By education most have been misled;  
So they believe, because they so were bred.  
The priest continues what the nurse began,  
And thus the child imposes on the man.  

—John Dryden, *The Hind and the Panther*

Science, like art, religion, commerce, warfare, and even sleep, is based on presuppositions. It differs, however, from most other branches of human activity in that not only are the pathways of scientific thought determined by the presuppositions of the scientists but their goals are the testing and revision of old presuppositions and the creation of new.

In this latter activity, it is clearly desirable (but not absolutely necessary) for the scientist to know consciously and be able to state his own presuppositions. It is also convenient and necessary for scientific judgment to know the presuppositions of colleagues working in the same field. Above all, it is necessary for the reader of scientific matter to know the presuppositions of the writer.

I have taught various branches of behavioral biology and cultural anthropology to American students, ranging from college freshmen to psychiatric residents, in various schools and teaching hospitals, and I have encountered a very strange gap in their thinking that springs from a lack of certain tools of thought. This lack is rather equally distributed at all levels of edu-
cation, among students of both sexes and among humanists as well as scientists. Specifically, it is lack of knowledge of the presuppositions not only of science but also of everyday life.

This gap is, strangely, less conspicuous in two groups of students that might have been expected to contrast strongly with each other: the Catholics and the Marxists. Both groups have thought about or have been told a little about the last 2,500 years of human thought, and both groups have some recognition of the importance of philosophic, scientific, and epistemological presuppositions. Both groups are difficult to teach because they attach such great importance to "right" premises and presuppositions that heresy becomes for them a threat of excommunication. Naturally, anybody who feels heresy to be a danger will devote some care to being conscious of his or her own presuppositions and will develop a sort of connoisseurship in these matters.

Those who lack all idea that it is possible to be wrong can learn nothing except know-how.

The subject matter of this book is notably close to the core of religion and to the core of scientific orthodoxy. The presuppositions—and most students need some instruction in what a presupposition looks like—are matters to be brought out into the open.

There is, however, another difficulty, almost peculiar to the American scene. Americans are, no doubt, as rigid in their presuppositions as any other people (and as rigid in these matters as the writer of this book), but they have a strange response to any articulate statement of presupposition. Such statement is commonly assumed to be hostile or mocking or—and this is the most serious—is heard to be authoritarian.

It thus happens that in this land founded for the freedom of religion, the teaching of religion is outlawed in the state educational system. Members of weakly religious families get, of course, no religious training from any source outside the family.

Consequently, to make any statement of premise or presupposition in a formal and articulate way is to challenge the rather subtle resistance, not of contradiction, because the hearers do not know the contradictory premises nor how to state them, but of the cultivated deafness that children use to keep out the pronouncements of parents, teachers, and religious authorities.

Be all that as it may, I believe in the importance of scientific presuppositions, in the notion that there are better and worse ways of constructing scientific theories, and in insisting on the articulate statement of presuppositions so that they may be improved.

Therefore, this chapter is devoted to a list of presuppositions, some familiar, some strange to readers whose thinking has been protected from the harsh notion that some propositions are simply wrong. Some tools of thought are so blunt that they are almost useless; others are so sharp that they are dangerous. But the wise man will have the use of both kinds.

It is worthwhile to attempt a tentative recognition of certain basic presuppositions which all minds must share or, conversely, to define mind by listing a number of such basic communicational characteristics.

1. SCIENCE NEVER PROVES ANYTHING

Science sometimes improves hypotheses and sometimes disproves them. But proof would be another matter and perhaps never occurs except in the realms of totally abstract tautology. We can sometimes say that if such and such abstract suppositions or postulates are given, then such and such must follow absolutely. But the truth about what can be perceived or arrived at by induction from perception is something else again.

Let us say that truth would mean a precise correspondence between our description and what we describe or between our total network of abstractions and deductions and some total understanding of the outside world. Truth in this sense is not obtainable. And even if we ignore the barriers of coding, the circumstance that our description will be in words or figures or pictures but that what we describe is going
to be in flesh and blood and action—even disregarding that hurdle of translation, we shall never be able to claim final knowledge of anything whatsoever.

A conventional way of arguing this matter is somewhat as follows: Let us say that I offer you a series—perhaps of numbers, perhaps of other indications—and that I provide the presupposition that the series is ordered. For the sake of simplicity, let it be a series of numbers:

2, 4, 6, 8, 10, 12

Then I ask you, “What is the next number in this series?” You will probably say, “14.”

But if you do, I will say, “Oh, no. The next number is 27.” In other words, the generalization to which you jumped from the data given in the first instance—that the series was the series of even numbers—was proved to be wrong or only approximate by the next event.

Let us pursue the matter further. Let me continue my statement by creating a series as follows:

2, 4, 6, 8, 10, 12, 27, 2, 4, 6, 8, 10, 12, 27, 2, 4, 6, 8, 10, 12, 27 . . .

Now if I ask you to guess the next number, you will probably say, “2.” After all, you have been given three repetitions of the sequence from 2 to 27; and if you are a good scientist, you will be influenced by the presupposition called Occam’s razor, or the rule of parsimony: that is, a preference for the simplest assumptions that will fit the facts. On the basis of simplicity, you will make the next prediction. But those facts—what are they? They are not, after all, available to you beyond the end of the (possibly incomplete) sequence that has been given.

You assume that you can predict, and indeed I suggested this presupposition to you. But the only basis you have is your (trained) preference for the simpler answer and your trust that my challenge indeed meant that the sequence was incomplete and ordered.

Unfortunately (or perhaps fortunately), it is so that the next fact is never available. All you have is the hope of simplicity, and the next fact may always drive you to the next level of complexity.

Or let us say that for any sequence of numbers I can offer, there will always be a few ways of describing that sequence which will be simple, but there will be an infinite number of alternative ways not limited by the criterion of simplicity.

Suppose the numbers are represented by letters:

x, w, p, n

and so on. Such letters could stand for any numbers whatsoever, even fractions. I have only to repeat the series three or four times in some verbal or visual or other sensory form, even in the forms of pain or kinesthesia, and you will begin to perceive pattern in what I offer you. It will become in your mind—and in mine—a theme, and it will have aesthetic value. To that extent, it will be familiar and understandable.

But the pattern may be changed or broken by addition, by repetition, by anything that will force you to a new perception of it, and these changes can never be predicted with absolute certainty because they have not yet happened.

We do not know enough about how the present will lead into the future. We shall never be able to say, “Ha! My perception, my accounting for that series, will indeed cover its next and future components,” or “Next time I meet with these phenomena, I shall be able to predict their total course.”

Prediction can never be absolutely valid and therefore science can never prove some generalization or even test a single descriptive statement and in that way arrive at final truth.

There are other ways of arguing this impossibility. The argument of this book—which again, surely, can only convince you insofar as what I say fits with what you know and which may be collapsed or totally changed in a few years—presupposes that science is a way of perceiving and making what we may call “sense” of our percepts. But perception operates only upon
difference. All receipt of information is necessarily the receipt of news of *difference*, and all perception of difference is limited by threshold. Differences that are too slight or too slowly presented are not perceivable. They are not food for perception.

It follows that what we, as scientists, can perceive is always limited by threshold. That is, what is subliminal will not be grist for our mill. Knowledge at any given moment will be a function of the thresholds of our available means of perception. The invention of the microscope or the telescope or of means of measuring time to the fraction of a nanosecond or weighing quantities of matter to millionths of a gram—all such improved devices of perception will disclose what was utterly unpredictable from the levels of perception that we could achieve before that discovery.

Not only can we not predict into the next instant of the future, but, more profoundly, we cannot predict into the next dimension of the microscopic, the astronomically distant, or the geologically ancient. As a method of perception—and that is all science can claim to be—science, like all other methods of perception, is limited in its ability to collect the outward and visible signs of whatever may be truth.

Science probes; it does not prove.

