The Dynamics of Information

Our time seems marked by a growing sense of being out of touch, of a too rapid growth in what there is to know. To deal effectively with informational problems, we need to understand the dynamics of information.

Each of us feels somewhat informed about his individual corner of the world. At the same time, we are aware that our understanding is incomplete. Each of us in his own way seeks to make sense out of his experience. Some spend their entire lives in increasing our understanding; they are scientists and scholars, not because of what they know but because of their persistence in seeking to know more. And indeed this innate curiosity is a ubiquitous part of all of us. Since these informational activities of others are themselves part of our experience, we seek as well to understand each other. And thus, the dynamics of information.

But the results of these separate acts of knowing are not converging. Our time seems marked by a growing sense of being out of touch, of a too rapid growth in what there is to know. Creativity itself seems suspect when so much that is created is beyond our ken. Our day is fraught with informational problems. To deal effectively with these problems, we need to understand these dynamics of information.

The Nature of Information

The process of becoming informed can be factored into two parts. The first of these is experiencing. It is by interacting directly with the reality that is around us that we gain the raw materials of information. But raw experience is not enough. We must organize experience into a conceptual structure before it is meaningful to us. Nor does this structure come from the experience itself. Rather, we must impose structure on our experience. The knower must actively participate in the act of knowing. The matter was put vividly by the American philosopher-scientist William James:

> The world's contents are given to each of us in an order
> so foreign to our subjective interests that we can hardly
> by an effort of the imagination picture to ourselves what it
> is really like. . . . Is not the sum of your actual experience
> taken at this moment and impartially added together an
> utter chaos? The strains of my voice, the lights and shades
> inside the room and out, the murmur of the wind, the
> ticking of the clock, the various organic feelings you may
> happen individually to possess, do these make a whole at
> all?. . . We break it; we break it into histories, and we
> break it into arts, and we break it into sciences;
> and then we begin to feel at home. . . . We discover among
> its various parts relations that were never given to sense
> at all; and out of an infinite number of these we call
> certain ones essential and law giving, and ignore the rest.

It is our subjective habit to organize the individual elements of our experience, to cross-correlate these

by Frederick B. Thompson

elements to others distant in space and time. It is only after this process of imposing organization that we feel informed.

Notice the essential role of abstraction and projection beyond what we have confirmed. Each moment of our experience is peculiar unto itself. It is only by ignoring differentiating aspects of past experience that we can see its application to current concerns. And these patterns that we exploit are not proffered by experience, which does not choose between the infinity that are there. They arise only when we back off and let the shadows of our own subjective structure cast perspective on our cluttered view. I am not questioning the objectivity of these patterns, once perceived. I am emphasizing the essential role of the subjective selection and imposition of organization that determines to as great an extent as experience itself the information that it yields.

Language and Conceptual Structure

Language is the embodiment of conceptual structure. We share our information with others. But to do so we must settle collectively on a structure into which our several experiences can be codified. It is this tacit, common structure that we exploit in communication. The essential characteristic of language is structure, as found in its word forms, its grammar, and its intrinsic logic. It is in the study of language that the common conceptual structures of a community are revealed.

Languages can give quite disparate perspective to the same experiences. This difference in languages, moreover, does not only refer to languages of different peoples. We often overlook the highly idiosyncratic nature of the varients of our own language. We often think a fluent native speaker speaks a common English. However, a moment's reflection brings us to realize that when we go from our work environment to our home, when we go from one class to another, we unconsciously shift from one idiolect—one form of thinking and communicating—to another.

