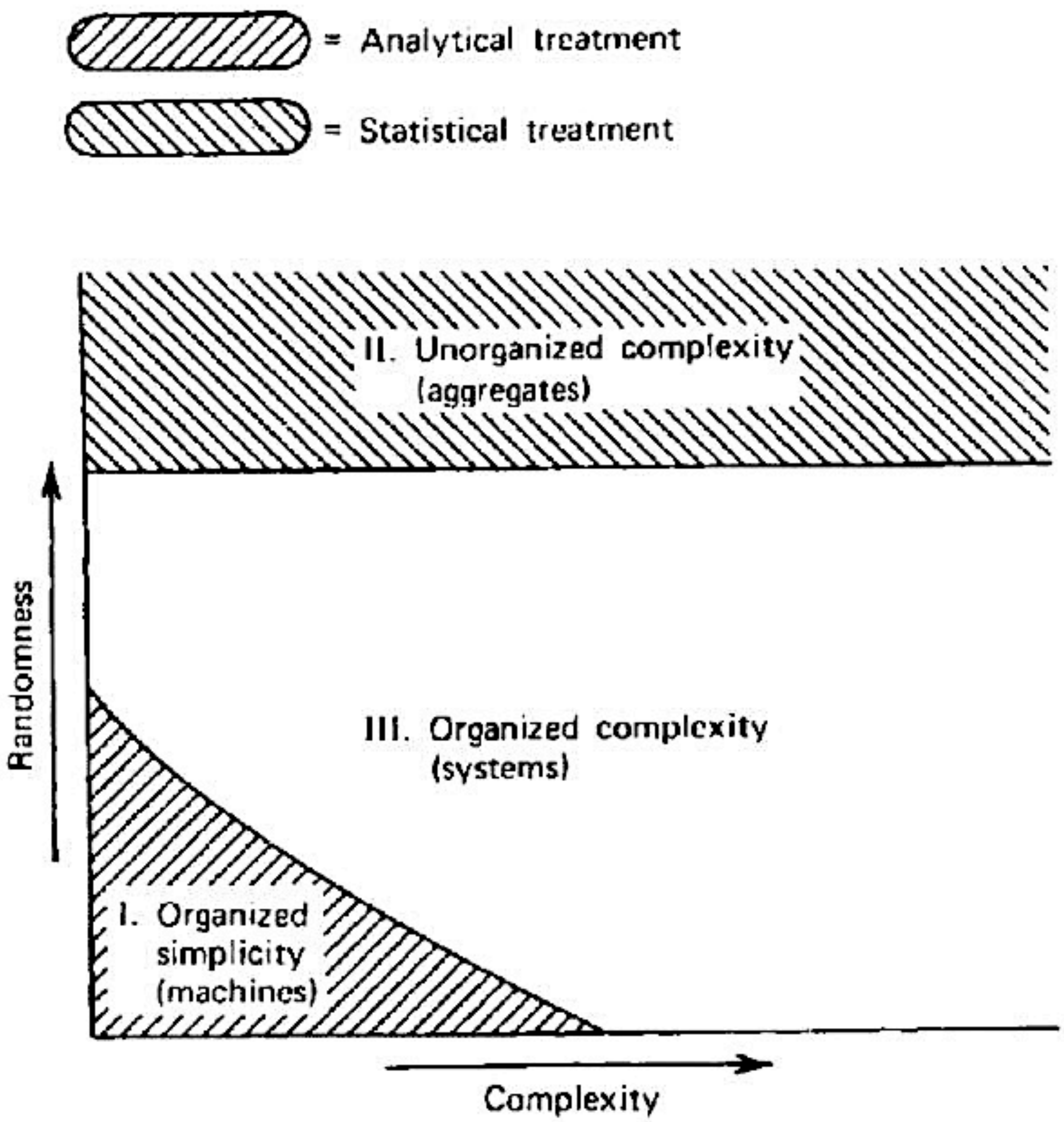


Figure 1.9. Types of systems with respect to methods of thinking.

Region I is the region that might be called "organized simplicity"—the region of machines, or mechanisms. Region II is the region of "unorganized complexity"—the region of populations, or aggregates, as we shall call them. Region III, the yawning gap in the middle, is the region of "organized complexity"—the region too complex for analysis and too organized for statistics. This is the region of systems.

The Law of Medium Numbers

> The mechanistic world view, taking the play of physical particles as ultimate reality, found its expression in a civilization which glorifies physical technology that has led eventually to the catastrophes of our time. Possibly the model of the world as a great organization can help to reinforce the sense of reverence for the living which we have almost lost in the last sanguinary decade of human history.[9] - Ludwig von Bertalanffy

Although technology often leads science in discovery, the philosophy of technology is usually drawn from the scientific philosophy of its time. In our time, the technology of machines has drawn its inspiration from mechanics, dealing with complexity by reducing the number of relevant parts. The technology of government, on the other hand, has drawn upon statistical mechanics, creating simplicity by dealing only with people in the structureless mass, as interchangeable units, and taking averages. As von Bertalanffy suggests, these philosophies may result from the lack of any scientific means of dealing with systems between these extremes—systems in the vast no-man's land of medium numbers.

For systems between the small and large number extremes, there is an essential failure of the two classical methods. On the one hand, the Square Law of Computation says that we cannot solve medium number systems by analysis, while on the other hand, the Square Root of N Law warns us not to expect too much from averages. By combining these two laws, then, we get a third: the Law of Medium Numbers:

> For medium number systems, we can expect that large fluctuations, irregularities, and discrepancy with any theory will occur more or less regularly.

The importance of the Law of Medium Numbers lies not in its power of prediction, but in the scope of its application. Although good mechanical and statistical systems are actually quite rare, we are literally surrounded by medium number systems. Computers have medium numbers of components; cells have medium numbers of enzymes; organizations have medium numbers of members; people have medium numbers of vocabulary words; and forests have medium numbers of trees, or flowers, or birds.

As with most general systems laws, we find a form of the Law of Medium Numbers in folklore. Translated into our daily experience—combining our familiarity with such systems and our ineptitude in their face—the Law of Medium Numbers becomes Murphy's Law:

> Anything that can happen, will happen.

Science, like any of us, is unable to cope with medium number systems, though its success with systems of its own choosing has misled many scientists and politicians into thinking of science as a way of dealing effectively with all systems. Science, as science, is no more to blame for the consequences than a band saw is responsible for the consequences of its being used to trim fingernails. If fingernails need cutting, and the band saw is the only available cutting tool, then the results are more or less predictable. A band saw is a most useful tool, but not for certain jobs.

Science, too, is a most useful tool—probably the most useful that man has ever discovered. Not even the most ardent naturist would actually be willing to live without tasting any of the fruits of science. But the fruits of science are simple fruits, or more precisely, fruits of simplification. Social scientists, for example, study us as great masses of humanity in order to plan for our overall needs, and engineers satisfy those needs by putting together small numbers of parts into large machines whose essential principle is to keep the parts from strong interactions.

Many of the ills of society come from too good an application of these simple fruits: a richness of means applied to impoverished ends. Yet many more of those ills—and perhaps the impoverished ends themselves—come from a vastly inadequate technology attempting what it can never do. We must begin to understand the limitations of brash technology, for its principal method is to squelch medium number systems.

Consider, for example, the methods of simplification applied to a large electronic device, such as a computer. The individual transistors depend on a single physical law and are manufactured with the utmost purity so that the law will hold within them. Such devices, though there may be 100,000 of them in one unit, rarely cause trouble. On the other hand, troubles frequently arise in the joints by which the transistors are connected to each other and to the rest of the system. Why? Because the purity of the transistor is achieved by pushing out to the joints all the dirty problems of physical strength, exposure to air, bonding of unlike materials, and so forth.

This separation of function has been carried to great extremes in our technology. Whenever a designer can transcend it, she can create a whole new technology. From time to time it is recognized that some device is not merely a collection of components, but a collection together with the relationships (joints) between them. Then, a new level of device—the "integrated circuit," for example—is created in which the previous components lose their separate identities as the joints disappear. This new device, in turn, becomes a "component" in the new way of thinking, and the connections to it again become the weakest part of the system.

Separation of function is not to be despised, but neither should it be exalted. Separation is not an unbreakable law, but a convenience for overcoming inadequate human abilities, whether in science or engineering.

As D'Arcy Thompson, one of the spiritual fathers of the general systems movement, said:

> As we analyze a thing into its parts or into its properties, we tend to magnify these, to exaggerate their apparent independence, and to hide from ourselves (at least for a time) the essential integrity and individuality of the composite whole. We divided the body into its organs, the skeleton into its bones, as in very much the same fashion we make a subjective analysis of the mind, according to the teaching of psychology, into component factors: but we know very well that judgement and knowledge, courage or gentleness, love or fear, have no separate existence, but are somehow mere manifestations, or imaginary coefficients, of a most complex integral.[10]

The world is one whole. The fragmentation of knowledge about the world is exactly analogous to the separation of a device into its components, the body into its organs, or the surface of the earth into political units: It is useful in some situations but is usually carried to extremes. Eventually, we get revolutionary movements for new syntheses of knowledge, creating whole new fields, such as electro-magnetism, physical chemistry, social psychology, or maybe even psychobotany—or perhaps movements for a new political synthesis, creating new forms of economy, culture, and society.

The biological and social sciences are not as "successful" as the physical sciences. They are not so free to chop up the world as it is given to them, for the piece they have taken for their own is essentially indivisible. Anatomists have had some success, but we are not so interested in how a man operates when he is disassembled. Social scientists have had even less success, because their main interest—"humanness"—is a medium number property that disappears when the system is taken apart or abstracted and averaged. When behavioral scientists try to understand the "individual" by averaging, the properties of the individual are smoothed out and lost. When they try to isolate the individual for study, they disconnect their subject from other humans and other parts of the world so that the individual becomes merely a laboratory artifact—and something less than human.

For most of his short history, man's physical environment was only indirectly and partially under his control. Very recently, man invented science to increase that control, and he has been so fascinated by the quick and easy success that he has not paid much attention to consequences outside his analyses and averages. As a result, we come to expect that the future will see even greater mastery of the environment—and of man himself.

But all too frequently, that mastery seems to be accompanied by creeping slavery. Perhaps we are beginning to feel the results of treating a system as if it were a collection of parts, and an individual as if she were only contributing to an average. Perhaps, too, we are reaching the useful limits of a science and technology whose philosophical underpinnings are techniques restricted to systems of small and large numbers.

The general systems movement itself, of course, is subject to the same abuses if it carries its principles beyond their useful limits. General systems thinking is not going to yield the kinds of control over medium number systems that we might imagine we would like to have, and its major contribution is most likely to be in limiting the excesses of other approaches to complexity.

Still, if we want to reverse the trend of "the last sanguinary decades of human history," we may have to turn more and more to some sort of synthesis. We already know how to transform prairies into dustbowls, lakes into cesspools, and cities into mausoleums. Can we turn around before it is too late?

QUESTIONS FOR FURTHER RESEARCH

Economics

Vilfredo Pareto, in his famous Manuel d'Economie Politique, mentioned that this general equilibrium theory, when applied to a system of 100 persons and 700 commodities, would require not less than 70,699 equations to be solved. Where does this figure come from, and how is it dependent on the number of persons and commodities? What does it mean for Pareto's theory? What might be done to save the theory from this vast number of equations.?

Social Psychology and Sociology

A frequently used method in studying group structures is the so-called sociometric method, perhaps modeled after the "econometric" method in economics. The method, originated by J. L. Moreno in his book, Who Shall Survive? (1934), has been elaborated in a number of directions by later workers. Essentially, the method involves determining the strength or quality of interactions between all pairs of persons involved in a group, possibly along several dimensions, such as like dislike, interact-avoid, important-indifferent. What might be the limit on the size of the group that could be studied effectively with such methods? Could this limit be the dividing line between social psychology and sociology? Under what special circumstances could larger groups be studied with such techniques?

Mechanics

For those who doubt the degree with which the success of physics depends upon the reduction of complex systems to simple ones, we need only reflect upon the three-body problem. As soon as a third body is added to the completely solved pair of bodies, the solution, in general, becomes impossible. Whereas the two-body problem can be solved by a high-school student, the intractability of the three-body problem can be gauged by considering that in July 1969, an international gathering of physicists met in Birmingham, England, to consider the "Three-Body Problem in Nuclear and Particle Physics." The proceedings of this conference, while dealing only with special cases of the three-body problem, contained over 70 papers on the subject—and, of course, the problem is still unsolved. Those interested in the success of physics at dealing with complex systems should prepare a report summarizing this conference.

Reference: J. S. C. McKee and P. M. Rolph, Eds., Three Body Problems in Nuclear and Particle Physics, Proceedings of an International Conference, Birmingham, England, July 1969. New York: Elsevier, 1970.

Archaeology

The complexity of seemingly simple objects is nowhere better illustrated than in archaeology, where from a single piece of stone that most of us would dismiss as uninteresting, whole patterns of a vanished society can be deduced. The collection:

Martin Levey, Ed., Archaeological Chemistry: A Symposium. Philadelphia: University of Pennsylvania Press, 1967. assembles 15 different reports on the extraction of information from small bits of matter as done by archaeologists. How does the work of these archaeologists compare with the work of the theoretical physicist? What simplifications do they share, and what simplifications dare they not share?

Thermodynamics (or "Thermostatics")

Of the three commonly observed states of matter, gases were the first to be reasonably well understood by physicists, starting, perhaps, with Boyle's Law. More recently, crystalline solids have become quite tractable for the physicist, but liquids remain the least known of the states. Discuss this historical sequence in terms of the Law of Medium Numbers.

Operations Research

The word "computation" in the Square Law of Computation does not necessarily refer to "solving equations" in only the ordinary senses of the term. A computer simulation is a method of computation in which the "equations" do not necessarily appear explicitly. Imagine we were simulating a production line, perhaps the assembly line for automobiles or a petroleum distillery. What changes in the simulation will tend to increase the computation by the Square Law? What elements might be found in the process that permitting detailed modeling than the Square Law might suggest? Reference: Thomas H. Naylor et al., Computer Simulation Techniques. New York: Wiley, 1966.

"Science" as Science

The misnaming of fields of study is so common as to lead to what might be general systems laws. For example, the mathematician, Frank Harary, once suggested this "law" to me:

> Any field with the word "science" in its name is guaranteed not to be a science.

He would cite as examples Military Science, Library Science, Political Science, Homemaking Science, Social Science, and Computer Science. Discuss the generality of this law, and possible reasons for its predictive power.

Poetry

Tagore said, "By plucking her petals you do not gather the beauty of the flower." Many poets are similarly renowned for their celebration of wholeness and complexity. Choose a particular poet and several representative works to discuss in the light of the Law of Medium Numbers.

Neuroendocrinology

Not many years ago, the pineal gland (then called pineal body) was thought by some anatomists to have no function, perhaps because of its small size. Today, the situation is reversed, with investigators attributing to this tiny piece of tissue actions on the midbrain, hypothalamus, and pituitary; participation in the syntheses of various enzymes and other vital substances; and modification of brain activity and behavior. Discuss the history of investigation of this organ in the light of scientific simplification.

Reference: G. E. W. Wolstenholme and Julie Knight, Eds., The Pineal Gland. Baltimore: Williams and Wilkins, 1971.

Utopian Thought

The ingestion of current scientific philosophy into popular thought is nowhere better illustrated than in Utopian writings. The French philosopher Saint-Simon lived at the beginning of the nineteenth century and was the inspiration of many Utopians of that time. He worked before the rise of statistical mechanics, and completely under the spell of Newtonian mechanics—so much so that he had a vision that Newton, not the Pope, had been elected by God to transmit His divine plan to humanity. Saint-Simon was especially interested in a "law of Universal Gravitation" for social bodies, evidently to make the social system as harmonious as the solar system.

It is a fascinating exercise, full of unexpected side branches into history, to trace the evolution of Utopian thought as influenced by the dominant scientific philosophy of its time.

Reference: Edmund Wilson, To the Finland Station; A Study in the Writing and Acting of History. New York: Harcourt Brace, 1940.