2. THE MAP IS NOT THE TERRITORY, AND THE NAME IS NOT THE THING NAMED

This principle, made famous by Alfred Korzybski, strikes at many levels. It reminds us in a general way that when we think of coconuts or pigs, there are no coconuts or pigs in the brain. But in a more abstract way, Korzybski's statement asserts that in all thought or perception or communication about perception, there is a transformation, a coding, between the report and the thing reported, the *Ding an sich*. Above all, the relation between the report and that mysterious thing reported tends to have the nature of a classification, an assignment of the thing to a class. Naming is always classifying, and mapping is essentially the same as naming.

Kozybski was, on the whole, speaking as a philosopher, attempting to persuade people to discipline their manner of thinking. But he could not win. When we come to apply his dictum to the natural history of human mental process, the matter is not quite so simple. The distinction between the name and the thing named or the map and the territory is perhaps really made only by the dominant hemisphere of the brain. The symbolic and affective hemisphere, normally on the right-hand side, is probably unable to distinguish name from thing named. It is certainly not concerned with this sort of distinction. It therefore happens that certain irrational types of behavior are necessarily present in human life. We do, in fact, have two hemispheres; and we cannot get away from that fact. Each hemisphere does, in fact, operate somewhat differently from the other, and we cannot get away from the tangles that that difference proposes.

For example, with the dominant hemisphere, we can regard such a thing as a flag as a sort of name of the country or organization that it represents. But the right hemisphere does not draw this distinction and regards the flag as sacramentally identical with what it represents. So "Old Glory" is the United States. If somebody steps on it, the response may be rage. And this rage will not be diminished by an explanation of map-territory relations. (After all, the man who tramples the flag is equally identifying it with that for which it stands.) There will always and necessarily be a large number of situations in which the response is not guided by the logical distinction between the name and the thing named.

3. THERE IS NO OBJECTIVE EXPERIENCE

All experience is subjective. This is only a simple corollary of a point made in section 4: that our brains make the images that we think we "perceive."

It is significant that all perception—all conscious
perception—has image characteristics. A pain is localize somewhere. It has a beginning and an end and a location and stands out against a background. These are the elementary components of an image. When somebody steps on my toe, what I experience is, not his stepping on my toe, but my image of his stepping on my toe reconstructed from neural reports reaching my brain somewhat after his foot has landed on mine. Experience of the exterior is always mediated by particular sense organs and neural pathways. To that extent, objects are my creation, and my experience of them is subjective, not objective.

It is, however, not a trivial assertion to note that very few persons, at least in occidental culture, doubt the objectivity of such sense data as pain or their visual images of the external world. Our civilization is deeply based on this illusion.

4. THE PROCESSES OF IMAGE FORMATION ARE UNCONSCIOUS

This generalization seems to be true of everything that happens between my sometimes conscious action of directing a sense organ at some source of information and my conscious action of deriving information from an image that “I” seem to see, hear, feel, taste, or smell. Even a pain is surely a created image.

No doubt men and donkeys and dogs are all conscious of listening and even of cocking their ears in the direction of sound. As for sight, something moving in the periphery of my visual field will call “attention” (whatever that means) so that I shift my eyes and even my head to look at it. This is often a conscious act, but it is sometimes so nearly automatic that it goes unnoticed. Often I am conscious of turning my head but unaware of the peripheral sighting that caused me to turn. The peripheral retina receives a lot of information that remains outside consciousness—possibly but not certainly in image form.

The processes of perception are inaccessible; only the products are conscious and, of course, it is the products that are necessary. The two general facts—first, that I am unconscious of the process of making the images which I consciously see and, second, that in these unconscious processes, I use a whole range of presuppositions which become built into the finished image—are, for me, the beginning of empirical epistemology.

Of course, we all know that the images which we “see” are indeed manufactured by the brain or mind. But to know this in an intellectual sense is very different from realizing that it is truly so. This aspect of the matter came forcibly to my attention some thirty years ago in New York, where Adalbert Ames, Jr., was demonstrating his experiments on how we endow our visual images with depth. Ames was an ophthalmologist who had worked with patients who suffered from anisocoria; that is, they formed images of different sizes in the two eyes. This led him to study the subjective components of the perception of depth. Because this matter is important and provides the very basis of empirical or experimental epistemology, I will narrate my encounter with the Ames experiments in some detail.

Ames had the experiments set up in a large, empty apartment in New York City. There were, as I recall, some fifty experiments. When I arrived to see the show, I was the only visitor. Ames greeted me and suggested that I start at the beginning of the sequence of demonstrations while he went back to work for awhile in a small room furnished as an office. Otherwise, the apartment contained no furniture except for two folding deck chairs.

I went from one experiment to the next. Each contained some sort of optical illusion affecting the perception of depth. The thesis of the whole series was that we use five main clues to guide us in creating the appearance of depth in the images that we create as we look out through our eyes at the world.

The first of these clues is size;* that is, the size of

* More precisely, I should have written: “The first of these clues is contrast in size...”
the physical image on the retina. Of course, we cannot see this image so it would be more exact to say that the first clue to distance is the angle which the object subtends at the eye. But indeed this angle is also not visible. The clue to distance which is reported on the optic nerve is perhaps change in angle subtended.* The demonstration of this truth was a pair of balloons in a dark area. The balloons themselves were equally illuminated, but their air could be passed from one balloon into the other. The balloons themselves did not move, but as one grew and the other shrank, it appeared to the observer that one which grew, approached, and the one which shrank, retreated. As the air was shifted from one balloon to the other and back again, the balloons appeared to move alternately forward and back.

The second clue was contrast in brightness. To demonstrate this, the balloons stayed the same size and, of course, did not really move. Only the illumination changed, shining first on one balloon and then on the other. This alternation of illumination, like the alternation in size, gave the balloons the appearance of approaching and retreating in turn as the light fell first on one and then on the other.

Then the sequence of experiments showed that these two clues, size and brightness, could be played against each other to give a contradiction. The shrinking balloon now always got the more light. This combined experiment introduced the idea that some clues are dominant over others.

The total sequence of clues demonstrated that day included size, brightness, overlap, binocular parallax, and parallax created by movements of the head. Of these, the most strongly dominant was parallax by head motion.

After looking at twenty or thirty such demonstrations, I was ready to take a break and went to sit in one of the folding deck chairs. It collapsed under me. Hearing the noise, Ames came out to check that all was well. He then stayed with me and demonstrated the two following experiments.

The first dealt with parallax (see Glossary). On a table perhaps five feet long, there were two objects: a pack of Lucky Strike cigarettes, supported on a slender spike some inches from the surface of the table and a book of paper matches, similarly raised on a spike, at the far end of the table.

Ames had me stand at the near end of the table and describe what I saw; that is, the location of the two objects and how big they seemed to be. (In Ames’s experiments, you are always made to observe the truth before being subjected to the illusions.)

Ames then pointed out to me that there was a wooden plank with a plain round hole in it set upright at the edge of the table at my end so that I could look through the hole down the length of the table. He had me look through this hole and tell him what I saw. Of course, the two objects still appeared to be where I knew them to be and to be of their familiar sizes.

Looking through the hole in the plank, I had lost the crow’s-eye view of the table and was reduced to the use of a single eye. But Ames suggested that I could get parallax on the objects by sliding the plank sideways.

As I moved my eye sideways with the plank, the image changed totally—as if by magic. The Lucky Strike pack was suddenly at the far end of the table and appeared to be about twice as tall and twice as wide as a normal pack of cigarettes. Even the surface of the paper of which the pack was made had changed in texture. Its small irregularities were now seemingly larger. The book of matches, on the other hand, suddenly appeared to be of dollhouse size and to be located halfway down the length of the table in the position where the pack of cigarettes had formerly been seen to be.

What had happened?

The answer was simple. Under the table, where I could not see them, there were two levers or rods that
moved the two objects sideways as I moved the plank. In normal parallax, as we all know, when we look out from a moving train, the objects close to us appear to be left behind fast; the cows beside the railroad track do not stay to be observed. The distant mountains, on the other hand, are left behind so slowly that, in contrast with the cows, they seem almost to travel with the train.