I should like to use the notion of language in this more precise form as synonymous with conceptual structure. In particular I am not restricting it to verbal language. Think of the language that a person is using at any instant as the embodiment of the organization that he has imposed upon his experience and as the means for framing his current information. I should like to introduce the notion of an informational community as a group of people who share a common language, whose conceptual views are based upon a common structure. An individual can be
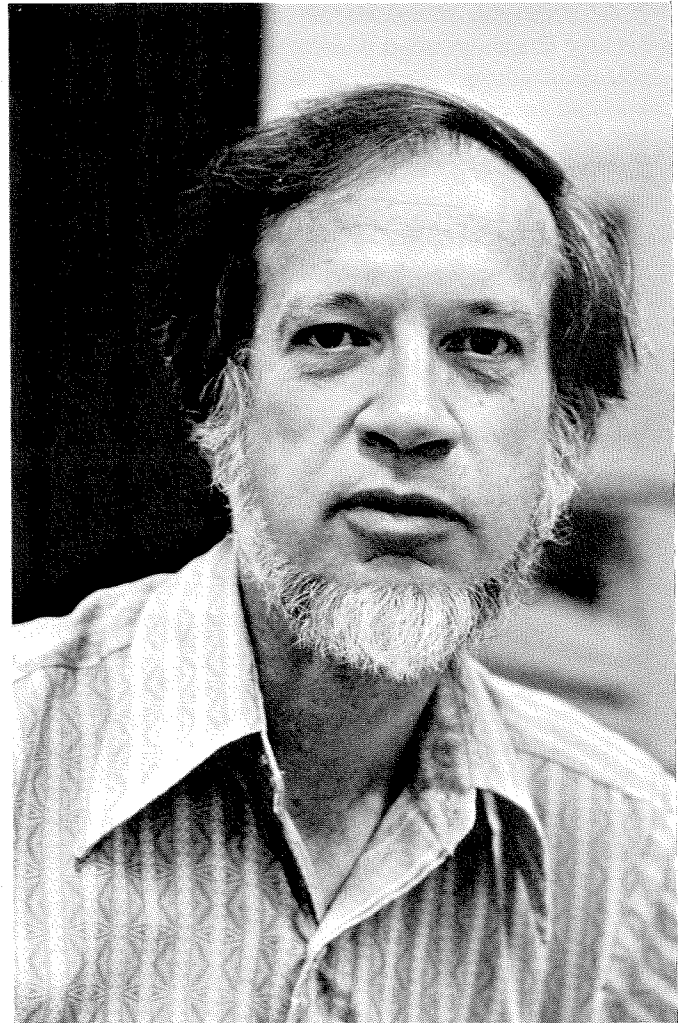
Frederick B. Thompson

considered as a special case of such a community. When looking at the dynamics of information, it is the community and its language which is the central focus.

The Dynamics of Information

Now let us imagine a situation where we have a certain fixed body of observations or experience. Let us compare what would happen if we were to organize and conceptualize this experience in terms of one language or another. Each language would reveal certain information from its peculiar point of view. The concepts and means of expression in one language might be just so as to be quite inadequate for the experience at hand, while another language may be ideally suited to elicit revealing insight.

One can construct for a formal language a measure of information. Thus given a language and a body of observations, we can define the amount of information that can be elicited from the given observations in terms of the conceptual structures provided by the language. Different languages yield different amounts of information about the same observations.

Languages can be compared in the amount of information they provide. When we say that one language (L_1) is at least as powerful as another (L_2), we mean that whatever distinctions between possible states of the universe can be made in L_2, they can be made in L_1. On the other hand one can show that for any formal language (L) there is a much more powerful language (L′) which can express things not possible in L. As a consequence there is no most powerful language.

Let's examine the situation wherein we have a family of more and more powerful languages. Again we will assume that we are considering a family E consisting of a number of observations. Thus for each language L, we can determine the amount of information $I(L,E)$ that can be obtained from E in terms of language L. Let L_0 be the least powerful language in which all aspects of the observations E can be fully expressed. In L_0, the experiences E can be completely described. The question is: What happens to the amount of information as we move to either more powerful or less powerful languages than L_0? What can be shown quite convincingly is somewhat surprising.