READINGS

Recommended

1. Ludwig von Bertalanffy, "The History and Status of General Systems Theory." In Trends in General Systems Theory. George J. Klir, Ed. New York: Wiley, 1972.

2. Karl Deutsch, "Mechanism, Organism, and Society." Philosophy of Science, 18, 230 (1951).

Suggested

1. Erwin Schrodinger, What Is Life? Cambridge: Cambridge University Press, 1945.

2. Kenneth Boulding, The Image. Ann Arbor: University of Michigan Press, 1956.

Chapter 2. The Approach

Then what is the answer?—Not to be deluded by dreams.
To know that great civilizations have broken down into violence,
and their tyrants come, many times before.
When open violence appears, to avoid it with honor or choose
the least ugly faction; these evils are essential.
To keep one's own integrity, be merciful and uncorrupted and
not wish for evil; and not be duped
By dreams of universal justice or happiness. These dreams will
not be fulfilled.
To know this, and know that however ugly the parts appear
the whole remains beautiful. A severed hand
Is an ugly thing, and man dissevered from the earth and stars
and his history... for contemplation or in fact...
Often appears atrociously ugly. Integrity is wholeness,
the greatest beauty is
Organic wholeness, the wholeness of life and things, the divine
beauty of the universe. Love that, not man
Apart from that, or else you will share man's pitiful confusions,
or drown in despair when his days darken.[1]
Robinson Jeffers, "The Answer"

Organism, Analogy, and Vitalism

I replied to someone who said I didn't see women as I represent them: "If I met such women in life, I should run away in horror." First of all, I do not create a woman, I make a picture.[2] - Henri Matisse

[NOTE: The main tone of this chapter was set in the early 1960s, when I was spending a lot of time with Kenneth Boulding, teaching a General Systems course with him at the University of Michigan. Ten years later, upon rereading his article, "General Systems as a Point of view"[10], I realize I cannot separate my thoughts from his. Since he is much smarter than I, a reader can safely assume that whatever is coincident between this chapter and that article is his. Since Ken is a far better writer than I, the reader is strongly advised to read the article—even if that means skipping this chapter.]

By finding general laws, the general systems movement attempts to aid thinking about medium number systems. Although these laws are stated informally to aid recall and initial understanding, an essential part of the general systems approach is the insistence that these laws be supportable, if necessary, by rigorous operations on rigorously defined models. This insistence is to some extent a reaction to the bad reputation of previous approaches to medium number systems, most of which can be classed as organismic. Faced with systems of organized complexity, some thinkers turned to living systems as models. Knowledge about living systems was applied by analogy to other systems, in order to gain some point of leverage on the complexity

Hobbes, for instance, viewed the state, the "body politic" as a literal body of a giant person, with the various organs representing the government agencies. Lamarck endowed plants and animals with a kind of "intelligence" by which they directed their evolution (Figure 2 1) Such analogies suffered first of all from lack of real knowledge of the analog. Hobbes's knowledge of physiology was inaccurate and incomplete, so how could he hope to draw useful conclusions from likening the state to a person? Lamarck certainly did not understand "intelligence" any better than we do today, so what was gained by modeling evolution on it? Today, in fact, most of the modeling actually goes the other way. with intelligence based on evolution.[3]

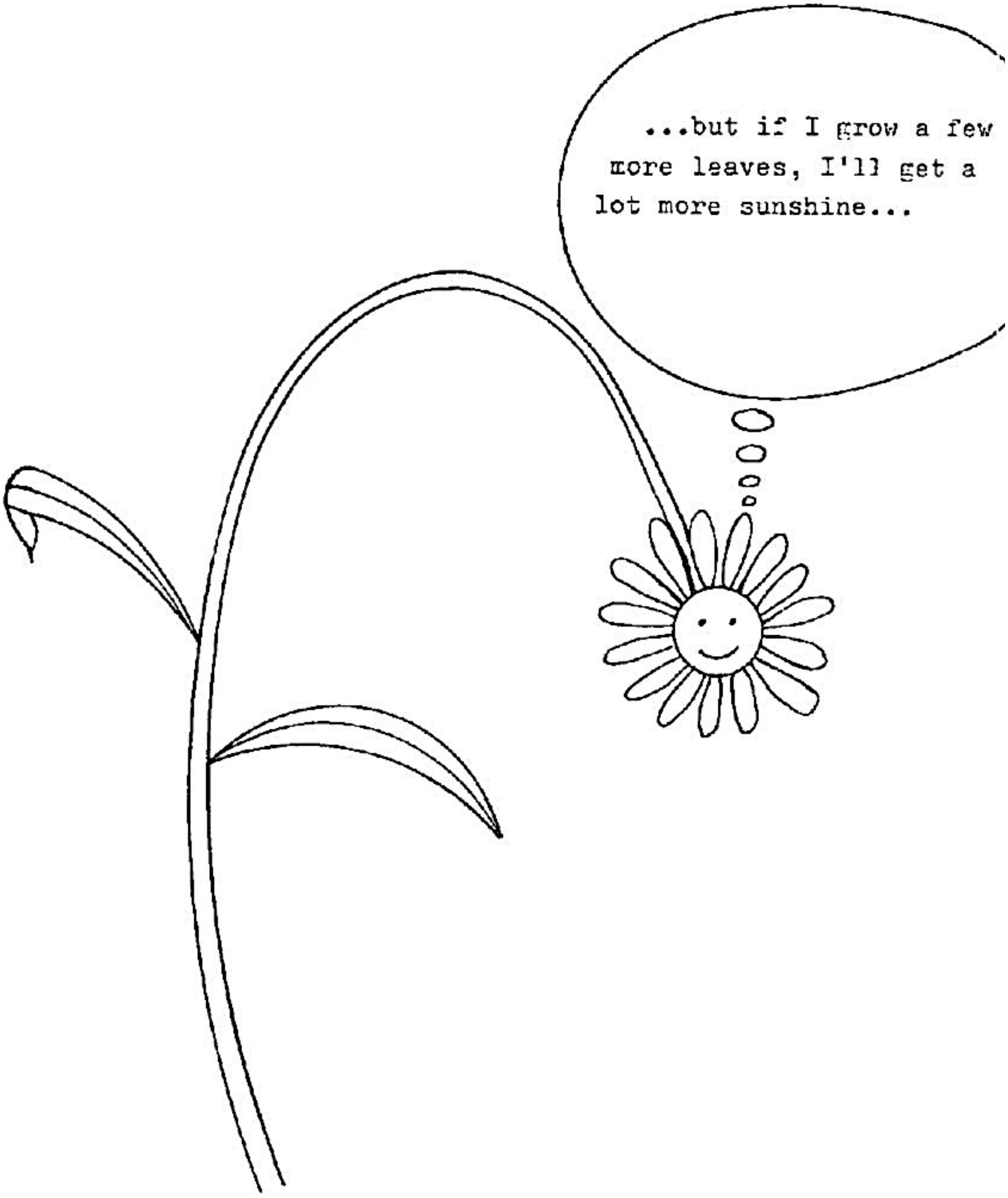


Figure 2.1. Lamarck endowed plants with a kind of "intelligence" by which they directed their evolution.

Actually, sometimes we can gain from modeling on a poorly known system A fresh point of view can be helpful if something is known about the analog. At the very least, an analog jiggles the mind-and heaven knows our minds need a little jiggling. In point of fact, however the organismic analogies were not all that careful, and the approach suffered as much from poorly drawn analogies as from poorly understood analogs. Systems thinkers hope to avoid these pitfalls by requiring the possibility of making the models rigorous.

Without this possibility of rigor, it is too tempting to ignore discordant parts of the mode—something for which the organismists were severely chastised. Again, however, this might not be too dangerous a practice as long as we do not take our models too seriously. We do not create the world. We make a model. Making models is what organismists do; making models is what painters do; and making models is also what scientists do, despite any protestations to the contrary.

Every model is ultimately the expression of one thing we think we hope to understand in terms of another thing we think we do understand. The chain of reasoning may be a hundred logical steps or a single analogical leap, but always ends in terms of some primitives we agree among ourselves not to question further. For a science to have explanatory "power," this set of primitives must be neither too large nor too small. For instance, animistic religions explain the behavior of every object by referring to its unique spirit. If a tree falls, that is the spirit of the tree. If a rock fails to move, that is the spirit of the rock. In Western religions, such explanations are not satisfying.

Some of us are more satisfied with reducing everything to a single primitive. If a tree falls, God willed it to fall. If a rock fails to move, God willed it not to move. But if something explains everything, it explains nothing. That, at least, is the scientific view, which is why organismic theories got into trouble with scientists.

The mechanists claimed that every phenomenon could be reduced to the primitives of physics, or physics and chemistry. They did not actually demonstrate this for "everything," but only claimed it. Some organismists countered by saying that not everything could be reduced to those primitives

—the process for living systems had to stop sometime earlier, with something called the "life force," or "vital essence." While "vital essence" is no more intrinsically mysterious than, say, "mass," everything the organismists did not understand was reduced to vital essence, which meant that vital essence really explained nothing, because, like God, it explained everything.

Whatever else such an explanatory primitive does, it discourages scientific investigation. Science is the study of those things that can be reduced to the study of other things. Science, in other words, is essentially reductionist, and the reductionists were right in saying that the vitalists were unscientific. When reductionists began to back their claims by reducing some of the "organismic" phenomena to physical or chemical primitives, the backers of "organism" went into hasty retreat.

It should be noted, however, that the reductionists have not yet succeeded in reducing all phenomena to physical and chemical primitives. Whether they can or not is a neat philosophical question, not a scientific one. The fact remains that there are lots and lots of medium number systems—not all of them "living systems" by any means—that have not been "explained" in terms of physical and chemical primitives. Among those systems are quite a few we cannot simply ignore while waiting for the reductionists to reduce.

Reductionism, in the end, is an article of faith, one that drives scientists to carry out certain investigations in the faith that they will thereby better "understand." No physicist, however, actually lives his life by his reductionist creed. He does not decide what he will eat for supper based on the "length-mass time-charge-..." reduction of the items on the menu. He employs other primitives, such as the "smells-looks-costs-..." system of units. Neither does he, when at work in the laboratory, rely on his most primitive of primitives. He uses a particular bracket because it is "strong," or a particular measuring stick because it is "stable." In doing so, he is making use of animist analogs, but he may still be doing excellent physics.

What we are saying is that the baby of organismic thinking should not be thrown out with the bath of vital essence. Vitalism is not a prescription for thinking, but the very opposite—a declaration that certain things are not to be thought about further. Organismic thought, on the other hand, is simply the reliance on analogy, something that every physicist has done from Newton forward and back. Every significant thinker in science has drawn upon useful analogies for simplifying certain stages of thought. What is important is not to stop with rough analogy when the occasion demands we continue—but, instead, to render the analogy into a precise, explicit, and predictive model.

In our time, biological systems are much better understood than they were a century ago, so organismic analogies may now prove more fruitful. The general systems approach, however, need not limit itself to organismic analogies. To the extent we can reduce the models of a science to explicit form, we can make models in any other field by analogy with that science—but an analogy with known mathematical characteristics. Therefore, we want to understand and communicate the ways in which thinkers in all fields use analogies and, when necessary, convert them into models.

The Scientist and Her Categories

> Man is by nature metaphysical and proud. He has gone so far as to think that the idealistic creations of his mind, which correspond to his feelings, also represent reality.[4] - Claude Bernard

In order to discover what the thinking of different disciplines has in common, we shall have to raise many epistemological questions—"How do we know what we know?" We shall not, however, take a philosophical approach to this subject, but a practical one. That is, we shall not ask "How do we know what we know is true?" but instead, "How do we come to hold the ideas we hold as knowledge" We are interested, in other words, in how thinking is done, not in proving some thinking is correct or incorrect.

Much thinking is done in completely personal, idiosyncratic terms, so much so that how it is done is incommunicable. There exist, however, many overt categories of thought, and many others that can be brought to the surface by a modest effort at introspection. Since our interest, fortunately, lies closer to "the conceptual schemes of science" than to "the delusions of psychotics," we may rely for our study on a certain measure of public behavior.

Among the scientists, the anthropologists come closest to doing our kind of work when they study the conceptual schemes of naturally evolving social groups. Conceptual schemes are also found, however, in any subculture that develops when people work together. By possessing a common set of standard categories of thought—usually symbolized by special words or phrases—groups can simplify the process of internal communication. Paradoxically, the more effective these categories are for internal communication, the more difficult they make communication with outsiders.

The anthropologist is faced with this problem in an obvious way when she endeavors to become a "participant-observer" in some culture. To become a participant observer, one must first become a participant, which involves at a minimum learning the native language—and actually involves far, far more learning of nonlinguistic patterns.[5] In the same way, becoming part of a working subculture means learning to use its forms of thought and communication.

In modern industrial society, most of us operate within the realms of a variety of groups and so have learned not only subcultural patterns, but also how to switch effortlessly from one pattern to another. The physicist generally experiences no difficulty in switching from the language of celestial mechanics to the language of auto mechanics. Only when he does experience difficulty is he likely to remark that category schemes seem to hinder communication. Moreover, when he does remark, he will ordinarily identify the "foreign" language of the auto mechanic as being the source of the difficulty. The anthropologists call this bias "ethnocentrism."

One manifestation of ethnocentrism is the belief that one's own culture is "superior" to those that one does not understand, or, rather, one whose natives "don't understand us, even though we are speaking perfectly clear English." If we but carry the "white man's burden" to the natives, surely they will make us their leader, or their god. After all, "in the kingdom of the blind, the one-eyed man is king."

Well, it never turns out quite that way, as H. G. Wells knew when he wrote his story "The Country of the Blind." A one-eyed man who happens upon a blind society does not become its king, for he cannot even function and is thought to be insane or sick. Because of the importance of category systems in a social group, it is not the outsider with a "better" system who becomes king, but the insider who most thoroughly masters the internal system. Should one of these "leaders" be removed to another group, his "native talent" evaporates, and probably becomes a severe handicap.

On the other hand, there are people who experience difficulty fitting into their own native group, yet who always seem to be moderately successful at getting by anywhere else. The anthropologist, for one, tends to be this way. Although a professional at fitting into all sorts of exotic cultures, when she comes home she never becomes smoothly integrated: a critic at home and a conformist elsewhere.

The disciplines within science also form social groups, and thus have category schemes to facilitate internal communication. Thomas Kuhn, in The Structure of Scientific Revolutions,[6] has begun the study of the ways in which new "paradigms" are created and old ones destroyed; how paradigms are transmitted from one generation to the next; and how paradigms both help and hinder the progress of science. In particular, he distinguished between "normal science"—working within the current paradigms, and "scientific revolutions"—in which the paradigms themselves come under assault.

If our observations about category schemes generalize to sciences, then "leading scientists" should be the least likely people to lead scientific revolutions. Kuhn concurs in this conclusion, as did Max Planck in his Scientific Autobiography[7]:

> A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

The average scientist is good for at most one revolution. Even if he has the power to make one change in his category system and carry others along, success will make him a recognized leader, with little to gain from another revolution.

Paradoxically, some scientists lead revolutions in several different disciplines—though not through a change in personal category systems. On the contrary, they carry a paradigm intact from one discipline to the other. While the colonialist may not master the natives' category system, he may become their king by introducing an entirely new element. One need not learn the language if one has the only rifle in town, lots of bullets, and the will to do a little shooting.

When England built The Empire, the young men who carried the white man's burden were seldom successes at home. They may have had talent, but the rather rigid social system had no room for them. In the same way, paradigms are often carried across disciplines by people who are having trouble rising in their own disciplinary hierarchy, whether for lack of talent or lack of room. In general, however, these "interdisciplinarians" are not what we would call "generalists." Like the mole, they know one thing exceedingly well, and apply it again and again to whatever discipline will have them.

The generalist, on the other hand, is like the fox, who knows many things. Just as anthropologists learn to live in many cultures, without rifles, so do certain scientists manage to adapt comfortably to the paradigms of several disciplines. How do they do it? When questioned, these generalists always express an inner faith in the unity of science. They, too, carry a single paradigm, but it is one taken from a much higher vantage point, one from which the paradigms of the different disciplines are seen to be very much alike, though often obscured by special language.