In this case, the levers under the table caused the nearer object to move along with the observer. The cigarette pack was made to act as if it were far away; the book of matches was made to move as if it were close by.

In other words, by moving my eye and with it the plank, I created a reversed appearance. Under such circumstances, the unconscious processes of image formation made the appropriate image. The information from the cigarette pack was read and built up to be the image of a distant pack, but the height of the pack still subtended the same angle at the eye. Therefore, the pack now appeared to be of giant size. The book of matches, correspondingly, was brought seemingly close but still subtended the same angle that it subtended from its true location. What I created was an image in which the book of matches appeared to be half as far away and half its familiar size.

The machinery of perception created the image in accordance with the rules of parallax, rules that were for the first time clearly verbalized by painters in the Renaissance; and this whole process, the creating of the image with its built-in conclusions from the clues of parallax, happened quite outside my consciousness. The rules of the universe that we think we know are deep buried in our processes of perception.

Epistemology, at the natural history level, is mostly unconscious and correspondingly difficult to change. The second experiment that Ames demonstrated illustrates this difficulty of change.

This experiment has been called the trapezoidal room. In this case, Ames had me inspect a large box about five feet long, three feet high, and three feet deep from front to back. The box was of strange trapezoidal shape, and Ames asked me to examine it carefully in order to learn its true shape and dimensions.

In the front of the box was a peephole big enough for two eyes, but before beginning the experiment, Ames had me put on a pair of prismatic spectacles that would corrupt my binocular vision. I was to have the subjective presupposition that I had the parallax of two eyes when indeed I had almost no binocular clues.

When I looked in through the peephole, the interior of the box appeared to be quite rectangular and was marked out like a room with rectangular windows. The true lines of paint suggesting windows were, of course, far from simple; they were drawn to give the impression of rectangularity, contradicting the true trapezoidal shape of the room. The side of the box toward which I faced when looking through the peephole was, I knew from my earlier inspection, obliquely placed, so that it was further from me at the left end and closer to me on the right.

Ames gave me a stick and asked me to reach in and touch with the point of the stick a sheet of type-writing paper pinned to the left-hand wall. I managed this fairly easily. Ames then said, "Do you see a similar piece of paper on the right-hand side? I want you to hit that second piece of paper with the stick. Start with the end of your stick against the left-hand paper, and hit as hard as you can."

I smote hard. The end of my stick moved about an inch and then hit the back of the room and could move no farther. Ames said, "Try again."

I tried perhaps fifty times, and my arm began to ache. I knew, of course, what correction I had to impose on my movement: I had to pull in as I struck in order to avoid that back wall. But what I did was governed by my image. I was trying to pull against my own spontaneous movement. (I suppose that if I had shut my eyes, I could have done better, but I did not try that.)

I never did succeed in hitting the second piece of paper, but, interestingly, my performance improved. I
was finally able to move my stick several inches before it hit the back wall. And as I practised and improved my action, my image changed to give me a more trapezoidal impression of the room's shape.

Ames told me afterward that, indeed, with more practice, people learned to hit the second paper very easily and, at the same time, learned to see the room in its true trapezoidal shape.

The trapezoidal room was the last in the sequence of experiments, and after it, Ames suggested that we go to lunch. I went to wash up in the bathroom of the apartment. I turned the faucet marked "C" and got a jet of boiling water mixed with steam.

Ames and I then went down to find a restaurant. My faith in my own image formation was so shaken that I could scarcely cross the street. I was not sure that the oncoming cars were really where they seemed to be from moment to moment.

In sum, there is no free will against the immediate commands of the images that perception presents to the "mind's eye." But through arduous practice and self-correction, it is partly possible to alter those images. (Such changes in calibration are further discussed in Chapter 7.)

In spite of this beautiful experimentation, the fact of image formation remains almost totally mysterious. How it is done, we know not—nor, indeed, for what purpose.

It is all very well to say that it makes a sort of adaptive sense to present only the images to consciousness without wasting psychological process on consciousness of their making. But there is no clear primary reason for using images at all or, indeed, for being aware of any part of our mental processes.

Speculation suggests that image formation is perhaps a convenient or economical method of passing information across some sort of interface. Notably, where a person must act in a context between two machines, it is convenient to have the machines feed their information to him or her in image form.

A case that has been studied systematically is that of a gunner controlling antiaircraft fire on a naval ship. The information from a series of sighting devices aimed at a flying target is summarized for the gunner in the form of a moving dot on a screen (i.e., an image). On the same screen is a second dot, whose position summarizes the direction in which an antiaircraft gun is aimed. The man can move this second dot by turning knobs on the device. These knobs also change the gun’s aim. The man must operate the knobs until the dots coincide on the screen. He then fires the gun.

The system contains two interfaces: sensory system—man and man–effector system. Of course, it is conceivable that in such a case, both the input information and the output information could be processed in digital form, without transformation into an iconic mode. But it seems to me that the iconic device is surely more convenient not only because, being human, I am a maker of mental images but also because at these interfaces images are economical or efficient. If that speculation is correct, then it would be reasonable to guess that mammals form images because the mental processes of mammals must deal with many interfaces.

There are some interesting side effects of our unawareness of the processes of perception. For example, when these processes work unchecked by input material from a sense organ, as in dream or hallucination or eidetic (see Glossary) imagery, it is sometimes difficult to doubt the external reality of what the images seem to represent. Conversely, it is perhaps a very good thing that we do not know too much about the work of creating perceptual images. In our ignorance of that work, we are free to believe what our senses tell us. To doubt continually the evidence of sensory report might be awkward.

* John Strood, personal communication.
5. THE DIVISION OF THE PERCEIVED
UNIVERSE INTO PARTS AND WHOLES
IS CONVENIENT AND MAY BE
NECESSARY,* BUT NO NECESSITY
DETERMINES HOW IT SHALL BE DONE

I have tried many times to reach this generality to
classes of students and for this purpose have used
Figure 1. The figure is presented to the class as a
reasonably accurate chalk drawing on the blackboard,
but without the letters marking the various angles. The
class is asked to describe "it" in a page of written
English. When each student has finished his or her
description, we compare the results. They fall into
several categories:

a. About 10 percent or less of students say, for ex-
ample, that the object is a boot or, more picturesquely,
the boot of a man with a gouty toe or even a toilet.

b. A much larger number of students see that the
object contains most of a rectangle and most of a
hexagon, and having divided it into parts in this way,
then devote themselves to trying to describe the rela-
tions between the incomplete rectangle and hexagon.
A small number of these (but, surprisingly, usually one
or two in every class) discover that a line, $BH$, can be
drawn and extended to cut the base line, $DC$, at a point
$I$ in such a way that $HI$ will complete a regular hexagon
(Figure 2). This imaginary line will define the propor-
tions of the rectangle but not, of course, the absolute
lengths. I usually congratulate these students on their
ability to create what resembles many scientific
hypotheses, which "explain" a perceptible regularity in
terms of some entity created by the imagination.

c. Many well-trained students resort to an oper-
tional method of description. They will start from some
point on the outline of the object (interestingly enough,
always an angle) and proceed from there, usually
clockwise, with instructions for drawing the object.

d. There are also two other well-known ways of
description that no student has yet followed. No student
has started from the statement "It's made of chalk and

diagram 1

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*The question of formal necessity raised here might have an answer as
follows: Evidently, the universe is characterized by an uneven distribution
of causal and other types of linkage between its parts; that is, there are
regions of dense linkage separated from each other by regions of less
dense linkage. It may be that there are necessarily and inevitably processes
which are responsive to the density of interconnection so that density is
increased or sparsity is made more sparse. In such a case, the universe
would necessarily present an appearance in which wholes would be
influenced by the relative sparseness of their interconnection.

diagram 2
blackboard.” No student has ever used the method of the halftone block, dividing the surface of the blackboard into a grid (arbitrarily rectangular) and reporting “yes” and “no” on whether each box of the grid contains or does not contain some part of the object. Of course, if the grid is coarse and the object small, a very large amount of information will be lost. (Imagine the case in which the entire object is smaller than the grid unit. The description will then consist of not more than four nor less than one affirmation, according to how the divisions of the grid fall upon the object.) However, this is, in principle, how the halftone blocks of newspaper illustration are transmitted by electric impulse and, indeed, how television works.