Consider a more powerful language, L_1. The observation E can be completely described in L_1, and more. Indeed, L_1 opens many issues which cannot be decided on the basis of E; it gives rise to ambiguities and uncertainties that cannot be resolved. It is not only the case that it distinguishes between two states that were
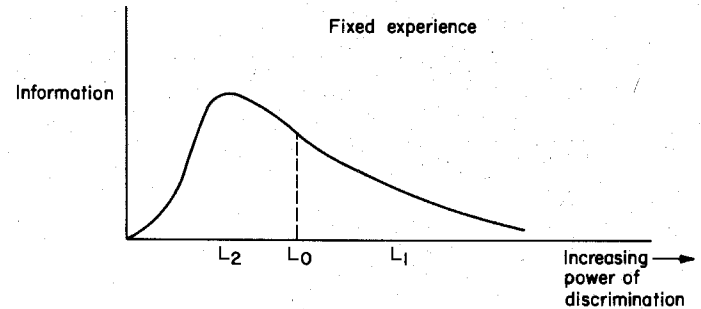
Information as a function of the conceptual structure made available by the underlying language. Each language determines the amount of information that can be obtained from a fixed body of experience.

indistinguishable in L_0, but it permits states that violated the logic of L_0, that could not exist as far as L_0 is concerned. A language is essentially a means of correlation of otherwise disparate experiences; thus it perforce must impose assumptions not inherent in the experience it explicates. It is this drastic extension of alternatives in the areas germain but unresolved by the experiences at hand that disrupts the correlations assumed in L_0, and causes information to fall.

What happens when we move to the left? Obviously, if we move all the way to the one-word language, we lose all information. Suppose there are certain aspects of each observation that do not reoccur in any systematic way in the other observations, thus appear random; one assumes them irrelevant. Others may occur quite regularly without perturbation in all the observations; whereupon one assumes their universal regularity, thus equating differentiable characteristics. This indeed is the process of induction, moving us to higher levels of abstraction. Thus there is an intermediate position in which information is maximized.

We maximize our information at a level of conceptualization above that of our raw experience. The very essence of science has been to find those highly abstract first principles and laws which encapsulate broad stretches of our experience.

**Our experience is not fixed
but ever extending. In the face
of changing experience, that
language which maximizes
our information also changes.**

Our experience is not fixed but ever extending. In the face of changing experience, that language which maximizes our information also changes. Indeed, this is our simple model of cognitive processes, a model of the dynamics of how we are informed. We constantly change our language in such a way as to maximize the information we can elicit from our experience. We constantly modify and adjust the forms and relationships into which we encapsulate our experience in such a way as to keep us maximally informed.

Creativity

Information processes, the processes by which we are informed, can thus be viewed as language change. Creativity is precisely such a process. To be creative is to impose upon experience a new structure which suddenly reveals insights which were obscured before. A poet's turn of phrase, a musician's variations on a simple melody, a painter's juxtaposition of shape and color, a dancer's mime in motion, all interpret anew things common to us all; and from these new interpretations we strangely draw a sense of knowing more.

The great moments of scientific advances are just such moments of new conceptualization. Copernicus moved the conceptual center of the universe from the earth to the sun. Kepler gave order to the confusing observations of the planets by placing them on an ethereal ellipse, tacked at a focus to the sun. Dalton observed the integral combinations of the elements in chemical compounds. Bohr gave us the basic model of the atom. Einstein grasped the absolute character of the speed of light. Each enormously expanded our information and opened highways for its further extension only by insightful shifts in conceptual structure.

But the innovative community is not an isolated thing. It exists in a wider culture. In this wider sense, the effect of creative change can be negative as well as positive. Great conceptual change calls for deep reverberating changes in the central conceptual structures that underpin whole cultures. For example, the Copernican shift shattered the image of man as central to the universe and thus opened to question the basic assumptions on which the religious institutions of the day were established. As we have already seen, this "opening to question" increases enormously the number of alternatives which have to be dealt with and thus reduces the information these expanded conceptual structures contain.