Kenneth Boulding once remarked that the generalist is like the tourist who, when he sees Bangkok, is reminded of Pittsburgh, because both are cities and have streets with people in them. Like the tourist, he relieves his fear of strange places—strange paradigm systems—by moving to higher and higher levels of generality until all things follow the same familiar, comfortable order. In ascending like this, general systems thinking is following the same human tendency that produces the paradigms in the first place.

The most dangerous pitfall in developing category systems is imagining that one system of paradigms is more "real"' than another. For example, stars in the heavens present the same "objective" picture over wide portions of the earth, and every human culture seems to have developed ways of looking at those stars as familiar objects—be they as animals, people, or kitchen utensils. Although each of those systems is different, each culture "really sees" its own pictures, often worships them, and is patently unable to "see" the pictures of another culture.

Our astronomers also claim to have a truthful ordering of the heavens, but how can we evaluate the merits of their claims relative to those of the others? If we appeal to "usefulness," then certainly each culture has as much claim to "truth" as any other, for none find the other systems understandable, let alone useful. But if we appeal to some intrinsic ""truth," then we are making a religious argument, and how shall we adjudicate the claims of the diverse religions?

Psychologically, it may be essential for a scientist to have faith in the truth of his own discipline, but such conviction can only diminish his chances of making a revolution or moving to another discipline. For the missionizing interdisciplinarian, such faith is doubly essential. Yet just as the gun impedes communication with the natives, the single model of the interdisciplinarian prevents him from learning about the field in which he uses it.

To be a good generalist, one should not have faith in anything. Faith, as Bertrand Russell once pointed out, is the belief in something for which there is no evidence. Every article of faith is a restriction on the free movement of thought, and thus on the free movement of the generalist among the disciplines. As Reichenbach[8] observed:

> The power of reason must be sought not in the rules that reason dictates to our imagination, but in the ability to free ourselves from any kind of rules to which we have been conditioned through experience and tradition.

The Main Article of General Systems Faith

> My advice to any young man at the beginning of his career is to try to look for the mere outlines of big things with his fresh, untrained, and unprejudiced mind.[9] - H. Selye

But nobody can exist without faith in something. Without faith, we could not move one foot in front of the other, not knowing whether the next piece of ground would support our weight. Moreover, we could not even stand still without faith in the continuity of the ground now beneath our feet. The general systems approach does not free us from the need for faith, but only attempts to supplement one set of beliefs with another, in the hope of sometimes being more useful.

On what basis does general systems thinking promise to be useful? The principal answer seems to lie in what Boulding calls "The Main Article of General Systems Faith":

> This is that the order of the empirical world itself has an order which might be called order of the second degree.[10]

About the generalist, Boulding says:

> If he delights to find a law he is ecstatic when he finds a law about laws. If laws in his eyes are good, laws about laws are delicious and are most praiseworthy objects of search.

This faith, this hunger, could be in vain. But if an order of the second degree does exist, then surely it will be useful to those who seek order of the first.

In a certain sense, order of the first degree underlies the order of the second, and the primary way of discovering general systems laws is by induction. The general systems researcher starts with the laws of different disciplines, searches for similarities among them, and then announces to the world a new "law about laws." The general laws of the disciplines are thus only particular cases to her.

The power of generalization through induction is that we can then use the general laws to draw conclusions about cases not yet observed. This is the source of the generalist's power to move from discipline to discipline. Each time she is successful, she provides one more piece of evidence for her belief in order of the second degree.

The main article of general systems faith is, therefore, not entirely based on faith. Faith is needed, however, because this leaping from discipline to discipline does not always work. Why not? Because induction does not always work. Even though it looks as if she is operating on the most general plane, the generalist is, like any scientist, only applying the results of induction. Philosophers have tried for a long time to demonstrate that induction must work, but now the smart ones have given up. As Reichenbach[11] said:

> We need (induction) if we want to establish a general truth, which includes a reference to unobserved things, and because we need it, we are willing to take the risk of error.

But why can't we be more careful? Why not wait until more evidence is in? Why such a hurry? The answer lies in the explosive growth of knowledge, and in the limits the Square Law of Computation places on our brain. As Boulding wrote:

> Even the most renaissance of renaissance men in these days cannot hope to know more than a very small fraction of what is known by somebody. The general systems man, therefore, is constantly taking leaps in the dark, constantly jumping to conclusions on insufficient evidence, constantly, in fact, making a fool of himself. Indeed, the willingness to make a fool of oneself should almost be a requirement for admission to the Society for General Systems Research, for this willingness is almost a prerequisite to rapid learning.[12]

To be a successful generalist, then, we must approach complex systems with a certain naive simplicity. We must be as little children, for we have much evidence that children learn most of their more complex ideas in just this manner, first forming a general impression of the whole and only then passing down to more particular discriminations. Piaget cites his observations that

> ... a child of 4 who did not know his letters and could not read music managed to recognize the different songs in a book from one day or one month to another, simply by their titles and from the look of the pages. For him, the general effect of each page constituted a special scheme, whereas to us, who perceive each word or even each letter analytically, all the pages of a book are exactly alike.[13]

In verbal matters, adults may lose their ability to grasp wholes before examining parts, masking it with superior analytical ability at reading or listening. Nevertheless, we all retain some ability to function without verbal clues. We can recognize a familiar city block even when it has no signs, and we can sense when something is different even when we cannot specify the change.

To be sure, by foregoing analysis we are exposed to certain errors. We are often mistaken in our impression we have been on this block before, as further analysis might clearly show. But in science, as Selye also said, "There is a great deal of difference between a sterile theory and a wrong theory."[14] When lost in a slightly familiar neighbor hood, we need general impressions as quick guides to more familiar territory. If we are mistaken and find ourselves on the wrong block, the mistake may be readily corrected. If we insist on reading every house number on every block, however, we may miss dinner.

No approach, be it analytic or synthetic, can guarantee a flawless search for understanding. Each approach has its characteristic errors. By taking the grand leap based on our faith in order of the second degree, we may often be completely wrong, but at least we shall find out soon enough. If time is of the essence, the slow-but-sure method of analysis may only guarantee that we cannot possibly arrive on schedule. Lord Rayleigh once remarked that:

> It happens not infrequently that results in the form of "laws" are put forward as novelties on the basis of elaborate experiments, which might have been predicted a priori after a few minutes consideration.

This is the characteristic error of analysis. Though in the long run it always rewards our patience, in the long run, as Keynes noted, we shall all be dead. Therefore, those who are impatient with precise methods are attracted to the general systems approach, but mere impatience is not sufficient. To be a successful generalist, one must study the art of ignoring data and of seeing only the "mere outlines" of things.

Perhaps the nature of this prescription will be better understood if we look at its very antithesis the Austrian school inspector described by Wertheimer[15]:

> The events are said to have happened in a small Moravian village in the time of the old Austrian empire. An inspector from the Ministry of Education arrived one day to visit the school room. It was part of his duty to make such periodic inspections of the schools. At. the end of the hour, after he had observed the class, he stood up and said: "I am glad to see that you children are doing well in your studies. You are a good class; I am satisfied with your progress. Therefore, before I go, there is one question I would like to ask: How many hairs does a horse have?" Very quickly one little nine-year-old boy raised his hand, to the astonishment of the teacher and the visitor. The boy stood up, and said: "The horse has 3,571,962 hairs." The inspector wonderingly asked: "And how do you know that this is the right number?" The boy replied: "If you do not believe me, you could count them yourself." The inspector broke into loud laughter, thoroughly enjoying the boy's remark. As the teacher escorted him along the aisle to the door, still laughing heartily, he said: "What an amusing story! I must tell it to my colleagues when I return to Vienna. I can already see how they will take it; they enjoy nothing better than a good joke." And with that he took his leave.
>
> It is a year later, the inspector is back again at the village school for his annual visit. As the teacher was walking along the aisle with him to the door, he stopped and said: "By the way, Mr. Inspector, how did your colleagues like the story of the horse and the number of his hairs?" The inspector slapped the teacher on the back. "Oh, yes," he said. "You know, I was really very anxious to tell this story and a fine

> story it was—but, you see, I couldn't. When I got back to Vienna I wasn't able for the life of me to remember the number of hairs."

The Nature of General Systems Laws

> It will be objected that this sharpness or clarity involves certain distortions or misrepresentations, depending on over-simplifications. But this is the perennial dilemma of the teacher: the teaching of facts and figures vs. the teaching of truth. To convey a model the teacher must reify and diagram and declare clearly what cannot be seen at all. The student must "learn" things in order to realize subsequently that they are not quite the way he learned them. But by that time he will have gotten into the spirit of the matter, and from this he may arrive at some approximation of the truth, an approximation he will continue to revise all his life long.[16] - Karl Menninger

We have so far discussed the role of analogy, category schemes, generalization, and other tools of general systems thought. Now we should like to explain the use of "laws" throughout this book. Before doing so, it will be necessary to remind ourselves of some aspects of scientific laws, aspects that are not always emphasized in standard works.

In particular, we want to be reminded that:

> The paradigm of a scientific assertion is "If so ... then so."[17]

One of the reasons we forget the conditional nature of scientific laws is that those laws are often stated in a shorthand manner, with the "If so ..." part simply dropped or abbreviated. This part must be abbreviated because of the enormous length it would have if we seriously attempted to write it all out. For example, one way of stating the First Law of Thermodynamics is:

> Total energy in a system is constant.

We could elaborate this statement in operational terms by something like this:

> If we have a system to which energy is neither brought nor taken away, and if we make measurements of the total energy of that system, while in the process of measurement neither bringing nor taking away energy, then every measurement will give us the same value.

This statement could be elaborated further, but it is clumsy enough as it stands. Certainly it would be harder to remember than the previous statement, and trying to be even more precise would only make it worse.

Still, we sometimes need very precise statements of the "if so" conditions under which a certain "then so" will hold. For instance, suppose we do measure the energy in a system and find that all measurements do not give the same value. We may then conclude:

> the Law of Conservation of Energy does not hold for this system;

or

> some energy was brought in or taken away;

or

> our measurement was not correct.

Most likely we shall preserve the law, for the law represents a codification of a great many previous experiments. Although, in theory, one negative experiment would force us to reject the Law of Conservation of Energy, in practice we shall probably do no such thing.

In the first place, we are most likely to suspect our measurements. In that case, the law may be used as a rule for defining "measurements of the total energy":

> If we have a system to which energy is neither brought nor taken away, and if we make measurements of some attribute of that system, without bringing or taking away energy, and if the attribute measured is not constant, then that attribute is not the total energy of the system.

Alternatively, we may conclude that some energy was taken away or brought to the system, in which case the law is a partial definition of a "closed system," or a reminder to look for an "opening":

> If we make measurements of the total energy of a system and if we find that the total energy changes from measurement to measurement, then the system is not closed.

A more drastic approach would be to change the definition of "total energy" so as to preserve the law. This was actually done to preserve the law when Einstein made his famous assertion about the equivalence of matter and energy:

$$E = mc^2$$

This equation could be interpreted as saying that matter can be converted into energy (and vice versa), or that matter is a form of energy. The second approach preserves the Law of Conservation of Energy. The first also preserves it, but with an added "if so" clause:

> ... and if no conversions between matter and energy take place within the system .. .

We see, then, how many different roles laws play in scientific thinking. They prescribe guides to measurement, they define the terms within them, they remind us to look for things we have not noticed, and they predict behavior. They also provide a sort of rallying point around which we can discuss ways of measurement, the meaning of terms, and heuristic, or problem-solving technique. The same law can do all of these things, though obviously not at the same time. Learning to think scientifically is not just a matter of remembering the laws, but of knowing when to use which law and in what way.

If a law has many if-so clauses, it will be difficult to remember when to use it, for each if-so clause limits the scope of application. The fewer the if so clauses, the more general the law. When faced with the problem of adding an if-so clause or changing definition of a term, the choice will usually be made toward redefining the term. Thus, while it is claimed that the Law of Conservation of Energy has withstood more than a century of testing, it has only been salvaged by a succession of redefinitions of "energy."

When measurements are found incompatible with a well-established law, the last thing to be changed is the law itself--contrary to the popular impression that one negative case invalidates a scientific law. Indeed, we might well forge a new general systems law that says:

> When the facts contradict the law, reject the facts or change the definitions, but never throw away the law.

This could be called The Law of Conservation of Laws.

Science obeys the Law of Conservation of Laws because scientific laws contain too much valuable information simply to be jettisoned when they are "invalidated." In the process of preservation, however, laws may become pickled in great lists of conditions, definitions, and exceptions. Eventually, they lose their original flavor as shorthand summaries of inductive knowledge, even as they yield more precise answers to ever-narrower questions.

"General systems laws," as used in this book, are not designed to yield answers; therefore, they can afford occasionally to be wrong. Presumably, general systems laws will never be used for precise conclusions without checking the insights they provide. Therefore, rather than make general systems laws more precise by pickling them with qualifying conditions, they are made more memorable by keeping their original flavor free of complications. Moreover, wherever possible, we try to increase their memorability by clever phrasing or a catchy name. Perhaps we would do bettor to call them "aphorisms," but, then, "law" is such a catchy name.

For some unknown psychological reason, one of the most memorable ways to phrase a law is in the form of a prohibition, a contradiction, or even better, a paradox. One formulation of the Law of Conservation of Energy was:

> It is impossible to build a perpetual-motion machine.

When it was discovered that the First Law did not exclude a certain kind of perpetual motion—though the Second Law did—the definition of "perpetual-motion machine" was changed to what we now call a perpetual-motion machine "of the first kind." What that means, of course, is that the kind of perpetual-motion machine we call the "first kind" is the kind the First Law says we cannot build—a neat application of the Law of Conservation of Laws.

Many of our general systems laws will be stated in several forms: as definitions, as measurement guides, as heuristic devices, and particularly in the more memorable negative forms. Often we shall present the law in an approximate form in order to simplify the discussion, and to draw attention to the conditions that will accrue to the more elaborate form without burdening the reader's mind with too many "first kinds," "second kinds," and so forth. A wrong law may be useful, but no law is useful if you don't remember it when you need it. Therefore, our laws should not be taken as constraints to thought, but as stimulants.

The memorability of our laws will also be enhanced if we do not fail to give illustrative examples. We hope to avoid the disease of hollow generalization, for it is not just the large generalization, but "the large generalization limited by a happy particularity, which is the fruitful conception."[18] For each law, we shall endeavor to give not just one, but two "happy particularities," sometimes as research problems at the end of the chapter. Anything that aspires to the highfalutin' title of "general systems law" should be demonstrably applicable to at least two concrete cases—the one from which it came and one more for security.

General systems literature has not always conformed to this principle. Perhaps, then, we should elevate it to a general systems law, which we might call the Law of Happy Particularities:

> Any general law must have at least two specific applications.

or, as Elise Boulding tells her husband whenever he flies too far from facts:

> If you are going to be the great integrator you ought to know something.[19]

Out of courtesy to my colleagues who have violated this law, I shall refrain from citing two specific applications. In doing so, I am providing one example myself. The reader will surely find others as she proceeds.

Overgeneralizing is the error of a fool or a hero, depending on your point of view. But just as an excess of courage leads to overgeneralizing, so does an excess of caution lead to under-generalizing. Balancing the Law of Happy Particularities is the Law of Unhappy Peculiarities:

> Any general law is bound to have at least two exceptions.

or, to put the emphasis in a negative way:

> If you never say anything wrong, you never say anything.

The reader is invited to look for the two exceptions to the Law of Unhappy Peculiarities.

While the Particularities and Peculiarities Laws are applicable to any generalizing behavior, there are also laws applying to the typical "systems" part of general systems thinking. Again, there are two complementary errors —composition and decomposition. An example of a composition error is this:

> I stand on a bridge and spit in the river. Seeing that it makes no noticeable difference in the purity of the water, I go to the polls and vote against the municipal bonds for a new water-treatment plant.

An example of a decompositional error, on the other hand, would be this:

> I stand on the bridge and notice that the river is clean, so I conclude that nobody spits in it.