Note that all these methods of description contribute nothing to an explanation of the object—the hexago-rectangle. Explanation must always grow out of description, but the description from which it grows will always necessarily contain arbitrary characteristics such as those exemplified here.

6. DIVERGENT SEQUENCES ARE UNPREDICTABLE

According to the popular image of science, everything is, in principle, predictable and controllable; and if some event or process is not predictable and controllable in the present state of our knowledge, a little more knowledge and, especially, a little more know-how will enable us to predict and control the wild variables.

This view is wrong, not merely in detail, but in principle. It is even possible to define large classes of phenomena where prediction and control are simply impossible for very basic but quite understandable reasons. Perhaps the most familiar example of this class of phenomena is the breaking of any superficially homogeneous material, such as glass. The Brownian movement (see Glossary) of molecules in liquids and gases is similarly unpredictable.

If I throw a stone at a glass window, I shall, under appropriate circumstances, break or crack the glass in a star-shaped pattern. If my stone hits the glass as fast as a bullet, it is possible that it will detach from the glass a neat conical plug called a cone of percussion. If my stone is too slow and too small, I may fail to break the glass at all. Prediction and control will be quite possible at this level. I can easily make sure which of three results (the star, the percussion cone, or no breakage) I shall achieve, provided I avoid marginal strengths of throw.

But within the conditions which produce the star-shaped break, it will be impossible to predict or control the pathways and the positions of the arms of the stars.

Curiously enough, the more precise my laboratory methods, the more unpredictable the events will become. If I use the most homogeneous glass available, polish its surface to the most exact optical flatness, and control the motion of my stone as precisely as possible, ensuring an almost precisely vertical impact on the surface of the glass, all my efforts will only make the events more impossible to predict.

If, on the other hand, I scratch the surface of the glass or use a piece of glass that is already cracked (which would be cheating), I shall be able to make some approximate predictions. For some reason (unknown to me), the break in the glass will run parallel to the scratch and about 1/100 of an inch to the side, so that the scratch mark will appear on only one side of the break. Beyond the end of the scratch, the break will veer off unpredictably.

Under tension, a chain will break at its weakest link. That much is predictable. What is difficult is to identify the weakest link before it breaks. The generic we can know, but the specific eludes us. Some chains are designed to break at a certain tension and at a certain link. But a good chain is homogeneous, and no prediction is possible. And because we cannot know which link is weakest, we cannot know precisely how much tension will be needed to break the chain.

If we heat a clear liquid (say, clean distilled water) in a clean, smooth beaker, at what point will the first
bubble of steam appear? At what temperature? And at what instant?

These questions are unanswerable unless there is a tiny roughness in the inner surface of the beaker or a speck of dust in the liquid. In the absence of such an evident nucleus for the beginning of the change of state, no prediction is possible; and because we cannot say where the change will start, we also cannot say when. Therefore, we cannot say at what temperature boiling will begin.

If the experiment is critically performed—that is, if the water is very clean and the beaker very smooth—there will be some superheating. In the end, the water will boil. In the end, there will always be a difference that can serve as the nucleus for the change. In the end, the superheated liquid will “find” this differentiated spot and will boil explosively for a few moments until the temperature is reduced to the regular boiling point appropriate to the surrounding barometric pressure.

The freezing of liquid is similar, as is the falling out of crystals from a supersaturated solution. A nucleus—that is, a differentiated point, which in the case of a supersaturated solution may, indeed, be a microscopic crystal—is needed for the process to start.

We shall note elsewhere in this book that there is a deep gulf between statements about an identified individual and statements about a class. Such statements are of different logical type, and prediction from one to the other is always unsure. The statement “The liquid is boiling” is of different logical type from the statement “That molecule will be the first to go.”

This matter has a number of sorts of relevance to the theory of history, to the philosophy behind evolutionary theory, and in general, to our understanding of the world in which we live.

In the theory of history, Marxian philosophy, following Tolstoi, insists that the great men who have been the historic nuclei for profound social change or invention are, in a certain sense, irrelevant to the changes they precipitated. It is argued, for example, that in 1859, the occidental world was ready and ripe (perhaps overripe) to create and receive a theory of evolution that could reflect and justify the ethics of the Industrial Revolution. From that point of view, Charles Darwin himself could be made to appear unimportant. He had not put out his theory, somebody else would have put out a similar theory within the next five years. Indeed, the parallelism between Alfred Russel Wallace’s theory and that of Darwin would seem at first sight to support this view.

The Marxians would, as I understand it, argue that there is bound to be a weakest link, that under appropriate social forces† or tensions, some individual will be the first to start the trend, and that it does not matter who.

But, of course, it does matter who starts the trend. If it had been Wallace instead of Darwin, we would have had a very different theory of evolution today. The whole cybernetics movement might have occurred 100 years earlier as a result of Wallace’s comparison between the steam engine with a governor and the process of natural selection. Or perhaps the big theoretical step might have occurred in France and evolved from the ideas of Claude Bernard who in the late nineteenth century, discovered what later came to be called the homeostasis of the body. He observed that the milieu interne—the internal environment—was balanced or self-correcting.

It is, I claim, nonsense to say that it does not matter.

† The story is worth repeating. Wallace was a young naturalist who, in 1856 (three years before the publication of Darwin’s Origin), while in the rain forests of Ternate, Indonesia, had an attack of malaria and, following delirium, a psychedelic experience in which he discovered the principle of natural selection. He wrote this out in a long letter to Darwin. In this letter he explained his discovery in the following words: “The notion of this principle is exactly like that of the centrifugal governor of the steam engine, which checks and corrects any irregularities almost before they become evident; and in like manner no unbalanced deficiency in the animal kingdom can ever reach any conspicuous magnitude because it would make itself felt at the very first step, by rendering existence difficult and extinction almost sure to follow.” (Reprinted in Darwin, a Norton Critical Edition, ed. Philip Appleman, W. W. Norton, 1970).

† Notice the use of physical metaphor, inappropriate to the crustal phenomena being discussed. Indeed, it may be argued that this whole comparison between social biological matters, on the one hand, and physical processes, on the other, is a monstrous use of inappropriate metaphor.
which individual man acted as the nucleus for the change. *It is precisely this that makes history unpredictable into the future.* The Marxian error is a simple blunder in logical typing, a confusion of individual with class.

7. **CONVERGENT SEQUENCES ARE PREDICTABLE**

This generality is the converse of the generality examined in section 6, and the relation between the two depends on the contrast between the concepts of divergence and convergence. This contrast is a special case, although a very fundamental one, of the difference between successive levels in a Russellian hierarchy, a matter to be discussed in Chapter 4. For the moment, it should be noted that the components of a Russellian hierarchy are to each other as member to class, as class to class of classes, or as thing named to name.

What is important about divergent sequences is that our description of them concerns individuals, especially individual molecules. The crack in the glass, the first step in the beginning of the boiling of water, and all the rest are cases in which the location and instant of the event is determined by some momentary constellation of a small number of individual molecules. Similarly, any description of the pathways of individual molecules in Brownian movement allows for no extrapolation. What happens at one moment, even if we could know it, would not give us data to predict that will happen at the next.

In contrast, the movement of planets in the solar system, the trend of a chemical reaction in an ionic mixture of salts, the impact of billiard balls, which involves millions of molecules—all are predictable because our description of the events has as its subject matter the behavior of immense crowds or classes of individuals. It is this that gives science some justification for statistics, providing the statistician always remembers that his statements have reference only to aggregates.