When one recalls that the previous views had themselves been constructed to be maximally informing in face of existing evidence, one can see how such a shift of view in one area can be a grave threat to the over-all conceptual accommodation of a society. As the cultural pattern of a society is built, a balance is maintained across the growing community that permits and enhances communication. If that balance is destroyed by an alien concept locally extended to account for local experience, it can drastically lower the information in the total society even while it increases sharply the local information. The global effect of a creative act must be analysed quite separately from the analysis which accounts for its local introduction.

A creative act is like an earth movement, an adjustment of local structure to the stresses built up by on-going processes of change, an accommodation to account for local experience. Like earthquakes, such creative adjustment of structure propagates throughout the conceptual structure of the society. And all along this propagating change, information falls as new alternatives are opened and uncertainty is increased. In a culture such as ours, there are continual occurrences of microquakes, thousands of quakes felt in local communities, and from time to time major conceptual quakes such as Darwin's announcement of evolution and the explosion of the first atomic weapon, which reverberate their unsettling implications throughout the society's cultural view.

Information Communities and Rates of Conceptual Change

A common language, a common conceptual view provides a community with a powerful tool. On such a basis, it can coordinate its activities, marshal its skills, share its experience. As a community increases its

information, it thereby increases its capabilities to meet its needs and to successfully adjust to its environment. It also increases its capability to gain information. The invention of the telephone added a small item of information to human knowledge, but this small piece of information, how to design a telephone, was multiplied manyfold by its impact on the information its use made readily available in the society. The processes of becoming informed are self-accelerating.

There are two roads open to a society faced with catastrophic fractionization of context, and we stand at the crossroads of these two paths today—the choice between the innovative society and the single conforming world.

What are the implications of this fact, the self-acceleration of information? As innovative change takes place in a community, it must be communicated throughout the community. The community's language must absorb the change, and all members of the community must recognize and adopt it. Communication takes time. The larger the community, the more time and effort are required to assimilate the result of innovative change. Thus the first conclusion we can draw is that community size must be inversely proportional to the rate of innovative change.

But information processes are self-accelerating; the rate of innovative change is increasing. As the community builds up a strong base of information, this base can be exploited on all sides. Innovation is stimulated at many places in the communitty. And if the community is to maintain itself, these changes must be communicated and absorbed. At some point in time, the rate of innovation becomes too great. People get out of touch. Some groups in the community are privy to information others do not have. Conflicts in view develop. The community fractionates. The seeds of its own fractionization are sown at the very birth of a community in the self-acceleration of its information.

But the fractionation of a community need not be catastrophic. In fact one can look at the evolution of social mechanisms as the development of means for retaining high levels of information in a society even while it fractionates into a multiplicity of communities. Diversity of views and skills can be tolerated by a society if there are maintained avenues along which communication can take place. Let us review several ways society has learned to accommodate orderly fractionization.

The acceptance of a common medium of exchange is one. In the economic sphere we call it money, in the political sphere it is the vote.

Social organizations are another way society accommodates orderly fractionization. It is a common presumption that an organization has a goal and all of its members work toward its accomplishment. The myth of its goal does indeed give common coinage to the activities of its members, but it is hardly more than myth. Indeed the very essence of organization is to create channels of communication which allow groups and individuals with diverse skills and goals and values to realize high levels of total information without the too costly maintenance of a single encompassing language. Think for a moment of the immense amount of information to be found in, say, the Department of Defense. The coordination of activities is worldwide and ties together in rational sequence such diverse affairs as the negotiation for the design of a new weapon system and its employment by men trained in its use years later on an unanticipated battlefield. But how few aspects of that information are to be found in any single Pentagon office, or at the fingertips of any single officer. Organization is thus a powerful means of maintaining orderly fractionization of a society.

Mechanisms such as the marketplace and social organizations are one way in which a society maintains higher levels of information in face of the self-acceleration of information. But there is another more basic one. Fractionization occurs when rates of innovation exceed the ability of the community to communicate the results of innovation. Thus if the technological means of communication can keep pace, the moment of fractionization can be postponed.