To warn us from these two errors, we have two laws. The Composition Law, which goes back at least to Aristotle, says:

> The whole is more than the sum of its parts.

The Decomposition Law, on the other hand, says:

> The part is more than a fraction of the whole.

Notice that the two laws seem contradictory, which should make them hard to forget.

Why should we want to remember them? Of what use, really, are general systems laws? Because they are so general, and because systems are so complex, we shall not find them very helpful at making exact predictions. But because systems are so general, and because systems are so complex, general systems laws can help us avoid the grand fallacy on the way to an exact prediction. "It isn't what we don't know that gives us trouble, it's what we know that ain't so."

Varieties of Systems Thinking

> The main role of models is not so much to explain and to predict though ultimately these are the main functions of science as to polarize thinking and to pose sharp questions. Above all, they are fun to invent and to play with, and they have a peculiar life of their own. The "survival of the fittest" applies to models even more than it does to living creatures. They should not., however, be allowed to multiply indiscriminately without real necessity or real purpose.[20]"

In this remarks on mathematical models, Mark Kac provides an outline of the joys, uses, and applications that could correctly be applied to the models of general systems. He implies that there are three sorts of activities involving models:

1. Improving thought processes—"to polarize thinking and to pose sharp questions"
2. Studying special systems—"real necessity or real purpose"
3. Creating new laws and refining old—"to invent and play with."

We can use this framework to review the "general systems approach" as outlined rather loosely in this chapter, and as a preface for the remainder of this work. We can start with improving thought processes, for this contribution will be most used by most people. We are not all engaged in studying special systems, and even fewer of us are engaged in creating new general systems laws, but most of us are engaged in thinking.

The contribution of the general systems approach to thinking is perhaps best seen in the way a generalist approaches some new subject. Students should be particularly interested in this application of general systems, for they have new subjects thrust upon them each semester. Unhappily, the trauma from four years of new subjects often paralyzes the mind, and many graduates remove their cap and gown uttering an oath never again to learn a new subject. The general systems approach promises to make learning new subjects less traumatic, so education may begin to give a taste for, rather than a disgust with, learning.

So, how does the generalist approach a new subject? Suppose, for instance, that he decides he must learn something about economics. He might find a textbook on the subject by seeing what is used in the introductory course in the local university, or he might simply browse among the economics books in his local library. When he opens such a book, however, he is not starting from scratch. He knows many general paradigms for thought and communication, and he is clever enough to penetrate their economics disguise.

For example, if he happened to pick up Samuelson's Economics,[21] he would find in Chapter 2 a variety of "production-possibility" curves, such as we see in Figure 2.2.

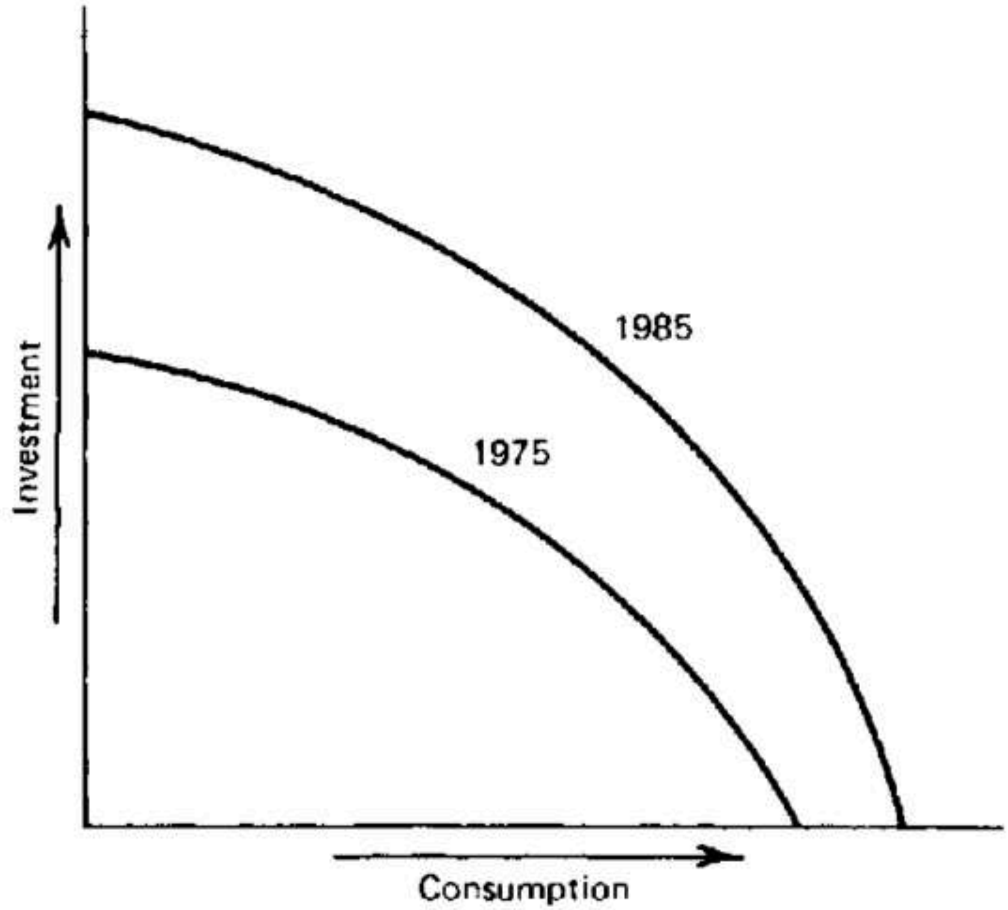


Figure 2.2. The economist's "production possibilities" are the generalists "state space."

Almost without explanation, he recognizes these as special cases of a more general representation, the state space (which we shall discuss in a few chapters). What the economist calls "the production-possibility frontier," the generalist recognizes as a family of systems all possessing a certain property, and any point on that curve representing a particular system within that family. He recognizes that the movement from one point to another in this state space is what he calls a line of behavior, so that all he knows about such lines may immediately be transferred to this new situation.

Because of the nature of general systems laws, the content transferred may actually be quite small, from the economist's point of view. Nevertheless, the generalist is already at an advantage over his colleagues because, like the tourist in Bangkok, he is not afraid of the unfamiliar. He has named the beast, and he has thus begun to tame it.

The generalist, then, has certain categories of thought that—because of their general nature—are not going to fail him completely in the study of any new field. He has special words in his vocabulary, words such as stability, behavior, state space, structure, regulation, noise, and adaptation, which he can relate to the words of the specialist. If he is wise, he will refrain from saying, "Oh, that's nothing but a line of behavior in a two-dimensional state space." Instead, he will make the translation internally and then surprise the specialist with the "sharp questions" he is able to ask.

When the generalist encounters laws in the special field, he will often be able to relate them to the general systems "laws" he knows. He identifies the special assumptions transforming his general systems laws into laws of economics, or whatever. For instance, he will immediately recognize the economist's Law of Diminishing Returns as a special instance of the Law of Limiting Factors. Of course, he does not boast that the economic law is "only a special case" of the general law, especially since he realizes the general law was probably dependent on the economic law for its discovery. While for him the one law is a special case of the other, in genesis the general systems law was probably induced from the economic.

The general systems approach, then, can engender a parsimony of thought for the study of subjects. A similar economy is introduced in the study of situations, or special systems. In our experience, the general systems approach has provided a starting point for the study of myriad information systems,[22] complex machines,[23] social systems,[24,25] individuals and work groups,[26] and systems for education.[27] Others have found the general systems approach useful in meteorology, political science, biology, sociology, psychiatry, ecology, engineering, and, in fact, just about any discipline with a name. The reader who is interested in specific examples will find a gold mine in the collected yearbooks of the Society for General

Systems Research.[28] She should be warned, however, that these collected articles represent but a small fraction of the applications of general systems thinking to special systems situations, because most of the time the thought is applied and not written up for publication in some journal. No, most of the application of general systems thinking is not done by professional academics, but by ordinary people going about their daily business.

The General Systems Yearbook also contains examples of the third kind of general systems activity—creating new laws and refining old. This activity we call general systems research, as opposed to general systems thinking and general systems application. Of the three activities, general systems research is practiced by the smallest number of people, and therefore is really the interest of specialists. We cannot say much more about how general systems research is conducted than we can say about how research is conducted in other fields. We do have a few general systems laws, such as the Law of Happy Particularities, which are really laws about how to conduct general systems research. Mostly, however, research in general systems is carried out in the same mysterious ways as research in any discipline.

The general systems movement did not start out as a discipline but is probably ossifying into one. In the foreword to his 1969 book,[29] von Bertalanffy surveyed three decades of general systems activity by warning that we may find

> ... systems theory—originally intended to overcome current overspecialization—another of the hundreds of academic specialties. Moreover, systems science, centered in computer technology, cybernetics, automation, and systems engineering, appears to make the systems idea another—and indeed the ultimate—technique to shape man and society ever more into "megamachine" ...

Years ago, in the innocent days before the move toward academic bureaucratization and military funding had begun to penetrate the Society for General Systems Research, I received a letter addressed to "The Society for Gentle Systems Research." As I watch in horror what is becoming of the "systems movement," I often recall that letter, and wonder whether there will still be room for the gentle people, and whether we shall perhaps help to build not "megamachines," but gentle systems.

How will it come out? Most likely, it will come out the way all movements come out, by killing its prophets and reversing their words. It has already reached the point of no return, but like any fanatic, I cannot resist making one last try. This work, which tries to bring general systems back to the ordinary people for whom it was conceived, is my desperate gesture.

QUESTIONS FOR FURTHER RESEARCH

Anthropology

In Mexico, there is a village of blind people, which was studied by a blind anthropologist. Speculate on the cultural categories this village might have different from a similarly situated village of sighted people. Would the blind anthropologist find his blindness gave him more in common with the villagers than his being Mexican would have? What would a one-eyed anthropologist have found different if he had studied this village?

History of Science

A summary of organismic analogies throughout history is given in: Howard Becker and Harry Elmer Barnes, Social Thought From Lore to Science, 2nd ed. Washington, D.C.: Harren Press, 1962. Has organismic thought ever been helpful to the advance of science? How would you account for the violence with which vitalists and mechanists are always at each other's throats? Can you identify similar controversies going on today?

Molecular Biology

One of the more recent scientific revolutions has been in molecular biology, where one of the great landmarks (for which its authors received the Nobel Prize) was the double-helix model of DNA. We are fortunate in having the highly personal account given by one of them: James D. Watson, The Double Helix. New York: Atheneum, 1968 plus a number of other accounts issued, as it were, in rebuttal to what some have called a most unflattering account of the scientist at work. Using examples from this book and the controversy surrounding it, discuss the changing paradigms in molecular biology, and what they meant in practical terms to these workers.

Order of the Second Degree

"Order of the second degree" is a slippery concept. We arc never sure of the source of the order we see, and a nice example of the difficulties we encounter in seeking order in order is the observation that first digits in all sorts of tables tend not to be evenly distributed but overly laden with the smaller digits, especially the ones. Ralph A. Raimi has surveyed this problem in a Scientific American article entitled "The Peculiar Distribution of First Digits" (December 1969, 221, 15). Study this problem and give your opinion as to the source of this order of the second degree.

Laws about Laws

As the inventory of human thought accumulates vast piles of ideas, people make attempts to manage the collection. One form of attempt is to catalog the great ideas, and record their development, as in Philip P. Wiener, Dictionary of the History of Ideas. New York: Charles Scribner, 1973. Using the theories and ideas presented in this volume as the source of your data, derive some general systems laws—which are, after all, another approach to managing the same inventory.

Order of the Third Degree

We now have two pairs of general systems laws dealing with errors. Examine the structure of these laws and see if you can make an appropriate leap of faith.

Environmental Pharmacology

Patients are often, given several drugs at the same time, and sometimes the combination results in an undesirable effect because one drug inhibits or stimulates the metabolism of the other.

Sometimes the "drugs" are given unintentionally, to people who are not "patients." As the number of different chemicals appearing in our environment increases, what sorts of effects are likely to "emerge," to what extent can these emergences be predicted, and to what extent will they be predicted by the people putting the chemicals in the environment?

Reference: A.H. Conney and J.J. Burns, "Metabolic Interactions Among Environmental Chemicals and Drugs." Science, 178, 576 (November 1972).

READINGS

Recommended

Kenneth Boulding, "General Systems as a Point of View." In Views of General Systems Theory, Mihajlo D. Mesarovic, Ed. New York: Wiley, 1964.

H. G. Wells, "The Country of the Blind." In The Country of the Blind and Other Stories. New York: Nelson, 1913 (also reprinted in several collections, such as The Complete Short Stories of H.G. Wells). (First edition, 20th impression) London: Bern, 1966.

Suggested

Thomas Kuhn, The Structure of Scientific Revolutions. Chicago: University of Chicago Press, 1962.

James D. Watson, The Double Helix. New York: Atheneum, 1968,

Chapter 3. System and Illusion

The real world gives the subset of what is; the product space represents the uncertainty of the observer. The product space may therefore change if the observer changes; and two observers may legitimately use different product spaces within which to record the same subset of actual events in some actual thing. The "constraint" is thus a relation between observer and thing; the properties of any particular constraint will depend on both the real thing and on the observer. It follows that a substantial part of the theory of organization will be concerned with properties that are not intrinsic to the thing but are relational between observer and thing. - W. Ross Ashby[1]

A sweet disorder in the dress

Kindles in clothes a wantonness:

A lawn about the shoulders thrown

Into a fine distraction,

An erring lace, which here and there

Enthralls the crimson stomacher,

A cuff neglectful, and thereby

Ribbands to flow confusedly,

A winning wave (deserving note)

In the tempestuous petticoat,A careless shoe-string, in whose tie

I see a wild civility,

Do more bewitch me, than when art

Is too precise in every part.[2]

- Robert Herrick

A System Is a Way of Looking at the World

> The understanding of the symbol did not necessarily pre-suppose an understanding of its conventional application. This is why I put up such a strong resistance when grandmama wanted to teach me the notes of the scale. Using a knitting needle, she pointed to the notes on the stave; this line, she tried to explain, corresponded to that note on the pianoforte. But why? How could it possibly do that? I could see nothing in common between the ruled manuscript paper and the keys of the instrument. Whenever people tried to impose on me such unjustified compulsions and assumptions, I rebelled: in the same way, I refused to accept truths which did not have an absolute basis. I would yield only to necessity; I felt that human decisions were dictated more or less by caprice, and they did not carry enough weight to justify my compliance. For days I persisted in my refusal to accept such arbitrary regulations, But I finally gave in: I could finally play the scale; but I felt I was learning the rules of a game, not acquiring knowledge. On the other hand I felt no compunction about embracing the rules of arithmetic, because I believed in the absolute reality of numbers.[1] - Simone de Beauvoir

What is a system? As any poet knows,
a system is a way of looking at the world.

The system is a point of view—natural for a poet, yet terrifying for a scientist! As soon as she recognizes the path we are about to take, she rebels, like Simone de Beauvoir, as if we are about to impose some falsehood on her. To speak of systems in this way is to play a game, not to acquire knowledge. Knowledge is "truth." Knowledge is "reality." If two scientists viewing the same scene have different "systems" then science will be "no better than" poetry, where one man can see a "wild civility" in another man's "sloppy clothes."

Very well, let us assault fears. Look at Figure 3.1. What do you see? A young maiden, "come forth, like the spring-time, fresh and green ..."? A crinkled hag, whose rose-buds are long ago gathered and whose youth and blood are spent? No matter. Whichever you see, look again until you see the other. If you see neither, all the better for my argument.

Figure 3.1. What do you see?

I have used this figure for several decades as a demonstration of the power of "point of view." Year after year, some see youth; some, age; a few, nothing. What is important in this demonstration is not what we see, but how we feel about what we see. After each class, students come to my office to coax me into admitting I know it is really an old (young) woman and that those who see a young (old) woman were fooled. But they are the fools—for believing that other people's points of view are foolish, or less true than their own.

Some students are more humble. They come merely to find out which is the true picture. They have seen the error of egocentrism and are operating on a higher plane. Their foolishness is thus all the greater, for they fail to see that the concept of observer-independent truth is the ultimate egocentrism. If there were an independent truth, who are they to know it?