In this sense, the so-called laws of probability mediate between descriptions of the behavior of the individual and descriptions of that of the gross crowd. We shall see later that this particular sort of conflict between the individual and the statistical has dogged the development of evolutionary theory from the time of Lamarck onward. If Lamarck had asserted that changes in environment would affect the general characteristics of whole populations, he would have been in step with the latest genetic experiments such as those of Waddington on genetic assimilation, to be discussed in Chapter 6. But Lamarck and, indeed, his followers ever since have seemed to have an innate proclivity for confusion of logical types. (This matter and the corresponding confusions of orthodox evolutionists will be discussed in Chapter 6.)

Be all that as it may, in the stochastic processes (see Glossary) either of evolution or of thought, the new can be plucked from nowhere but the random. And to pluck the new from the random, if and when it happens to show itself, requires some sort of selective machinery to account for the ongoing persistence of the new idea. Something like natural selection, in all its truism and tautology, must obtain. To persist, the new must be of such a sort that it will endure longer than the alternatives. What lasts longer among the ripples of the random must last longer than those ripples that last not so long. That is the theory of natural selection in a nutshell.

The Marxian view of history—which in its crudest form would argue that if Darwin had not written *The Origin of Species,* somebody else would have produced a similar book within the next five years—is an unfortunate effort to apply a theory that would view social process as convergent to events involving unique human beings. The error is, again, one of logical typing.

8. **"NOTHING WILL COME OF NOTHING"**

This quotation from *King Lear* telescopes into a single utterance a whole series of medieval and more modern wise saws. These include:
a. The law of the conservation of matter and its converse, that no new matter can be expected to appear in the laboratory. (Lucretius said, "Nothing can ever be created out of nothing by divine power." *)

b. The law of the conservation of energy and its converse, that no new energy can be expected in the laboratory.

c. The principle demonstrated by Pasteur, that no new living matter can be expected to appear in the laboratory.

d. The principle that no new order or pattern can be created without information.

Of all these and other similar negative statements, it may be said that they are rules for expectation rather than laws of nature. They are so nearly true that all exceptions are of extreme interest.

What is especially interesting is hidden in the relations between these profound negations. For example, we know today that between the conservation of energy and the conservation of matter, there is a bridge whereby each of these negations is itself negated by an interchange of matter into energy and, presumably, of energy into matter.

In the present connection, however, it is the last of the series that is of chief interest, the proposition that in the realms of communication, organization, thought, learning, and evolution, "nothing will come of nothing" without information.

This law differs from the conservative laws of energy and mass in that it contains no clause to deny the destruction and loss of information, pattern, or negative entropy. Alas—but also be glad of it—pattern and/or information is all too easily eaten up by the random. The messages and guidelines for order exist only, as it were, in sand or are written on the surface of waters. Almost any disturbance, even mere Brownian movement, will destroy them. Information can be forgotten or blurred. The code books can be lost.


The messages cease to be messages when nobody can read them. Without a Rosetta stone, we would know nothing of all that was written in Egyptian hieroglyphs. They would be only elegant ornaments on papyrus or rock. To be meaningful—even to be recognized as pattern—every regularity must meet with complementary regularities, perhaps skills, and these skills are as evanescent as the patterns themselves. They, too, are written on sand or the surface of waters.

The genesis of the skill to respond to the message is the obverse, the other side of the process of evolution. It is coevolution (see Glossary).

Paradoxically, the deep partial truth that "nothing will come of nothing" in the world of information and organization encounters an interesting contradiction in the circumstance that zero, the complete absence of any indicative event, can be a message. The larval tick climbs a tree and waits on some outer twig. If he smells sweat, he falls, perhaps landing on a mammal. But if he smells no sweat after some weeks, he falls and goes to climb another tree.

The letter that you do not write, the apology you do not offer, the food that you do not put out for the cat—all these can be sufficient and effective messages because zero, in context, can be meaningful; and it is the recipient of the message who creates the context. This power to create context is the recipient's skill; to acquire which is his half of the coevolution mentioned above. He or she must acquire that skill by learning or by lucky mutation, that is, by a successful raid on the random. The recipient must be, in some sense, ready for the appropriate discovery when it comes.

Thus, the converse of the proposition that "nothing will come of nothing" without information is conceivably possible with stochastic process. Readiness can serve to select components of the random which thereby become new information. But always a supply of random appearances must be available from which new information can be made.

This circumstance splits the entire field of organization, evolution, maturation and learning, into two separate realms, of which one is the realm of epigenesis,
or embryology, and the other the realm of evolution and learning.

Epigenesis is the word preferred by C. H. Waddington for his central field of interest, whose old name was embryology. It stresses the fact that every embryological step is an act of becoming (Greek genesis) which must be built upon (Greek epi) the immediate status quo ante. Characteristically, Waddington was contemptuous of conventional information theory, which allowed nothing, as he saw it, for the “new” information he felt was generated at each stage of epigenesis. Indeed, according to conventional theory, there is no new information in this case.

Ideally, epigenesis should resemble the development of a complex tautology (see Glossary) in which nothing is added after the axioms and definitions have been laid down. The Pythagorean theorem is implicit (i.e., already folded into) Euclid’s axioms, definitions, and postulates. All that is required is its unfolding and, for human beings, some knowledge of the order of steps to be taken. This latter species of information will become necessary only when Euclid’s tautology is modeled in words and symbols sequentially arranged on paper or in time. In the ideal tautology, there is no time, no unfolding, and no argument. What is implicit is there, but, of course, not located in space.

In contrast with epigenesis and tautology, which constitute the worlds of replication, there is the whole realm of creativity, art, learning, and evolution, in which the ongoing processes of change feed on the random. The essence of epigenesis is predictable repetition; the essence of learning and evolution is exploration and change.

In the transmission of human culture, people always attempt to replicate, to pass on to the next generation the skills and values of the parents; but the attempt always and inevitably fails because cultural transmission is geared to learning, not to DNA. The process of transmission of culture is a sort of hybrid or mix-up of the two realms. It must attempt to use the phenomena of learning for the purpose of replication because what the parents have been learned by them. If the off-spring miraculously had the DNA that would give them the parental skills, those skills would be different and perhaps nonviable.

It is interesting that between the two worlds is the cultural phenomenon of explanation—the mapping onto a tautology of unfamiliar sequences of events.

Finally, it will be noted that the realms of epigenesis and of evolution are, at a deeper level, typified in the twin paradigms of the second law of thermodynamics: (1) that the random workings of probability will always eat up order, pattern, and negative entropy but (2) that for the creation of new order, the workings of the random, the plethora of uncommitted alternatives (entropy) is necessary. It is out of the random that organisms collect new mutations, and it is there that stochastic learning gathers its solutions. Evolution leads to climax: ecological saturation of all the possibilities of differentiation. Learning leads to the overpacked mind. By return to the unlearned and mass-produced egg, the ongoing species again and again clears its memory banks to be ready for the new.

9. NUMBER IS DIFFERENT FROM QUANTITY

This difference is basic for any sort of theorizing in behavioral science, for any sort of imagining of what goes on between organisms or inside organisms as part of their processes of thought.

Numbers are the product of counting. Quantities are the product of measurement. This means that num-

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*I use the phrase, *to map onto*, for the following reasons: All description, explanation, or representation is necessarily in some sense a mapping of derivatives from the phenomena to be described onto some surface or network of coordinates. In the case of an actual map, the receiving matrix is commonly a flat sheet of paper of finite extent, and difficulties occur when that which is to be mapped is too big or, for example, spherical. Other difficulties would be generated if the receiving matrix were the surface of a torus (doughnut), or if it were a discontinuous linear sequence of points. Every receiving matrix, even a language or a taxonomical network of propositions, will have its formal characteristics which will *in principle* be distinctive of the phenomena to be mapped onto it. The universe was, perhaps, designed by Procrustes, that sinister character of Greek mythology in whose inn every traveler had to fit the bed on pain of amputation or elongation of the legs.
bers can conceivably be accurate because there is a discontinuity between each integer and the next. Between two and three, there is a jump. In the case of quantity, there is no such jump; and because jump is missing in the world of quantity, it is impossible for any quantity to be exact. You can have exactly three tomatoes. You can never have exactly three gallons of water. Always quantity is approximate.