The Impact of the Computer

What activities of an informational community determine this fractionization? It is its data gathering and communicating that ties a community together, maintains the cohesiveness and consistency of its underlying conceptual structure. It is the activities of structuring and theorizing that are innovative activities that tend to fractionate the community.

Ever since the invention of the printing press there has been one major technological innovation after another

that enhances our capabilities to communicate and to observe; the telegraph, radio, television, in fact the whole electronic revolution—the microscope, camera, linear accelerators, and bathyspheres—all support the gathering and communicating activity. As far as technological support of structuring, little has been done beyond pencils and paper.

We can record and communicate enormous amounts of data. As a consequence, the commonality of conceptual structure and the confirmation of that structure are very high. At no time in history has there been the commonality of human culture that exists today. The same popular music, the same kinds of transportation, the same values, the same technology are found almost everywhere. We virtually exist as a single informational community.

Into this situation has come the computer. So far it has been used largely to apply known theories and models to special cases in engineering and business. But the potential for technologically supporting the processes of structuring and theorizing, the innovative processes, are there and beginning to be realized.

Let me enlarge upon this somewhat. Suppose I have a large body of data or find myself in an experimental laboratory and I try to make some sense out of what I find at hand. I try to construct a conceptual framework that accounts for the data or the experimental results in an insightful way. This is precisely the process we discussed earlier in the paper, the process in which one seeks to find that higher level structure that maximizes one's information. To do this I examine some small sector of the data or I conduct a limited sequence of experiments. On the basis of these, I form a hypothesis, which I proceed to test by further examination of data or further experimentation. In this way I build up an increasingly complex model or theory. But the process is not only one of accretion of structure. There comes a time when the model becomes unwieldy and unaesthetic. I try a variant on the theory, I simplify the model in a novel way that I could not have seen prior to its construction. I begin to change the model in quite creative ways, much like a sculptor takes a bit of clay off here and puts a bit on there. And at each stage I must step back and assess the implications across the entire theory, and see if the change still fits the data or the results of my experiments. This reverberating adjustment of the conceptual model is the tedious, time-consuming part of research. In the past, each research step was small, simply because checking out the implications of small changes in theory was already taxing.

In such a laboratory as I have described above, the construction of models has always played an important role. If we could make an actual physical model of what we were working on, then we could poke it, warp it, and change it here and there, and the implications of our change would be evaluated quickly and immediately by the model itself. In the design of electronic equipment we could build a prototype, a "breadboard," and then we could turn dials and switches, and see immediately on our oscilloscope their over-all effects.

But there has been no apparatus in which the abstract conceptual theory itself could be held and manipulated; there has been no way short of tedious calculations with pencil and paper to change the theory in one area and check the implications of these changes in other areas— capability to build complex models and then to set them in motion and see how they work. That is, there has been no such apparatus up to now. But this is precisely what the digital computer is suited to provide.

For example, in our laboratories at Caltech we build complex conceptual models of nerve cells. We then take many of these simulated cells and build them into networks similar to those found in the nervous system, all of course in the computer. The computer is also hooked up to tiny electronic probes that are inserted into the nervous systems of living animals and that can sense their nervous activity. Both our conceptual model and the actual living nervous system feed the same analysis programs. We can thus compare them, adjusting the parameters of our model in immediate interaction with computer analysis, to fit the reality we are trying to understand. In this process the computer is handling data rates from the model and from the animal of 50,000 to 1000,00 items a second.

Let me cite another example. Caltech anthropologist Thayer Scudder is studying a Tonga population of about 50,000 individuals in Zambia. Ten years ago they lived as simple farmers in an isolated valley. The Kariba Dam was built at the head of the valley, and these people had to be relocated. Recently industry has come to the area into which they were moved. Professor Scudder and his associates have extensive field notes covering this entire period, giving family relationships, vocations, education, property, etc., of hundreds of these people. We are now putting these data in the computer. In this computer system, Professor Scudder can ask questions and build conceptual models of cultural change, testing these models against the data, all in natural English and in direct conversation with the computer. This capability accelerates the processes of understanding and theory building manyfold.