Egocentrism is a form of animism, and animism, in turn, of vitalism. Through centuries of painstaking effort, scientists have worked to rid themselves of thoughts like these:

- If I were a planet, sailing through space, how would I be attracted to the great mass of the sun?

If they cannot help thinking that way, at least they have learned to keep it to themselves. Biologists face the same problem, but it is more painful to them, for they feel closer to their subjects:

- If I were an oyster, would I be irritated by a grain of sand?

and closer

- If I were a frog, would I be frightened by a shadow?
- If I were a dog, would I like a pound of raw hamburger?

Psychologists, of course, have it even worse.

Ultimately, though, we all share the difficulty of ridding ourselves of such thoughts as these:

- If I were nature, would I tell lies?
- If I were nature, would I throw dice?

How would we known how nature (read "reality") feels? Or if there is any more meaning in speaking of how nature feels than in empathizing with a planet, an oyster, a frog, or a dog?

Each such animism has barred the way to scientific progress, yet each would have been far easier to eliminate had it been totally useless. We can gain insight into the ideas of force and motion from our internal responses to situations. Newton could do this, and we still teach physics that way.

We can gain insights into biological laws from such subjective experiences as irritation, fright, and liking. And we can make progress in science by believing in the reality of the external world.

At this point, the "realists" in such a discussion will quote Einstein:

> The belief in an external world independent of the percipient subject is the foundation of all science.[4]

This quotation might have been used instead of Figure 3.1, for we each read it according to our preconceived notions. Note well that Einstein did not say

> An external world independent of the percipient subject is the foundation of all science.

Einstein was a careful man, a careful scientist. He did not say that an external world is essential, but that "belief in" an external world is essential. And he was exactly right. Yet it was Einstein who put forth the Theory of Relativity, which rocked the scientific world just because it was based on the premise that we could only know the external world through our perceptions.

"Belief in an external world independent of the percipient subject" is a heuristic device, a mental tool to aid in discovery. Like all heuristic devices, it cannot tell us when and where it can be successfully applied. We learn a little rhyme—"I before E, except after C"—that helps us learn to spell in English, but fails us on "either and neither...." Or, as the little boy said, "Today we learned how to spell 'banana,' but we didn't learn when to stop."

We have encountered this idea before. Mechanics alone cannot say which systems will yield to mechanical analysis. Mathematics cannot tell us its range of successful application. In honor of that little speller boy, we can elevate his idea to a principle, The Banana Principle:

> Heuristic devices don't tell you when to stop.

We have a scale of ascending values for heuristic devices, depending on how far you go before you must stop. Going from the narrow to the broad, we find: "idea," "concept," "rule," "principle," "law," "reality," "truth." The further along this scale, the less we notice that a heuristic device is only a device. We forget the Banana Principle and think that we can go on using the device forever. The more success we have, the more sure we become.

But the more sure we are, the more likely we are to suffer an illusion, for the illusion consists

> ... in the conviction that there is only one way of interpreting the visual pattern in front of us. ... The most famous story of illusion in classical antiquity illustrates the point to perfection; it is the anecdote from Pliny, how Parrhasios trumped Zeuxis, who had painted grapes so deceptively that birds came to peck at them. He invited his rivals to his studio to show them his own work, and when Zeuxis eagerly tried to lift the curtain from the panel, he found it was not real but painted ...[5]

Our aim is to improve thinking. "The belief in an external world independent of the percipient subject" is one of the most powerful thinking tools we have. We have not the slightest intention of discarding such a powerful tool, any more than we intend to discard analogical thinking. Nor could we discard it if we wished to. We shall soon enough lapse into speaking in the more familiar terms of an independent reality—for a while, though, we should like to dwell on the complementary tool: relational thinking.

There may actually be "real objects" out there in the world, but if there are, it is not because we perceive them as real. Perception responds just as well to illusion as to reality, and many of these perceptions are so deep that we are essentially powerless to unlearn them, even in illusion situations.[6] Similarly, there may indeed be "real laws of nature," but if there are, our very strong belief in their existence may be preventing their discovery. Therefore, let us see what we can learn if we occasionally suspend belief in "independent reality," never forgetting, of course, that this, too, is but a heuristic device.

In this regard, there is a pertinent story about the great American linguist and anthropologist Edward Sapir, who had allegedly been working with an informant on an American Indian language with a grammar he was having trouble sorting out. Finally, he felt he had caught on to the principles involved, and to test his hypothesis he began making up sentences in the language himself. "Can you say this?" he would ask his informant and would then produce his utterance in the informant's language. He repeated this several times, each time composing a different expression. Each time his informant nodded his head and said "Yes, you can say that." This apparently was confirmation that he was on the right track. Then an awful suspicion crossed Sapir's mind. Once more he asked "Can you say this?" and once more received the answer "Yes." Then he asked, "What does it mean?" "Not a darn thing!" came the reply.'

It is possible to speak or write perfectly acceptable things that do not mean anything. If we study some meaningless statements, we shall better understand how to speak meaningfully, for the exception does not prove the rule, it teaches it.

"The exception proves the rule" is an excellent starting point for a discussion of meaningless utterances. A "proof" in its original sense was a test applied to substances to determine if they are of satisfactory quality.

We retain this meaning in the "proofs" of printing or photography, in the "proof' of a whiskey, and in "the proof of the pudding." Over the centuries, the meaning of the word "prove" began to shift, eliminating the negative possibilities to take on an additional, sense:

> To establish, to demonstrate, or to show truth or genuineness.

Although the meaning of the critical word was changing, the saying was preserved. As a consequence, we have to contend with illiterates who delight in parroting

> The exception proves the rule

whenever we contradict one of their favorite prejudices.

Statements in a language have meaning only in relation to certain accepted meanings of the words in them. "Accepted meanings" implies somebody doing the accepting—an observer. If I say the exception proves the rule in front of a large class, there will be a division in understanding, just as there was a division of perception over Figure 3.1. Some will believe I have uttered nonsense, while others will understand:

> The exception puts the rule to the test.

The appearance of absolute meaning in certain statements comes because there is almost universal agreement on the meanings it contains. Consider, for example, the following passage:

> General Motors exists to put out cars, not metal scraps, although it extrudes both. Universities exist to produce educated persons and scholars, not retired professors or academic failures.[9]

That seems incontrovertible, but now consider what we would have thought had Miller written:

> Beavers exist to control floods, not to produce piles of wood chips. The oceans exist to produce fresh fish, not mud deposits or dead whales washed ashore.

With "man-made" systems, we talk about "purpose," whereas such language is forbidden for "natural" systems. Yet much of the dissatisfaction with our man-made systems stems precisely from disagreement about what the "purpose" of the system is: that is, what the system "really" is. The answer, of course, is that the system has no "purpose," for "purpose" is a relation, not a thing to "have." To the junk dealers and recyclers, General Motors does exist to put out scrap metal, yet the stockholders probably couldn't care less whether General Motors is producing cars or string beans, as long as it is producing profits.

Or consider the university. There has been much talk about university reform, but we have seen little action. Why not? At least part of the reason is the failure to recognize that a university is many things to many people. Certainly one of the most important social functions of the American university is to turn out academic failures, people who will be resigned to taking less lucrative and less prestigious roles in the class structure. As I can attest from inside observation, some professors know that the real reason for our institution is precisely to provide us with graceful retirement—even on the job!

What Miller is talking about, then, is not the reason for existence of these institutions, but a more or less official public reason, much like the public agreement on the meaning of a word. Miller knows this, and need not qualify every statement to death, as in:

> From the point of view of most people, most of the time when they think about General Motors they think in terms of producing cars, even though some people, some of the time, have different points of view about the purposes of General Motors.

It is much more forceful to speak in absolute terms, as if there were one single real true "purpose" of General Motors. Most of the time, absolute speech will not get us into trouble, though we may learn something if we bother to examine the relative nature of some seemingly absolute statements.

A simple example of absolute thinking is seen in answers to the question:

> What happens to the reading on a candy thermometer if we suddenly plunge it into hot water?

Everyone knows the reading will rise, but if you try this experiment and observe very closely, you will see that before the rise, the reading actually drops for a moment. Few people have ever observed this drop, not because it is difficult to see, but because they are not looking for it. And why are they not looking for it? Because they know the reading will rise.

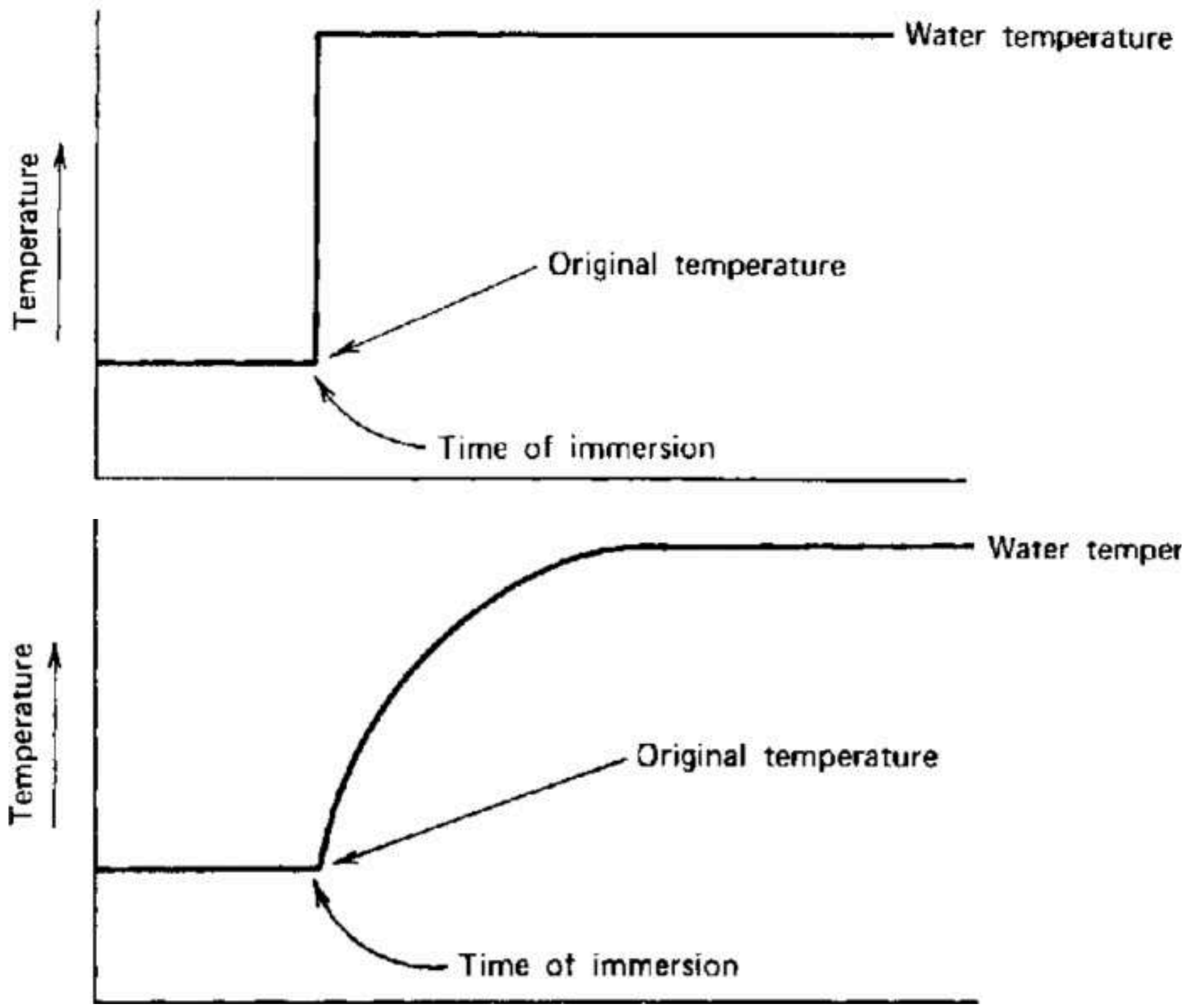
They may know it will rise because they have been told so, in which case they will more easily accept being told otherwise. But those who know the "theory" behind the thermometer will be harder to convince. They know "better"—which is to say that their illusion is stronger. They will argue that the reading must rise because

> ... the reading measures the expansion of the mercury, and the mercury expands when heated.

There are at least two concealed absolutisms in this simple statement. One has to do with the time scale of the observation. The statement seems to imply instantaneous expansion of the mercury, but what it could more precisely say is

> ... and the mercury expands as its temperature rises, which takes a relatively short time on the human time scale.

We know, of course, that it does take time for the mercury to warm, otherwise we would not have to hold a mercury thermometer in our body for several minutes when we take our temperature. (Figure 3.2)



Time -->

Figure 3.2. Two models of a rising mercury column.

The time scale explains why the rise may follow a curve such as shown in Figure 3.2, but why does it fall first? The answer lies in the second concealed absolutism, "the expansion of the mercury." The reading does not measure the expansion of the mercury, but the difference in expansion between the mercury and the glass. That is, it measures the relative expansion of the mercury, not the absolute expansion.

When we plunge the thermometer into hot water, the glass, being on the outside, warms first, and therefore begins to expand first. Since the the mercury expands..." (instantly)

"... the mercury expands as the temperature rises..."
mercury has not yet begun to warm, so the mercury has not expanded and thus begins to fall in the tube of the candy thermometer. (Not in a fever thermometer, of course, which prevents the mercury from falling back in the bulb, so as to hold the highest reading. In any case, you should never plunge a fever thermometer into hot water.) The resulting behavior is something like that in Figure 3.3, which indeed shows a drop before the rise.

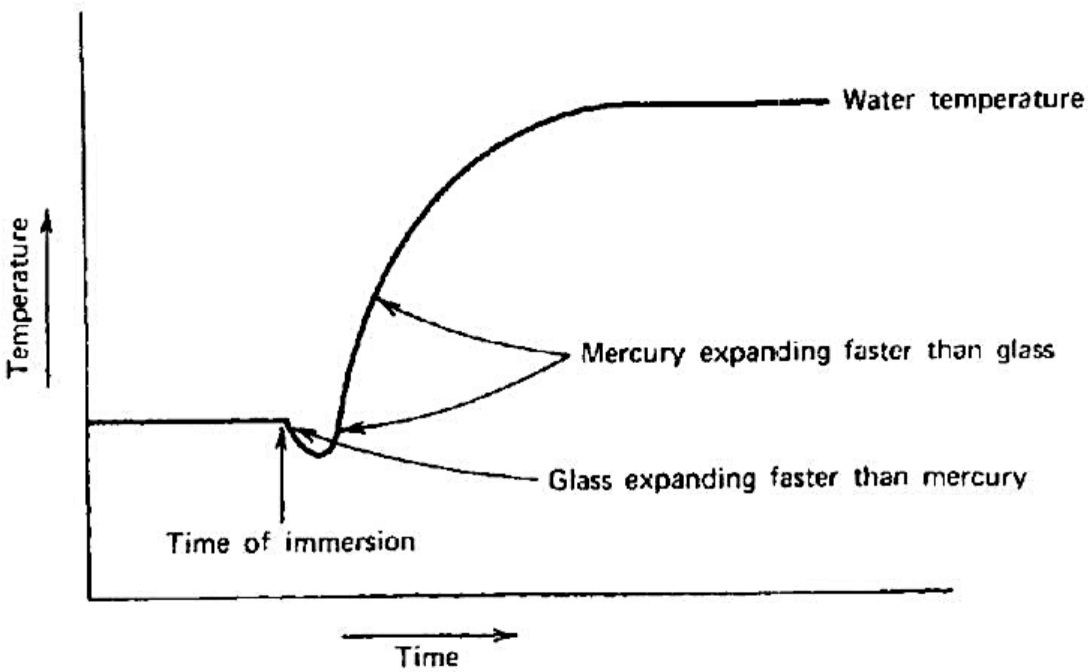


Figure 3.3. "... the difference in expansion between mercury and glass ...