Even when number and quantity are clearly discriminated, there is another concept that must be recognized and distinguished from both number and quantity. For this other concept, there is, I think, no English word, so we have to be content with remembering that there is a subset of patterns whose members are commonly called “numbers.” Not all numbers are the products of counting. Indeed, it is the smaller, and therefore commoner, numbers that are often not counted but recognized as patterns at a single glance. Card-players do not stop to count the pips in the eight of spades and can even recognize the characteristic patterning of pips up to “ten.”

In other words, number is of the world of pattern, gestalt, and digital computation; quantity is of the world of analogic and probabilistic computation.

Some birds can somehow distinguish number up to seven. But whether this is done by counting or by pattern recognition is not known. The experiment that came closest to testing this difference between the two methods was performed by Otto Koehler with a jackdaw. The bird was trained to the following routine: A number of small cups with lids are set out. In these cups, small pieces of meat are placed. Some cups have one piece of meat, some have two or three, and some cups have none. Separate from the cups, there is a plate on which there is a number of pieces of meat greater than the total number of pieces in the cups. The jackdaw learns to open each cup, taking off the lid, and then eats any pieces of meat that are in the cup. Finally, when he has eaten all the meat in the cups, he may go to the plate and there eat the same number of pieces of meat that he got from the cups. The bird is punished if he eats more meat from the plate than was in the cups. This routine he is able to learn.

Now, the question is: Is the jackdaw counting the pieces of meat, or is he using some alternative method of identifying the number of pieces? The experiment has been carefully designed to push the bird toward counting. His actions are interrupted by his having to lift the lids, and the sequence has been further confused by having some cups contain more than one piece of meat and some contain none. By these devices, the experimenter has tried to make it impossible for the jackdaw to create some sort of pattern or rhythm by which to recognize the number of the pieces of meat. The bird is thus forced, so far as the experimenter could force the matter, to count the pieces of meat.

It is still conceivable, of course, that the taking of the meat from the cups becomes some sort of rhythmic dance and that this rhythm is in some way repeated when the bird takes the meat from the plate. The matter is still conceivably in doubt, but on the whole, the experiment is rather convincing in favor of the hypothesis that the jackdaw is counting the pieces of meat rather than recognizing a pattern either of pieces or of his own actions.

It is interesting to look at the biological world in terms of this question: Should the various instances in which number is exhibited be regarded as instances of gestalt, of counted number, or of mere quantity? There is a rather conspicuous difference between, for example, the statement “This single rose has five petals, and it has five sepals, and indeed its symmetry is of a pentad pattern,” and the statement “This rose has one hundred and twelve stamens, and that other has ninety-seven, and this has only sixty-four.” The process which controls the number of stamens is surely different from the process that controls the number of petals or sepals. And, interestingly, in the double rose, what seems to have happened is that some of the stamens have been converted into petals, so that the process for determining how many petals to make has now become, not the normal process delimiting petals to a pattern of five,
but more like the process determining the quantity of stamens. We may say that petals are normally "five" in the single rose but that stamens are "many" where "many" is a quantity that will vary from one rose to another.

With this difference in mind, we can look at the biological world and ask what is the largest number that the processes of growth can handle as a fixed pattern, beyond which the matter is handled as quantity. So far as I know, the "numbers" two, three, four, and five are the common ones in symmetry of plants and animals, particularly in radial symmetry.

The reader may find pleasure in collecting cases of rigidly controlled or patterned numbers in nature. For some reason, the larger numbers seem to be confined to linear series of segments, such as the vertebrae of mammals, the abdominal segments of insects, and the anterior segmentation of earthworms. (At the front end, the segmentation is rather rigidly controlled down to the segments bearing genital organs. The numbers vary with the species but may reach fifteen. After that, the tail has "many" segments.) An interesting addition to these observations is the common circumstance that an organism, having chosen a number for the radial symmetry of some set of parts, will repeat that number in other parts. A lily has three sepals and then three petals and then six stamens and a trilocular ovary.

It appears that what seemed to be a quirk or peculiarity of human operation—namely, that we occidental humans get numbers by counting or pattern recognition while we get quantities by measurement—turns out to be some sort of universal truth. Not only the jackdaw but also the rose are constrained to show that for them, too—for the rose in its anatomy and for the jackdaw in its behavior (and, of course, in its vertebral segmentation)—there is this profound difference between numbers and quantity.

What does this mean? That question is very ancient and certainly goes back to Pythagoras, who is said to have encountered a similar regularity in the relation between harmonies.

The hexago-rectangle discussed in section 5 provides a means of posing these questions. We saw, in that case, that the components of description could be quite various. In that particular case, to attach more validity to one rather than to another way of organizing the description would be to indulge illusion. But in this matter of biological numbers and quantities, it seems that we encounter something more profound. Does this case differ from that of the hexago-rectangle? And if so, how?

I suggest that neither case is as trivial as the problem of the hexago-rectangle seemed to be at first sight. We go back to the eternal verities of Saint Augustine: "Listen to the thunder of that saint, in about A.D. 500: 7 and 3 are 10; 7 and 3 have always been 10; 7 and 3 at no time and in no way have ever been anything but 10; 7 and 3 will always be 10."*—

No doubt, in asserting the contrast between numbers and quantities, I am close to asserting an eternal verity, and Augustine would surely agree.

But we can reply to the saint, "Yes, very true. But is that really what you want and mean to say? It is also true, surely, that 3 and 7 are 10, and that 2 and 1 and 7 are 10, and that 1 and 1 and 1 and 1 and 1 and 1 and 1 and 1 and 1 are 10. In fact, the eternal verity that you are trying to assert is much more general and profound than the special case used by you to carry that profound message." But we can agree that the more abstract eternal verity will be difficult to state with unambiguous precision.

In other words, it is possible that many of the ways of describing my hexago-rectangle could be only different surfacings of the same more profound and more general tautology (where Euclidean geometry is viewed as a tautological system).

It is, I think, correct to say, not only that the various phrasings of the description of the hexago-rectangle ultimately agree about what the describers thought they saw but also that there is an agreement about a single more general and profound tautology in terms of which the various descriptions are organized.

In this sense, the distinction between numbers and quantities is, I believe, nontrivial and is shown to be so by the anatomy of the rose with its "5" petals and its "many" stamens, and I have put quotation marks into my description of the rose to suggest that the names of the numbers and of the quantities are the surfacing of formal ideas, immanent within the growing rose.

10. QUANTITATIVE DOES NOT DETERMINE PATTERN

It is impossible, in principle, to explain any pattern by invoking a single quantity. But note that a ratio between two quantities is already the beginning of pattern. In other words, quantity and pattern are of different logical type* and do not readily fit together in the same thinking.

What appears to be a genesis of pattern by quantity arises where the pattern was latent before the quantity had impact on the system. The familiar case is that of tension which will break a chain at the weakest link. Under change of a quantity, tension, a latent difference is made manifest or, as the photographers would say, developed. The development of a photographic negative is precisely the making manifest of latent differences laid down in the photographic emulsion by previous differential exposure to light.

Imagine an island with two mountains on it. A quantitative change, a rise, in the level of the ocean may convert this single island into two islands. This will happen at the point where the level of the ocean rises higher than the saddle between the two mountains. Again, the qualitative pattern was latent before the quantity had impact on it; and when the pattern changed, the change was sudden and discontinuous.

11. THERE ARE NO MONOTONE "VALUES" IN BIOLOGY

A monotone value is one that either only increases or only decreases. Its curve has no kinks; that is, its curve never changes from increase to decrease or vice versa. Desired substances, things, patterns, or sequences of experience that are in some sense "good" for the organism—items of diet, conditions of life, temperature, entertainment, sex, and so forth—are never such that more of the something is always better than less of the something. Rather, for all objects and experiences, there is a quantity that has optimum value. Above that quantity, the variable becomes toxic. To fall below that value is to be deprived.