The introduction of the computer is for the first time giving major technological support to structuring and theorizing. What is its effect? There will be a large return

in information for this movement. Thus the economic coercions for this change can be expected to be great. And indeed they are, as evidenced by the extremely rapid growth of the computer market and the application of computers in all aspects of our life. We should not underestimate the ubiquitous effect computers have already had. Our highway program, as well as our space program, could not exist without them. The effect on industrial inventories is a major factor in our economic stability. But it will be in the vast expansion of our information frontiers that they will have their greatest effects.

Our Current Situation

As greater use is made of computers, the balance between conceptualizing and communicating changes. And this change will be such as to reduce drastically the size of the viable informational community. The rate of fractionization will be greatly increased. We should expect a time of rapid divergence in points of view and values. Because innovative change in conceptualizations of our environment will be accelerated, we will feel more and more out of touch with others; and their effectiveness in dealing with affairs in ways we neither understand nor value will threaten even more our sense of being informed.

I have mentioned methods a society may use in attaining orderly fractionization. In this regard we discussed the marketplace and the use of social organization. These social mechanisms can be drawn upon and strengthened under current conditions too. However, what are the roads open to a society when faced with catastrophic fractionization of context? There are two, and we stand at the crossroads of these two paths today.

The first is to slow down the rates of conceptual change. Cut the national research budget. Reduce the support of public education relative to the general economy. Repress divergent groups. Enforce conformity to established codes of behavior. But the explosive forces of change cannot be controlled by half measures. This road leads to dictatorship.

The second road is characterized by the tolerance for diversity. It seeks a new, more enlightened conceptual base for our culture—one that recognizes that divergence of views can be enriching to a culture. What a challenge there is to society when innovation runs high! Are there deeper wellsprings of humanity on which we can base a new communication, one that revels in the richness of human diversity and welcomes the kaleidoscopic patterns of a creative culture? It is this choice between the challenge of the innovative society and the grim maintenance of a single conforming world that we face today.

Creativity in an Automated Society

But let us turn away from this crucial issue. Let's suppose we take the challenge. And indeed there is no question in my mind that we ultimately will, even if that ultimate follows a difficult period for free men. What is in store for creativity in an automated society?

It has taken the best brains and a prolonged and intense effort to forge our single science. Today science stands as a single edifice of astonishing complexity, yet yielding stunning simplicities of view. With the limited tools for conceptual structuring we have had in the past, the belief in science's uniqueness of objective view has been a necessary discipline. Science is the result of those forces that maximize the information that we can obtain from our experience. The intolerance of science of its own history is evidence that it dared not recognize its many changes. The belief that there can be only a single science, that truth lies in only one package, has been necessary when the effort to uncover that truth has taxed our ablest minds.

Yet even now the humanistic aspects of science are well recognized, at least by our scientific leaders. Conant referred to science as policy, not truth, policy to guide further experimentation. Schrödinger, while acknowledging the objectivity of science, called attention to its highly subjective aspects as well. The great expanses of unexplored reality leave open to the subjective curiosity of the individual scientist what corner he will examine, what experiments he will perform. Whatever our philosophical views on reductionism, as a practical matter the scientific landscape is sparsely settled. There are no bridges today between political science and psychology, individual psychology and psychobiology, psychobiology and molecular biology.

But what of the future? As we augment radically the technological support of the processes of conceptual structuring, each community can build its own science. From its accumulated experience it can distill that conceptual view that best expresses its own inner feelings, its values, its aesthetic taste. Science itself will become our greatest art form. With the material affluence of our automated society, we can turn our full attention to that which is most peculiarly human, the building and communicating of conceptual structure. The humanities— philosophy, the arts, literature, and science too—these will be the proper province of creative man in the automated society. We will find again in the spiritual values, in our oneness as human beings, the people of the glorious blue planet, that commonality which is necessary for communication. And in that humaneness, we will glory in the creative diversity that will enrich our lives beyond our brightest dreams.