A thermometer, like our language, is an instrument for understanding our world. When we use the thermometer for simple things, we can use simple language to describe what it does. We do not care how the thermometer "really" behaves—we are satisfied if it behaves the way our simple language says. Glancing at the thermometer mounted outside our window, we say "the temperature is 17 degrees." We are not concerned with time-scale effects, even though the temperature might be just changing.

Taking our body temperature, however, we become aware of the time scale because we must use the instrument differently. Finally, when we use a thermometer as part of an automatic-control system for a nuclear power plant, we may need to refine our view to the level of Figure 3.3 and beyond.

One more example: Systems writers sometimes speak of "emergent" properties of a system, properties that did not exist in the parts but are found in the whole. Other writers attack this idea, saying that emergent properties are but another name for vital essence. Moreover, others can support their arguments with specific examples of "emergent" properties that turned out to be perfectly predictable. Which is right?

Both are right, but both are in trouble because they speak in absolute terms, as if the "emergence" were "stuff' in the system, rather than a relationship between system and observer. Properties "emerge" for a particular observer when he could not or did not predict their appearance. We can always find cases in which a property will be "emergent" to one observer and "predictable" to another.

Demonstrations that a property could have been predicted have nothing to do with "emergence." By recognizing emergence as a relationship between the observer and what he observes, we understand that properties will "emerge" when we put together more and more complex systems. In other words, the property of "emergence" no longer emerges for us, though it surprises those who take the absolute view. They may demonstrate afterwards that they need not have been surprised—small consolation if the emergent property was an explosion.

How can we avoid fallacies of absolute thought? The key, I believe, is always to remember the human origins of our models, words, instruments, and techniques. Absolute thought is a simplification serving us well at certain times, on a certain scale of observation, and for certain purposes. When we say something or when we think in a certain way, we are usually following conventional patterns. Those patterns will work out well if the situation remains conventional, which most of the time it will. (Isn't that what we mean by "conventional"?)

The conventional situation is well characterized by the following story:

> A minister was walking by a construction project and saw two men laying bricks. "What are you doing?" he asked the first.
>
> "I'm laying bricks," he answered gruffly.
>
> "And you?" he asked the other.
>
> "I'm building a cathedral," came the happy reply.
>
> The minister was agreeably impressed with this man's idealism and sense of participation in God's Grand Plan. He composed a sermon on the subject, and returned the next day to speak to the inspired bricklayer. Only the first man was at work.
>
> "Where's your friend?" asked the minister.
>
> "He got fired."
>
> "How terrible. Why?"
>
> "He thought we were building a cathedral, but we're building a garage."

In the workaday world, it seems, we must be practical, keep our eye on the ball, and not get lost with our head in the clouds. If we are going to build garages, we must follow our orders and lay bricks the way we always do. But if we are building a cathedral, then we must look behind what we conventionally do.

Who decided to build a garage? To build cars? To turn out educated persons? Who decided that particular modes of thought were more correct than others? Are their decisions still appropriate in this new situation? Our ways of the world have been handed down to us, but not on stone tablets:

> Systems are thoroughly man-made... When we include a given relation in a system, or omit it, we may do well or ill; but such an inclusion creates no truth, and such omission indicates no falsity. The justification for one's procedure, in this respect, is purely pragmatic; it depends upon the relevance of what is included or omitted to the purposes which the system is designed to satisfy,[9]

Because we are here more concerned with building cathedrals than garages, we take the point of view that a system, any system, is the point of view of one or several observers. Whether our view—or their view—is "good" or "bad" can be judged only according "to the purposes which the system is designed to satisfy."

A System Is a Set

> More often than not, the classes of objects encountered in the real physical world do not have precisely defined criteria of membership.[10]
> - L. A. Zadeh

Although any arbitrary way of looking at the world—"a lawn about the shoulders thrown," "an erring lace," "a cuff neglectful"—can be a system, we could never say anything general about truly arbitrary systems. Indeed, we may make a definition:

> Arbitrary systems: Systems about which nothing general can be said, except that "nothing general can be said."

If, then, we are to begin a general systems approach, we must narrow our attention to some nonarbitrary systems, though in such a way as to force attention to the reasons for the nonarbitrariness. These reasons are the source of the order that makes systems thinking possible at all—and the most general of them are the wellspring of general systems thinking.

Nonarbitrariness can come from one of two sources. It could be "out there" in the "real physical world," or it could be in the observer. For the present, we shall focus on the observer. We note immediately that "a lawn about the shoulders thrown," "an erring lace," and "a cuff neglectful" do not form an arbitrary system, for they are seen to belong together by the mind of at least one observer—Herrick. Arbitrary systems, in fact, are hard to find, for as soon as we think of one, it becomes somewhat nonarbitrary.

This argument may sound of the utmost impracticality, but please note it was exactly in this way Freud started on the road to discovery in psychoanalysis. As a matter of fact, nobody has ever demonstrated that he can choose things arbitrarily. Therefore, if we cannot keep structure out of a conscious attempt to make arbitrary choices, we may find that unwanted structure is creeping into other systems by way of the observer.

The role of observer is often ignored in systems writing. The most popular way of ignoring the observer is to move right into a mathematical representation of a system—a so-called "mathematical system"—without saying anything about how that particular representation was chosen. For example, Hall and Fagen[11] give this definition:

> A system is a set of objects together with relationships between the objects and between their attributes.

Where did these objects come from? Hall and Fagen give no clue. They might have dropped from the sky, except we happen to know they came from the mind of some observer.

Hall and Fagen rightly emphasize "relationships" as an essential part of the system concept, but fail to give the slightest hint that the system itself is relative to the viewpoint of some observer. The idea of set is very common in mathematics, but contrary to the impression of precision it gives, it is one of the undefined primitives in most theories. The mathematics of sets (set theory[12]) tells us much about the properties of sets, but tells us nothing about how observers might choose them.

If systems are to be sets of things, the notation of set theory will be a great convenience to us. For instance, Herrick's system could be described mathematically in the following way:

Let X stand for a lawn about the shoulders thrown.

Let Y stand for an erring lace.

Let Z stand for a cuff neglectful.

Then the set in question is denoted by

$\{X, Y, Z\}$

which is not very poetic, but at times, being prosaic can be an advantage.

The primitive act in all conceptual schemes for choosing sets is the simple, finite act of enumeration—we "set" them down, as it were. We may do this by actually producing all the members of the set for inspection, as a chess set or a set of teeth. Usually, however, we specify a set of names, which is taken to represent some set of "things," which might be other names, as in the Herrick example. Ordinarily, it is easier to display the names than the things, as with the set:

{Statue of Liberty, Eiffel Tower, Lenin's Tomb, Great Wall of China}

We may, however, want to use names to designate set members that we could not possibly display, no matter how much effort we expended. Such a set might be

{The hemlock that killed Socrates, a proof of Fermat's last theorem, a critical mass of uranium}

The hemlock no longer exists, the proof has not yet existed (at the time this was written), and that much uranium could not exist in one place long enough for us to observe it and remain alive.

Naming nonexistent set members is naturally a source of potential fallacies. Even more pernicious are those set members that do not exist but whose existence we do not question. The anthropologist may speak of "the kinship terminology rules"; the archaeologist used to speak of "Piltdown Man." The muddles created by erroneous or falsified data fully justify the elaborate safeguards erected by science. On the other hand, data for intuitive thinking have not been subject to these safeguards. The most definite impression of a system may be built on the shifting sands of an imaginary set, even when we have actually enumerated each member.

In any event, we rarely enumerate the collections that form the basis for our thinking. Enumeration, which forms the conceptual basis for the other operations, has perils of its own, but these are as naught compared with the possibilities for mischief in derived methods. Perhaps the nastiest of these methods is the representation of a set by a typical member. This method rests on the assumption that the set can be typified, an idea that goes back at least to Plato.

Platonists argued that the ideal type is a better representation of the set than any enumeration could be, since the actual members of a set could at best be faulty realizations of the ideal type. The ideal type, however, is strictly an observers's mental construction, which may be a useful way to summarize a mass of data. As taxonomists have often discovered, however, it may simply be the primrose path to a decomposition fallacy.

Setting down a typical member or members may he troublesome even when they actually exist in the set, because different people may have different ideas about what set they typify. If I write

{Browning, Blake, Byron, ... }

what do the three dots stand for? Do I mean the set of all English poets whose names start with B? Or all English poets? Or all great English poets? Or all great Englishmen? Or all great poets? Or all great poets with 5 or 8 letters in their names, but no S or U? You could easily think of a thousand sets I might have had in mind. Indeed, in a literary essay, the ambiguity might be intentional. As a basis for scientific work, on the other hand, the method is dangerous, even when the author has a perfectly clear idea and is merely citing typical members as a shorthand. When her own thought is fuzzy, so much the worse.

The three dots in {Browning, Blake, Byron, ... } imply an "and so on" process, a process that follows a rule, a rule that supposedly can be induced without effort from the three exemplars. Rules, either implicit or explicit, form the third method (after enumeration and typical numbers) commonly used to specify sets.

Rules have an advantage over enumeration when the list of members would otherwise be very long. They are superior to typical members when they can be made explicit and operational. Most often, however, explicit rules are used only in mathematical operations, such as choosing the set of even numbers. In dealing with the world, however, rules are often prohibitively difficult to construct.

Computers have a way of exposing flaws in explicit rules. In the attempt to mechanize a classification procedure, we usually discover much more than meets the eye. Cytologists have long been able to select slides of cells with "abnormal" chromosomes; lawyers have always been able to choose precedents "relevant" to a case; and grammarians never had much difficulty classifying sentences according to their "structure." But when they tried to mechanize—to make the rules explicit enough for a computer—cytologists, lawyers, and grammarians discovered that they never knew precisely what they were doing.

Everyone is familiar with classifying sentences according to grammatical structure. In this area, one of the classic computer examples is the sentence:

TIME FLIES LIKE AN ARROW.

Few of us have difficulty recognizing the grammatical structure of this sentence: TIME is the subject, FLIES is the verb, LIKE AN ARROW is the predicate. This seems to be a purely grammatical analysis. It uses only parts of speech, and not the probable meanings of the words, which would make it a semantic analysis.

When using the computer, things are not so easy. TIME may be a noun, but it may also be an adjective, as in TIME CLOCK. FLIES may be a verb, but it could also be a noun, as in FRUIT FLIES. LIKE may be a preposition, but it may also be a verb, as in I LIKE YOU. Given these possibilities, how do we know that the structure of

TIME FLIES LIKE AN ARROW, is not the same as the structure of

FRUIT FLIES LIKE A BANANA.

The answer is that we do not know. We jumped to a conclusion based on a probable semantic interpretation. If the sentence had been

FRUIT FLIES LIKE AN ARROW.

we might have more easily recognized the ambiguity. Instead, this parsing "emerges" from the computer.

Initially, we thought this classification involved only grammatical considerations, but it went much deeper. We were unconscious of the choice process taking place in our own mind, yet even when we feel aware of possible ambiguities, more may be lurking in the shadows. As the computer revealed, there is yet another perfectly grammatical interpretation of

TIME FLIES LIKE AN ARROW.

in which TIME is a verb, and the sentence is imperative, analogous to the form of the sentence:

TIME RACES LIKE A TIMEKEEPER

Without the computer to keep us on our toes, we would remain sloppy grammarians, but unaware of our sloppiness.

There remains another subtle difficulty with rules for choosing sets. When we specify a rule of choice, we imply a "choice set": that is, a set of objects to whose members the rule will be applied. Thus, the set of even numbers may not be the set of all numbers divisible by 2 without a remainder, but the set of all positive integers so divisible (and does that make zero an even number?).

In the same way, a rule for selecting cells with abnormal chromosomes starts with the assumption that the observer can recognize the members of the set of "all cells," normal and abnormal. Choosing this precursor set, however, may be altogether as difficult as dividing it according to the stated rule. Integers are easy enough to recognize, but cells are not so easy. Even integers can be troublesome if they are not displayed explicitly. Consider an equation such as

$$x = 2\ b$$

Clearly, x must be divisible by 2 without a remainder, but in order to determine whether x is an integer (and therefore even) we must know more about b.

Once again, the grammatical classification of sentences by computer reveals hidden assumptions—in this case, the difficulties of an implied choice set. To select grammatical sentences, we must first know how to recognize sentences. To make the choice explicit for a computer, we might say that

> A sentence is a body of text that begins with a capital letter and ends with a period.

Applying this rule to the text

> The length of the rod was 3.572 meters.

a computer would conclude that

> The length of the rod was 3.

is the sentence in question.

One way to resolve the difficulty is by looking ahead to the leftover piece:

> 572 meters.

We might reject the previous recognition because this piece does not meet our criterion of starting with a capital letter. While this "look-ahead" rule will resolve some cases, it will complicate things, and also leave us unable to deal with such a sentence as

> 007 spies.

As we proceed with our analysis, heaping one ad hoc case upon the other, semantic rules upon grammatical rules upon orthographic rules, we begin to learn what poor little Buttercup knew all along—"things are seldom what they seem." Our simplest mental acts are not at all simple. Although not completely rational, neither are they entirely arbitrary. Although our minds can perform them, these mental acts are mostly invisible to us. If we ever succeed in making ourselves more aware of what goes on inside our own heads, the outside half of general systems thinking will be easy.

Observers and Observations

> I have told you these details of asteroid B612 and I have given you its number because of grownups. Grownups love numbers. When you speak to them of a new friend, they never inquire about essentials. They never say to you: "What is the sound of his voice? What are his favorite games? Does he collect butterflies?" They ask you: "How old is he? How many brothers does he have? How much does he weigh? How much does his father make?" Only then do they think they know him.[13] - Antoine de Saint Exupery

We have, up until now, been intentionally vague about what the set underlying a system was a set of. Hall and Fagen, being engineers, made no bones about saying that it was a set of objects. Other writers speak of "parts," "elements," "attributes," "components," or "variables." This discord implies that nobody knows what a system is a set of.

We should not be surprised. All this diversity of names suggests that the members of the system set are one of the undefined primitives of systems thinking. Although systems thinkers talk about these members all the time, they never say what they are, any more than the physicist says what "mass" is. In fact, if we do tell what they are, we are no longer talking about systems in general, but about a particular system.

This situation is well characterized by the story about the three baseball umpires. Each was asked in turn how he called balls from strikes.

The first replied "if they cross the plate between the knees and the shoulders, they're strikes, otherwise they're balls."

The second, however, said "If they're balls, I call them balls. If they're strikes, T call them strikes."

"No," said the third. "They ain't nothin' 'til I call 'em."

In deciding on the nature of our primitives, we are the umpire, the sole arbiter. As long as the members of the set "ain't nothin'," our theorizing is strictly contentless—that is, mathematical. As Bertrand Russell remarked, mathematics gets its appearance of truth from not saying what it is talking about.

A mathematical argument cannot be true or false, but, as the mathematician says, only "valid" or "invalid." "Valid," in effect, means that it is internally consistent. When we set up a correspondence between the mathematical argument and something "real," then we can speak of that argument as being "true" for that correspondence. Mathematicians generally assume that an invalid argument can never be true, no matter what correspondence is made—but that is a philosophical assertion, since it is obviously not a mathematical one.

One of the problems with the mathematical view is that it cannot distinguish between "sterile" and "productive" arguments. A degenerative disease sporadically afflicting the general systems movement is hypermathematisis: the generation of grand, sweeping, and valid mathematical theories—often called "general systems theories"—which are as sterile as a castrated mule. They are sterile because they can be applied to anything and thus to nothing; but they are doubly sterile because they are indistinguishable—on a mathematical level—from productive theories. They waste our energy and give productive theories a bad name.

How can we prevent hypermathematisis? First, we shall follow the admonition of Maxwell:

> Mathematicians may flatter themselves that they possess new ideas which mere human language is as yet unable to express. Let them make the effort to express these ideas in appropriate words without the aid of symbols, and if they succeed they will not only lay us laymen under a lasting obligation, but, we venture to say, they will find themselves very much enlightened during the process, and will even be doubtful whether the ideas as expressed in symbols had ever quite found their way out of the equations into their minds.

By using words, we shall sacrifice the appearance of elegance, but we shall stay closer to the things we want to think about.