This characteristic of biological value does not hold for money. Money is always transitively valued. More money is supposedly always better than less money. For example, $1001 is to be preferred to $1,000. But this is not so for biological values. More calcium is not always better than less calcium. There is an optimum quantity of calcium that a given organism may need in its diet. Beyond this, calcium becomes toxic. Similarly, for oxygen that we breathe or foods or components of diet and probably all components of relationship, enough is better than a feast. We can even have too much psychotherapy. A relationship with no combat is dull, and a relationship with too much combat is toxic. What is desirable is a relationship with a certain optimum of conflict. It is even possible that when we consider money, not by itself, but as acting on human beings who own it, we may find that money, too, becomes toxic beyond a certain point. In any case,
the philosophy of money, the set of presuppositions by which money is supposedly better and better the more you have of it, is totally antibiological. It seems, nevertheless, that this philosophy can be taught to living things.

12. SOMETIMES SMALL IS BEAUTIFUL

Perhaps no variable brings the problems of being alive so vividly and clearly before the analyst’s eye as does size. The elephant is afflicted with the problems of bigness; the shrew, with those of smallness. But for each, there is an optimum size. The elephant would not be better off if he were much smaller, nor would the shrew be relieved by being much bigger. We may say that each is addicted to the size that is.

There are purely physical problems of bigness or smallness, problems that affect the solar system, the bridge, and the wristwatch. But in addition to these, there are problems special to aggregates of living matter, whether these be single creatures or whole cities.

Let us first look at the physical. Problems of mechanical instability arise because, for example, the forces of gravity do not follow the same quantitative regularities as those of cohesion. A large clod of earth is easier to break by dropping it on the ground than is a small one. The glacier grows and therefore, partly melting and partly breaking, must begin a changed existence in the form of avalanches, smaller units that must fall off the larger matrix. Conversely, even in the physical universe, the very small may become unstable because the relation between surface area and weight is nonlinear. We break up any material which we wish to dissolve because the smaller pieces have a greater ratio of surface to volume and will therefore give more access to the solvent. The larger lumps will be the last to disappear. And so on.

To carry these thoughts over into the more complex world of living things, a fable may be offered:

THE TALE OF THE POLYPLOID HORSE

They say the Nobel people are still embarrassed when anybody mentions polyploid horses. Anyhow, Dr. P. U. Posif, the great Brewhonian genetist, got his prize in the late 1980s for jiggling with the DNA of the common cart horse (Equus caballus). It was said that he made a great contribution to the then new science of transportology. At any rate, he got his prize for creating—no other word would be good enough for a piece of applied science so nearly usurping the role of deity—creating, I say, a horse precisely twice the size of the ordinary Clydesdale. It was twice as long, twice as high, and twice as thick. It was a polyploid, with four times the usual number of chromosomes.

P. U. Posif always claimed that there was a time, when this wonderful animal was still a colt, when it was able to stand on its four legs. A wonderful sight it must have been! But anyhow, by the time the horse was shown to the public and recorded with all the communicational devices of modern civilization, the horse was not doing any standing. In a word, it was too heavy. It weighed, of course, eight times as much as a normal Clydesdale.

For a public showing and for the media, Dr. Posif always insisted on turning off the horses that were continuously necessary to keep the beast at normal mammalian temperature. But we were always afraid that the innermost parts would begin to cook. After all, the poor beast’s skin and dermal fat were twice as thick as normal, and its surface area was only four times that of a normal horse, so it didn’t cool properly.

Every morning, the horse had to be raised to its feet with the aid of a small crane and hung in a sort of box on wheels, in which it was suspended on springs, adjusted to take half its weight off its legs.

Dr. Posif used to claim that the animal was outstandingly intelligent. It had, of course, eight times as much brain (by weight) as any other horse,
but I could never see that it was concerned with any questions more complex than those which interest other horses. It had very little free time, what with one thing and another—always panting, partly to keep cool and partly to oxygenate its eight-times body. Its windpipe, after all, had only four times the normal area of cross section.

And then there was eating. Somehow it had to eat, every day, eight times the amount that would satisfy a normal horse and had to push all that food down an esophagus only four times the caliber of the normal. The blood vessels, too, were reduced in relative size, and this made circulation more difficult and put extra strain on the heart.

A sad beast.

The fable shows what inevitably happens when two or more variables, whose curves are discrepant, interact. That is what produces the interaction between change and tolerance. For instance, gradual growth in a population, whether of automobiles or of people, has no perceptible effect upon a transportation system until suddenly the threshold of tolerance is passed and the traffic jams. The changing of one variable exposes a critical value of the other.

Of all such cases, the best known today is the behavior of fissionable material in the atom bomb. The uranium occurs in nature and is continually undergoing fission, but no explosion occurs because no chain reaction is established. Each atom, as it breaks, gives off neutrons that, if they hit another uranium atom, may cause fission, but many neutrons are merely lost. Unless the lump of uranium is of critical size, an average of less than one neutron from each fission will break another atom, and the chain will dwindle. If the lump is made bigger, a larger fraction of the neutrons will hit uranium atoms to cause fission. The process will then achieve positive exponential gain and become an explosion.

In the case of the imaginary horse, length, surface area, and volume (or mass) become discrepant because their curves of increase have mutually nonlinear characteristics. Surface varies as the square of length, volume varies as the cube of length, and surface varies as the \( \frac{2}{3} \) power of volume.

For the horse (and for all real creatures), the matter becomes more serious because to remain alive, many internal motions must be maintained. There is an internal logistics of blood, food, oxygen, and excretory products and a logistics of information in the form of neural and hormonal messages.

The harbor porpoise, which is about three feet long, with a jacket of blubber about one inch thick and a surface area of about six square feet, has a known heat budget that balances comfortably in Arctic waters. The heat budget of a big whale, which is about ten times the length of the porpoise (i.e., 1,000 times the volume and 100 times the surface), with a blubber jacket nearly twelve inches thick, is totally mysterious. Presumably, they have a superior logistic system moving blood through the dorsal fins and tail flukes, where all cetaceans get rid of heat.

The fact of growth adds another order of complexity to the problems of bigness in living things. Will growth alter the proportions of the organism? These problems of the limitation of growth are met in very different ways by different creatures.

A simple case is that of the palms, which do not adjust their girth to compensate for their height. An oak tree with growing tissue (cambium) between its wood, and its bark grows in length and width throughout its life. But a coconut palm, whose only growing tissue is at the apex of the trunk (the so-called millionaire's salad, which can only be got at the price of killing the palm), simply gets taller and taller, with some slow increase of the bole at its base. For this organism, the limitation of height is simply a normal part of its adaptation to a niche. The sheer mechanical instability of excessive height without compensation in girth provides its normal way of death.

Many plants avoid (or solve?) these problems of the limitation of growth by linking their life-span to the calendar or to their own reproductive cycle. Annuals
start a new generation each year, and plants like the
so-called century plant (yuca) may live many years but, like the salmon, inevitably die when they repro-
duce. Except for multiple branching within the flowering
head, the yuca makes no branches. The branching
fluorescence itself is its terminal stem; when that has
completed its function, the plant dies. Its death is
normal to its way of life.

Among some higher animals, growth is controlled.
The creature reaches a size or age or stage at which
growth simply stops (i.e., is stopped by chemical or
other messages within the organization of the creature).
The cells, under control, cease to grow and divide.
When controls no longer operate (by failure to generate
the message or failure to receive it), the result is cancer.
Where do such messages originate, what triggers their
sending, and in what presumably chemical code are
these messages immanent? What controls the nearly
perfect external bilateral symmetry of the mammalian
body? We have remarkably little knowledge of the
message system that controls growth. There must be a
whole interlocking system as yet scarcely studied.

13. LOGIC IS A POOR MODEL OF CAUSE
AND EFFECT

We use the same words to talk about logical
sequences and about sequences of cause and effect. We
say, "If Euclid's definitions and postulates are accepted,
then two triangles having three sides of one equal
to three sides of the other are equal each to each." And
we say, "If the temperature falls below 0°C, then the
water begins to become ice."

But the if . . . then of logic in the syllogism is very
different from the if . . . then of cause and effect.

In a computer, which works by cause and effect,
with one transistor triggering another, the sequences
of cause and effect are used to simulate logic. Thirty
years ago, we used to ask: Can a computer simulate all
the processes of logic? The answer was yes, but the
question was surely wrong. We should have asked: Can
logic simulate all sequences of cause and effect? And
the answer would have been no.

When the sequences of cause and effect become
circular (or more complex than circular), then the
description or mapping of those sequences onto time-
less logic becomes self-contradictory. Paradoxes are
generated that pure logic cannot tolerate. An ordinary
buzzer circuit will serve as an example, a single instance
of the apparent paradoxes generated in a million cases
of homeostasis throughout biology. The buzzer circuit
(see Figure 3) is so rigged that current will pass around
the circuit when the armature makes contact with the
electrode at A. But the passage of current activates the
electromagnet that will draw the armature away, break-
ing the contact at A. The current will then cease to pass
around the circuit, the electromagnet will become in-
active, and the armature will return to make contact at
A and so repeat the cycle.

Figure 3

If we spell out this cycle onto a causal sequence,
we get the following:

If contact is made at A, then the magnet is activated.
If the magnet is activated, then contact at A is broken.
If contact at A is broken, then the magnet is inactivated.
If magnet is inactivated, then contact is made.

This sequence is perfectly satisfactory provided it is
clearly understood that the if . . . then junctures are
causal. But the bad pun that would move the if's and then's over into the world of logic will create havoc:

*If the contact is made, then the contact is broken.*
*If P, then not P.*

The *if...then* of causality contains *time*, but the *if...then* of logic is timeless. It follows that logic is an incomplete model of causality.

14. CAUSALITY DOES NOT WORK BACKWARD

Logic can often be reversed, but the effect does not precede the cause. This generalization has been a stumbling block for the psychological and biological sciences since the times of Plato and Aristotle. The Greeks were inclined to believe in what were later called *final* causes. They believed that the pattern generated at the end of a sequence of events could be regarded as in some way causal of the pathway followed by that sequence. This led to the whole of teleology, as it was called (*telos* meaning the end or purpose of a sequence).

The problem which confronted biological thinkers was the problem of adaptation. It appeared that a crab had claws in order to hold things. The difficulty was always in arguing backward from the purpose of claws to the causation of the development of claws. For a long time, it was considered heretical in biology to believe that claws were there *because* they were useful. This belief contained the teleological fallacy, an inversion of causality in time.

Linear thinking will always generate either the teleological fallacy (that end determines process) or the myth of some supernatural controlling agency.

What is the case is that when causal systems become circular (a matter to be discussed in Chapter 4), a change in any part of the circle can be regarded as cause for change at a later time in any variable anywhere in the circle. It thus appears that a rise in the temperature of the room can be regarded as the cause of the change in the switch of the thermostat and, alternatively, that the action of the thermostat can be regarded as controlling the temperature of the room.

15. LANGUAGE COMMONLY STRESSES ONLY ONE SIDE OF ANY INTERACTION

We commonly speak as though a single “thing” could “have” some characteristic. A stone, we say, is “hard,” “small,” “heavy,” “yellow,” “dense,” “fragile,” “hot,” “moving,” “stationary,” “visible,” “edible,” “indefinite,” and so on.

That is how our language is made: “The stone is hard.” And so on. And that way of talking is good enough for the marketplace: “That is a new brand.” “The potatoes are rotten.” “The eggs are fresh.” “The container is damaged.” “The diamond is flawed.” “A pound of apples is enough.” And so on.

But this way of talking is not good enough in science or epistemology. To think straight, it is advisable to expect all qualities and attributes, adjectives, and so on to refer to at least two sets of interactions in time.

“The stone is hard” means a) that when poked it resisted penetration and b) that certain continual interactions among the molecular *parts* of the stone in some way bond the parts together.

“The stone is stationary” comments on the location of the stone relative to the location of the speaker and other possible moving things. It also comments on matters internal to the stone: its inertia, lack of internal distortion, lack of friction at the surface, and so on.

Language continually asserts by the syntax of subject and predicate that “things” somehow “have” qualities and attributes. A more precise way of talking would insist that the “things” are produced, are seen as separate from other things, and are made “real” by their internal relations and by their behavior in relationship with other things and with the speaker.
It is necessary to be quite clear about the universal truth that whatever "things" may be in their pleromatic and thingish world, they can only enter the world of communication and meaning by their names, their qualities and their attributes (i.e., by reports of their internal and external relations and interactions).

16. "STABILITY" and "CHANGE" DESCRIBE PARTS OF OUR DESCRIPTIONS

In other parts of this book, the word stable and also, necessarily, the word change will become very important. It is therefore wise to examine these words now in the introductory phase of our task. What traps do these words contain or conceal?

Stable is commonly used as an adjective applied to a thing. A chemical compound, house, ecosystem, or government is described as stable. If we pursue this matter further, we shall be told that the stable object is unchanging under the impact or stress of some particular external or internal variable or, perhaps, that it resists the passage of time.

If we start to investigate what lies behind this use of stability, we shall find a wide range of mechanisms. At the simplest level, we have simple physical hardness or viscosity, qualities descriptive of relations of impact between the stable object and some other. At more complex levels, the whole mass of interlocking processes called life may be involved in keeping our object in a state of change that can maintain some necessary constants, such as body temperature, blood circulation, blood sugar, or even life itself.

The acrobat on the high wire maintains his stability by continual correction of his imbalance.

These more complex examples suggest that when we use stability in talking about living things or self-corrective circuits, we should follow the example of the entities about which we are talking. For the acrobat on the high wire, his or her so-called "balance" is important; so, for the mammalian body, is its "tem-
various ways. It would be a nontrivial exercise to list the ways in which such verities or presuppositions may be connected. The grouping I have imposed is as follows:

A first cluster includes numbers 1 to 5, which seem to be related aspects of the necessary phenomenon of coding. Here, for example, the proposition that "science never proves anything" is rather easily recognized as a synonym for the distinction between map and territory; both follow from the Ames experiments and the generalization of natural history that "there is no objective experience."

It is interesting to note that on the abstract and philosophical side, this group of generalizations has to depend very closely on something like Occam's razor or the rule of parsimony. Without some such ultimate criterion, there is no ultimate way of choosing between one hypothesis and another. The criterion found necessary is of simplicity versus complexity. But along with these generalizations stands their connection with neurophysiology, Ames experiments, and the like. One wonders immediately whether the material on perception does not go along with the more philosophical material because the process of perception contains something like an Occam's razor or a criterion of parsimony. The discussion of wholes and parts in number 5 is a spelling out of a common form of transformation that occurs in those processes we call description.

Numbers 6, 7, and 8 form a second cluster, dealing with questions of the random and the ordered. The reader will observe that the notion that the new can be plucked only out of the random is in almost total contradiction to the inevitability of entropy. The whole matter of entropy and negentropy (see Glossary) and the contrasts between the set of generalities associated with these words and those associated with energy will be dealt with in Chapter 6 in the discussion of the economics of flexibility. Here it is only necessary to note the interesting formal analogy between the apparent contradiction in this cluster and the discrimination drawn in the third cluster, in which number 9 contrasts number with quantity. The sort of thinking that deals with quantity resembles in many ways the thinking that surrounds the concept of energy; whereas the concept of number is much more closely related to the concepts of pattern and negentropy.

The central mystery of evolution lies, of course, in the contrast between statements of the second law of thermodynamics and the observation that the new can only be plucked from the random. It was this contrast that Darwin partly resolved by his theory of natural selection.

The other two clusters in the list as given are 9 to 12 and 13 to 16. I will leave it to the reader to construct his or her phrasings of how these clusters are internally related and to create other clusters according to his/her own ways of thought.

In Chapter 3 I shall continue to sketch in the background of my thesis with a listing of generalities or presuppositions. I shall, however, come closer to the central problems of thought and evolution, trying to give answers to the question: In what ways can two or more items of information or command work together or in opposition? This question with its multiple answers seems to me to be central to any theory of thought or evolution.