Second, we shall follow the Law of Happy Particularities and avoid using any mathematical notation unless we intend to use it more than once.

Multiple use will permit a little explanation of the mathematical idea and still provide an economy of notation. For instance, we introduce set notation not because

> The stature of a science is commonly measured by the degree to which it makes use of mathematics.[14]

By introducing set notation, we do not increase our stature by a single cubit, but merely give ourselves a convenient way to talk about a delimited range of possibilities.

Our first happy particularity for the use of sets is the elaboration of our concept of observer. What an observer does is make observations. These may be sensations on the sense organs of a biological organism; they may be readings taken by instruments; or they might be a combination of the two. An observation may be characterized as the act of choosing an element from a set, the set of all possible observations of that type for that observer.

In other words, an observer may be characterized by the observations he can make. The notation of sets helps us to recognize that there are two aspects to an observer—the kinds of observations he can make and the range of choices he can make within each kind. For instance, Herrick might be said to be able to make two kinds of observations, types of dress and types of disorder. His "scope'" as an observer may then be characterized by the set

{Dress, Disorder}

His range as an observer may be derived from the range, or "resolution level," or "grain" of each part of his scope. Thus, under Dress Herrick can distinguish the elements of the set:

{lawn, lace, cuff, ribbands, petticoat, shoestring}

while under Disorder he knows at least:

{distracted, erring, neglectful, confused, tempestuous, careless, wild, wanton}

In other words, Herrick as an observer could be modeled by a set:

{Dress, Disorder}

which is, in fact, a set of sets—"Dress" having six members, and "Disorder" having eight.

Our characterization of an observer may be at once too narrow and too broad. It may be too narrow because we may have excluded some of the scope or failed to make the grain sufficiently fine. We may not be aware of the full scope or the full resolution level, or we may not be interested in certain possible observations. For example, in psychological experiments, there may be tiny clues that the experimenter does not notice but the subject does.

In one case, a pigeon was trained to respond to red circles presented on a card in a window. When each card was presented, the apparatus made a slight click, and the click was different for each card. The experimenter thought that the pigeon's scope was

{Color, Shape}

but in actuality it was

{Color, Shape, Click}

The pigeon was responding to the click, and not particularly to the color and shape. The reader who is beginning to be a generalist will note the similarity between the psychologist's view of his pigeon and Miller's view of General Motors.

A complete observation by an observer would consist of one selection from each set in his scope. Thus, for Herrick, {lace, erring} would be one complete observation, and so would {cuff, neglectful}. How many such combinations might our idealized Herrick make? Since there are 6 members of Dress and 8 members of Disorder, there will be 6 times 8, or 48 members of {Dress, Disorder}including {lace, erring}, {lace, neglectful}, {cuff, erring}, {cuff, neglectful}, and many others.

This set of all possible pairs—this set of sets—is called the "product set," or "Cartesian product," after Descartes, and could be symbolized:

{Dress X Disorder}

It can be read "the Cartesian product of the set Dress and the set Disorder," or "the Cartesian product of Dress and Disorder," or "the product of Dress and Disorder." The full product set is indicated in Figure 3.4, which the reader is invited to finish. We see that although it is a set of sets, it is another example of the use of set notation to delimit a range of possibilities.

Dress ={lawn, lace, cuff, ribbands, petticoat, shoestring}

Disorder = {distracted, erring, neglectful, confused, tempestuous, careless, will, wanton}

Dress X Disorder = {(lawn, distracted), (lace, distracted), (cuff, distracted), (ribbands, distracted), (petticoat, distracted), (shoestring, distracted), (lawn, erring), (lace, erring), (cuff, erring), (ribbands, wanton), (petticoat, wanton), (shoestring, wanton). ...}

Figure 3.4. The Cartesian product. Dress x Disorder.

The product set may be too broad a model of our observer because though he can make each of the component discriminations, he may not be able to make all combinations. We know from the poem that Herrick can recognize {lace, erring}, but perhaps he will be incapable of recognizing an erring shoestring or an erring petticoat. If he cannot, these two pairs, {shoestring, erring}, and {petticoat, erring}, must be excluded from a more precise characterization of Herrick's powers of observation.

In that case, the Cartesian product, Dress X Disorder, is too broad a characterization of Herrick. If we use it we will be committing an error of composition. Using such a model, we might conclude that Herrick could observe things he is actually incapable of observing—that is, our model might be too general. On the other hand, if we have properly characterized his scope and the grain of each component, then the Cartesian product model will at least not exclude any observations he might make. The product set, then, gives us a way of preventing undergeneralization, within the assumptions of scope and grain.

We may note in passing that one symptom of general systems hypermathematisis is the use of product sets on everything in sight. The Cartesian product converts "all possible discriminations" into "all possible combinations of discriminations." which has great appeal for generalists. If we use Cartesian products willy-nilly, however, we rapidly generate sets of enormous size—which, because the Cartesian product generates all possible combinations, we call "combinatorial size". General systems theories that fail to take account of the Square Law of Computation may make perfectly general but vacuous laws because they exceed the computational capacity of any imaginable system.

In our model of an "observer," we shall remind ourselves from time to time how much computational capacity our model requires. Notice we have no requirement that our "observer" be able to make individual observations (the members of Dress and Disorder) "correctly." Because these are our primitive, undefined elements, the word "correct" is meaningless when applied to them. All our observer must be able to do is to recognize two sensations or measurements as being "the same"—and he is the final arbiter. In other words, "they ain't nothin' 'til he calls 'em."

The Principle of Indifference

"If you call a tail a leg, how many legs has a dog?" "Five?"

"No, four. Calling a tail a leg doesn't make it a leg."

- Attributed to Abraham Lincoln

We may not speak of an observation as being correct or incorrect. Without some notion like "correctness," however, we shall find it difficult to say much about observers and their observations. Therefore, we want to introduce a concept of consistency: that is, the compatibility of one set of observations with another.

Clearly, as Lincoln pointed out, a notion of consistency cannot depend on how the observer names his observations. If Andrew Marvell calls something {ribbands, tempestuous} and Herrick says it is {cuff, careless}, we do not on that account want to say that they are inconsistent observers. Otherwise, we should have to say that {manchette, négligente} is inconsistent with {cuff, careless} merely because one is in French and the other in English.

We may state this idea in the form of a Principle of Indifference:

Laws should not depend on a particular choice of notation.

The Principle of Indifference is a powerful reasoning instrument. Consider the case of a systems researcher who derived a formula purporting to measure the difficulty of a selection process. He had expressed the difficulty in terms of

S = percentage of items selected.

R = percentage of items not selected (rejected)

Although the formula was rather long and involved, I was able to eliminate it as implausible in less than 15 seconds, by applying the Principle of Indifference. The reasoning went like this: Suppose his formula had been

$D = R^2$

where D is the difficulty of doing the selection. Of course, the actual formula was much more complicated, but the reasoning is the same. Suppose, for instance, the problem was to separate 10 sheep from 90 goats (100 animals). Then

S = percentage of sheep = 0.1

R = percentage of goats = 0.9

$D = R^2 = 0.9^2 = 0.81$

Now suppose I simply look at the problem the other way and say I am trying to separate 90 goats from 100 sheep. Then

S = percentage of goats = 0.9

$$R = \text{percentage of sheep} = 0.1$$

$$D = R^2 = 0.1^2 = 0.01$$

In other words, according to his formula, it was intrinsically easier to separate the goats from the sheep than to separate the sheep from the goats! Yet if that were the case, we could separate the goats from the sheep and then, after they were separated, say "Oh, I changed my mind. I was actually separating the sheep from the goats."

Since his formula for D was supposed to calculate the best you could possibly do, this is intuitively a ludicrous conclusion. By contrast, had his formula been

$$D = R^2 + S^2$$

then separating sheep from goats would give a difficulty of

$$D = 0.1^2 + 0.9^2 = 0.82$$

while separating goats from sheep would give

$$D = 0.9^2 + 0.1^2 = 0.82$$

This formula, at least, obeys the Principle of Indifference. It is indifferent to what we pretend we are doing, and gives the same value either way. It, too, could be a wrong formula, but not on the basis of the Principle of Indifference alone. With his original formula, though, the Principle of Indifference allowed me to separate the wheat from the chaff, and suggest he throw away his ridiculous formula.

A rose by any other name should smell as sweet, yet nobody can seriously doubt we are often fooled by the names of things. During and after a revolution things are often renamed just to change thinking patterns. In seventeenth-century England, for example, one religious person renamed himself (or herself) "Put-Thy-Trust-in-Christ-and-Flee-Fornication Williams." In France, in the nineteenth century, "queen bee" was changed to "laying bee," as part of the effort to expunge all records of royalty. In twentieth-century Russia, Tsaritsyn became Stalingrad, and later became

"Volgograd," as first the Tsar, and then Stalin, toppled from the ranks of the saints.[15]

In scientific work, too, names may have to be changed by revolutionary acts, once they get established in some arbitrary way. In computing, for example, we are stuck with the terms "fixed-point" and "floating-point" arithmetic, when it is in fixed point that the point floats, and vice versa. That a revolution is required to change such things (consider the metric system in France, or the calendar in Russia) indicates the magnitude of their grip on our minds.

To put the Principle of Indifference into operation, we usually rely on mathematical symbols, which take the sting out of words. The first step in testing the consistency of two observers would be to neutralize the form of their observations. We thus give each observation—each pair, in Herrick's case—an arbitrary name. We might let

a = {lawn, distracted} b = {lawn, erring} c = {lawn, neglectful}

and so forth. This translation has the further advantage of getting rid of the substructure of the observations, when we are not concerned if the scope or grain differs from observer to observer.

For instance, a second poet might have a language in which Dress and Disorder form a single concept called "Dresorder." In his language, there is no such thing as a {lawn, distracted}, but only a "qualg"; no such thing as a {cuff, neglectful}, but only a "rotz"; no such thing as a {shoestring, careless}, but only a "gliggle." We take the structure out of these observations by the translation:

x = {qualg} y = {rotz)} z = {gliggle}

and so reduce his viewpoint to the same "one-symbol-one-observation." In this way, each symbol in each set represents precisely one observation for that observer.

Once we have reduced observer A (Herrick) to the range:

(a, b, c, .. .)

and observer B to the range:

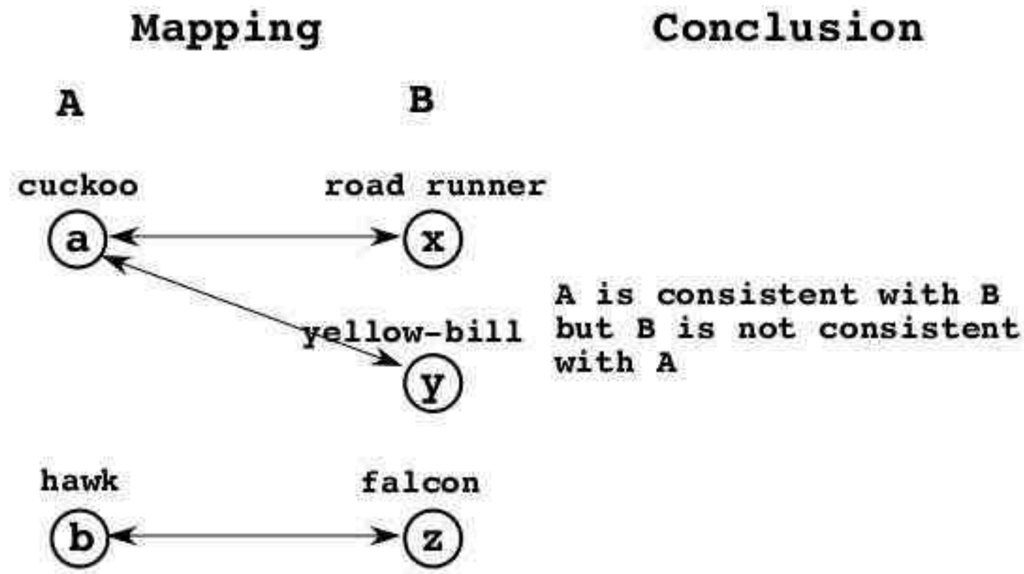
(x, y, z, . ..)

the question of consistency can be easily answered:

> A is said to be consistent with B if he never gives two different symbols for one of B's symbols.

Suppose A and B are watching birds. Every time B says he sees a road runner, A says it is a cuckoo—that much is clearly consistent, since a road runner is a kind of cuckoo. Even if B says he sees a yellow-bill, and A still says he is observing a cuckoo, that is still consistent, for a yellow-bill is another kind of cuckoo. A simply does not, or cannot, make as fine grained a discrimination of birds as B.

If A is consistent with B, we can always tell what A is going to say once we hear B's identification. B says roadrunner, A says cuckoo. B says yellow-bill, A again says cuckoo. B says falcon, A says hawk. Figure 3.5 shows this relationship in several ways. First a diagram connects B's observations with A's using arrows, then a tabular form shows the same mapping of what B says onto what A says. When we try to construct the inverse mapping, however, we find that we cannot predict what B will say when A says cuckoo.



If B says	x	y	z
Then A says	a	a	b

or

road runner	yellow-bill	falcon
cuckoo	cuckoo	hawk

If A says	a	b
Then B says	x? y?	z

or

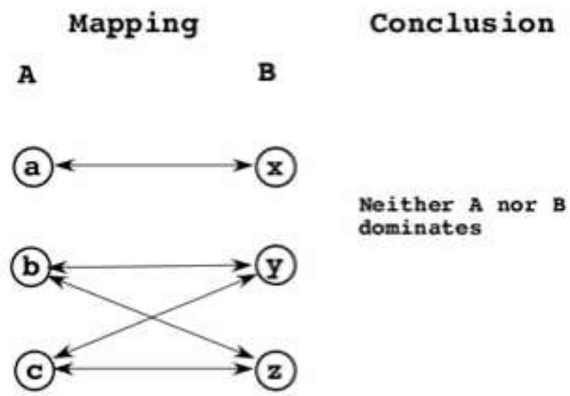
cuckoo	hawk
road runner? yellow-bill?	falcon

Figure 3.5. One observer dominating another.

Mathematically, we characterize this situation by saying that there is a many-to-one mapping from B onto A, but a one-to-many mapping from A onto B. Since one symbol of A's may map into any one of several of B's, B is inconsistent with A, even though A is consistent with B.

Since A is consistent with B, his observations add nothing to those of B. The poet, Herrick, was able to make numerous discriminations in a situation where another man would only observe "Look at her messy clothes!"—which is why the one is a poet and the other a clod. We can dispense with the clod if we have a poet, for the poet dominates the clod, as an observer.

Under most general circumstances, neither of two observers will dominate the other in this way. In Figure 3.6 we see a case neither A nor B dominates. We sometimes learn things from A that we could not from B, and vice versa.



If B says	x	y	z
Then A says	a	b or c?	b or c?

If A says	a	b	c
Then B says	a	y or z?	y or z?

Figure 3.6. Two inconsistent observers.

An interpretation of this situation is shown in Figure 3.7, where A and B are imagined to be looking at a table, one from one side and one from an adjacent side. Because the table is at eye level, if we toss a penny on it, each will be able to tell whether it is to his left or right, but not how close it is. In addition, each can tell whether the penny is on or off the table.

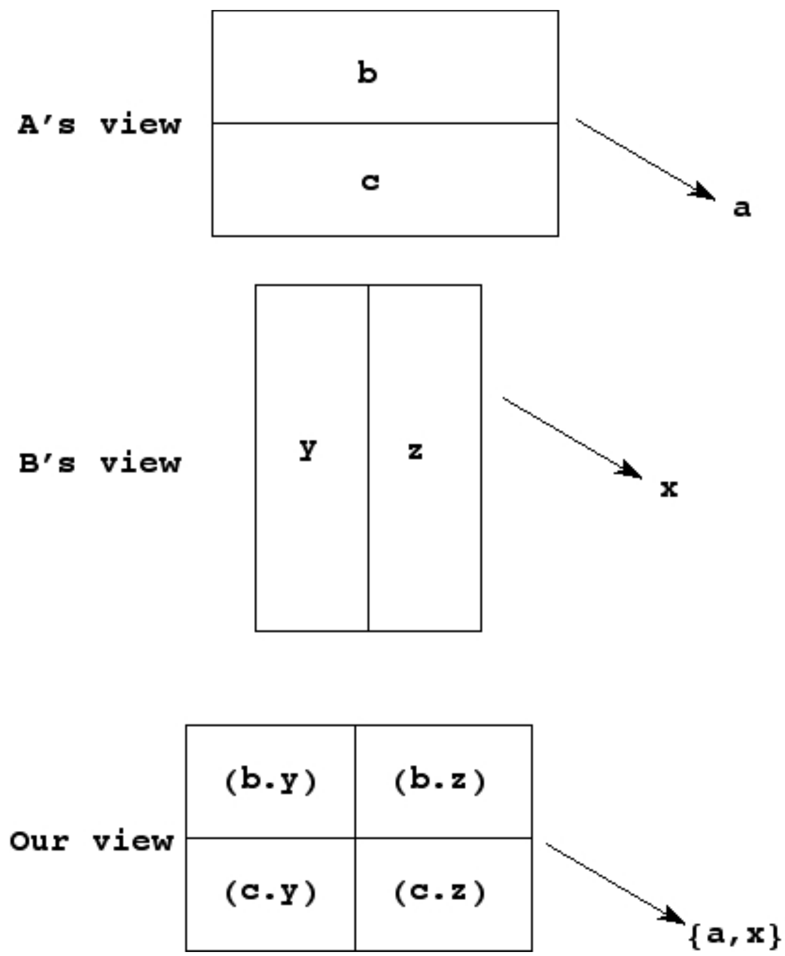


Figure 3.7. Two points of view—and a third, the superobserver.

To A, there are three observations in this range:

a = penny off the table

b = penny to my left

c = penny to my right

B's range is also three observations:

x = penny off the table

y = penny to my right

z = penny to my left

If we toss a penny towards the table, A and B will be able to agree if it happens to fall off, though A will call that condition a and B will call it x. Anywhere on the table, however, we shall not be able to predict what A will say from what B says, or vice versa. If we can use their information properly, each will make a contribution to our exact understanding of just where the penny lies.

In this discussion, we have been assuming a special position for ourselves, a point of view that is labeled "Our view" in Figure 3.7. It is very easy to slip into imagining that we can somehow get "above the table" when talking about other people's viewpoints, but we really have no reason to believe that we have such super powers of observation.

For simple cases, however, we can talk about different points of view if we are willing to introduce an explicit fiction—the "superobserver." It will not be necessary to endow our superobserver with omniscience, but only with a viewing capacity dependent on the abilities of the other observers present. In Figure 3.7, for example, the superobserver would have to be able to discriminate 5 conditions:

[(a,x), (b,y), (b,z), (c,y), (c,z)]

while for Figure 3.5, he would only have to have the powers of B, since B dominates A.

In fact, we can define our superobserver's capacities precisely if we say that his view must dominate the view of every other observer present. In the extreme case, this dominance can be assured if the superobserver's set of observing states is the Cartesian product of all of the others, as shown in Figure 3.8. Why? Because the product set covers all possible combinations of the other observations, which is the property that makes us like the Cartesian product.

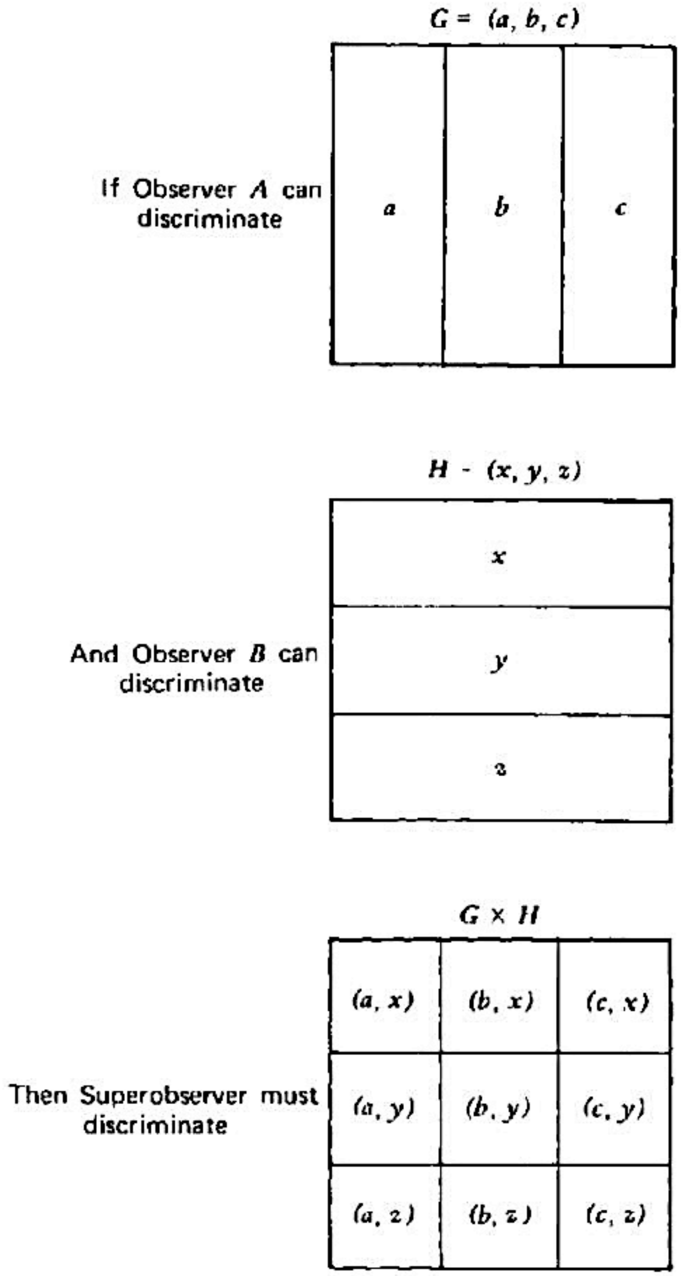


Figure 3.8. The combinatorial powers of a superobserver.

As before, the Cartesian product is the largest case we have to consider. In Figure 3.7, only 5 of the 9 members of the product set were needed, and in Figure 3.5, a superobserver would need only 3. But if we want to be perfectly general and know nothing about the individual observers except their range, we must allow for this maximum case. Note that this concept introduces a combinatorial element: the superobserver's powers, though always finite, must grow much faster than those of the other observers present.

For example, if two observers are present, each capable of discriminating 10 situations, the superobserver must be potentially capable of discriminating 10 times 10, or 10^2. Add a third similar observer and the number grows to 10^3, or 1000. In other words, as we add more and more observers, the exponent grows in the discriminatory powers of the superobserver.

Combinatorial growth is a critical flaw in any discussion of multiple points of view, for though we can imagine that a superobserver might exist in simple situations, there is little chance of having one in situations of even modest complexity. We may discuss simple situations using the artifice of the superobserver, but we must not imagine that a superobserver can exist in any practical sense. We must particularly refrain from imagining that we are the superobserver, capable of seeing what ordinary mortals cannot. Otherwise, A will say that we are a cuckoo!

QUESTIONS FOR FURTHER RESEARCH

Children's Games

The requirement that the observer be able to recognize the "same" state when it reappears seems easy enough, but our confidence is shaken when we see the type of game shown in Figure 3.9. Try to solve the puzzle and then, using your experiences, tell what you have learned about observers and observations.

Figure 3.9. There are ten differences between the two pictures: What are they? A popular game in Europe, this example being taken from Femina, 25 June 1971 < 10, Rue du Valentin, 1004 Lausanne, Switzerland).

Sociology

Social scientists are particularly prone to defining sets by implied rules that may be ambiguous to the reader. Consider the following statement by Philip Slater:

> Like so many of the more successful nineteenth century Utopian communities (Oneida and Amana, for example) the puritans became corrupted by involvement in successful economic enterprise... .

Investigate the question of the size of the implied set ("like so many"), the rule for choice ("more successful nineteenth century Utopian communities"), and the examples as typical members (Oneida and Amana).

References: Philip Slater, The Pursuit of Loneliness. Boston: Beacon Press, 1970.

John Humphrey Noyes, History of American Socialisms. New York: Dover, 1966.

Sets

Give at least five plausible next members for each of the sets given below:

{1,2, 3,...}

{Mathew, Mark, ...}

{pain, gorge, face, ...}

Pharmacology

> Drugs are sometimes relabeled when their "side effects" prove to be more interesting than their main effect. The history of psychoactive drugs is replete with such examples. Phenothiazine was initially used as a urinary antiseptic and chlorpromazine was then used to induce artificial hibernation to facilitate anesthesia during surgery... . Only later were its psychoactive properties identified as its main attribute. The discovery of the "specific" effects of lithium, amphetamines, iproniazid, and others have similar histories.

Reference: Henry L. Lennard, et al., "Hazards Implicit in Prescribing Psychoactive Drugs." Science, 169, 438 (1970).

Discuss the concept of "side effect" and "main effect" in terms of relativist-absolutist thinking.

Physics—Theory of Elasticity

Discuss the following statement in terms of relativist-absolutist thinking:

> In general, the deflections in an elastic structure may be said to be "small" if, and only if, they are determined with sufficient accuracy by the classical linear theory of elasticity.

University Life

In China, according to reports, the universities no longer extrude "academic failures." Discuss what effect this change may have on the role of the university in society—in China, and also (hypothetically) in the United States.

Reference: E. Signer and A. W. Galston, "Education and Science in China." Science, 175, (1972).

Demography

A village is a system often studied by anthropologists and sociologists. One aspect of a village system is the "set of people living in the village." Discuss how this set might be enumerated, and what practical and conceptual difficulties you might encounter.

Law

Discuss the analogy between an arbitrator or judge and a superobserver.

History as Observation

> Let us suppose that a military commander has just won a victory. That, immediately, he sets to work writing an account in his own hand. That it was he who conceived the plan of the battle, and that it was he who directed it. And finally that, thanks to the moderate size of the field (for in order to sharpen the argument, we are imagining a battle of former times, drawn up in a confined space), he has been able to see almost the entire conflict develop before his eyes. Nevertheless, we cannot doubt that, in more than one essential episode, he will be forced to refer to the reports of his lieutenants. In acting thus as narrator, he would only be behaving as he had a few hours before in the action. Then as commander, regulating the movements of his troops to the swaying tide of battle, what sort of information shall we think to have served him best? Was it the rather confused scenes viewed through his binoculars, or the reports brought in hot haste by the couriers and aides-de-camp? Seldom can a leader of troops be his own observer. Meanwhile, even in so favorable a hypothesis as this, what has become of that marvel of "direct" observation which is claimed as the prerogative of the studies of the present?

> In truth, it is scarcely ever anything but a delusion, at least as soon as the observer has expanded his horizon only slightly. A good half of all we see is seen through the eyes of others.

Discuss how much of the "observation" in your own discipline is "through the eyes of others."

Reference: Marc Bloch, The Historian's Craft, p. 49. New York: Vintage Books, 1953.

Schools and the Banana Principle

One of my students, Jim Addiss, made this comment about an application of the Banana Principle:

> I decided to go back to school, but I don't yet know how to stop.

Another (anonymous) student commented:

> Students are taught in school the method of doubting, but they never are taught when to stop, so they wind up committing suicide.

Comment on these comments, in the light of the Banana Principle; give a few examples from your own school experience of how schools obey the principle; and make some suggestions as to how schools could teach when (or how) to stop applying what they teach.

READINGS

Recommended

Authur, D. Hall and R. E. Fagen, "Definition of System." In Modern Systems Research for the Behavioral Scientist, Walter Buckley, Ed. Chicago: Aldine, 1968.

Eleanor Gibson, "The Development of Perception as an Adaptive Process." American Scientist, 58, 98 (January-February 1970).

Suggested

E. H. Gombrich, Art and Illusion. New York: Pantheon Books, 1961.

Studs Terkel, Hard Times. New York: Avon Books, 1971.

NOTATIONAL EXERCISES

NOTE: Whenever new notation is introduced, exercises will be supplied far the convenience of the reader who wishes to practice. Since mathematically trained readers will probably not need to do these exercises, they are kept separate from the Research Questions. They are, moreover, not research questions, but simply practice in notation. The reader should check her work against the answers, to verify her mastery of notation.

1. Write down the set of all "first words of a line" from Herrick's poem. How many elements are in this set?

2. Take the set from Exercise 1 and divide it into subsets according to the first letter of the word. That is, all words in each subset should start with the same letter.

3. Take the set from Exercise 2 and give each subset a symbol the symbol being the first letter of each word in the subset. Write down the set of all these symbols. Describe in words what it is a set of.

4. Repeat Exercises 2 and 3, but based on the last letter of the last word in each line.

5. Assume we have two observers, "First-letter" and "Last-letter," who can only see, respectively, the first and last letter of each line of Herrick's poem. Write down the product set that a superobserver would have to be able to resolve to guarantee being a superobserver relative to this pair of observers.

6. Does the superobserver in Exercise 5 actually have to resolve all pairs in this product set? Explain your answer.

7. Suppose we have a third observer, "Odd-even," who can only discriminate, by some means or another, whether a line is an odd or even line of a poem, so his grain is the set {O,E} corresponding to lines {1, 3, 5, 7, 9, 11, 13j for O and {2, 4, 6, 8, 10, 12, 14} for E. Is Odd-even dominated by either First-letter or Last-letter? Write down the mappings needed to determine the answer.

8. Does the superobserver of Exercise 6 have to expand his powers in order to dominate Odd even?

ANSWERS TO NOTATIONAL EXERCISES

1. {A, Kindles, Into, An, Enthralls, Ribbands, In, I, Do, Is} Notice that in set theory, known duplicates are conventionally discarded from the set, so that A only appears once, so there are only 10 elements, even though it is a sonnet form of 14 lines.

2. {(A, An), Kindles, (Into, In, I, Is), Enthralls, Ribbands, Do}
Technically, since each element is a set, single words should also be written with parentheses, such as (Kindles), but we will avoid this detail unless it is needed for clarity.

3. {|A, K, I, E, R, D}
This is the set of all initial letters of lines in Herrick's poem.

4. {dress, wantonness, thrown, distraction, there, stomacher, thereby, confusedly, note, petticoat, tie, civility, art, part}

{(dress, wantonness), (thrown, distraction), (there, note, tie), stomacher, (thereby, confusedly, civility), (petticoat, art, part)}

{S,N,E,R, Y,T}
This is the set of all final letters in Herrick's poem.

5. {
(A,S), (A,N), (A,E), (A,R), (A,Y). (A,T),
(K,S), (K,N), (K,E), (K,R), (K,Y). (K,T),
(I,S), (I,N), (I,E), (I,R), (I,Y). (I,T),
(E,S), (E,N), (E,E), (E,R), (E,Y). (E,T),
(R,S), (R,N), (R,E), (R,R), (R,Y). (R,T),
(D,S), (D,N), (D,E), (D,R), (D,Y). (D,T)}

6. Given this particular poem, the superobserver actually needs only to be able to discriminate the 11 pairs:

{(A,S), (K,S), (A,N), (I,N), (A,E), (E,R), (A,Y), (R,Y), (I,T), (I,Y), (D,T)} because first of all, there are only 14 lines to the poem, so he couldn't possibly have to discriminate more than 14 states. Second, three lines correspond to (A,E) and two to (I,T), which eliminates the need for three discriminations, since the pair of observers together can only discriminate 11 lines.

This observer is dominated by First-letter but not by Last-letter. The mapping from First-letter onto Odd even is the following:

First says: A K I E R D

Odd-even says: O E E E E O

which is perfectly predictable, because of the highly odd-even pattern of first words.

The best mapping we can do from Last-letter to Odd-even is:

Last says: S N R Y E T

Odd-even says: ? ? O E ? ?

because rhyme pairs on adjacent lines tend to have the same last letter.

8. No, because if superobserver already dominates First-letter and First-letter dominates Odd-even, then superobserver will also dominate Odd even. As we shall see, "dominance" is what we call a "transitive" property.