ENTROPY AND ART
AN ESSAY ON DISORDER AND ORDER

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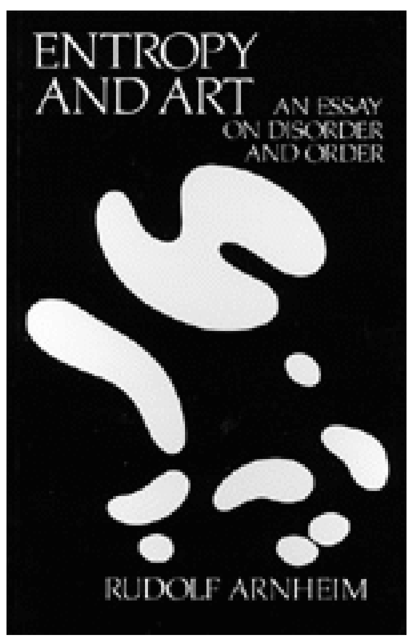
ABSTRACT. Order is a necessary condition for anything the human mind is to understand. Arrangements such as the layout of a city or building, a set of tools, a display of merchandise, the verbal exposition of facts or ideas, or a painting or piece of music are called orderly when an observer or listener can grasp their overall structure and the ramification of the structure in some detail. Order makes it possible to focus on what is alike and what is different, what belongs together and what is segregated. When nothing superfluous is included and nothing indispensable left out, one can understand the interrelation of the whole and its parts, as well as the hierarchic scale of importance and power by which some structural features are dominant, others subordinate.



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Part 1.

1. USEFUL ORDER

In many instances, order is apprehended first of all by the senses. The observer perceives an organized structure in the shapes and colors or sounds facing him. But it is hard, perhaps impossible, to find examples in which the order of a given object or event is limited to what is directly apparent in perception. Rather, the perceivable order tends to be manifested and understood as a reflection of an underlying order, whether physical, social, or cognitive. Our kinesthetic sense tells us through our muscular reactions whether a device or engine works with a smooth ordering of its parts; in fact, it informs us similarly about the perfect or imperfect functioning of our own bodies. The spatial layout of a building reflects and serves the distribution and interconnections of various functions; the groupings of the cans and packages on the shelves of a store guide the customer to the ordered varieties of household goods, and the shapes and colors of a painting or the sounds of a piece of music symbolize the interaction of meaningful entities.

Since outer order so often represents inner or functional order, orderly form must not be evaluated by itself, that is, apart from its relation to the organization it signifies. The form may be quite orderly and yet misleading, because its structure does not correspond to the order it stands for. Blaise Pascal observes in his *Pensees* [54, §1, no.27]: "Those who make antitheses by forcing the words are like those who make false windows for symmetry's sake: their rule is not to speak right but to make right figures." A lack of correspondence between outer and inner order produces a clash of orders, which is to say that it introduces an element of disorder.

External orderliness hiding disorder may be experienced as offensive. Michel Butor, discussing the New York City of the 1950's, speaks of marvelous walls of glass with their delicate screens of horizontals and verticals, in which the sky reflects itself; but inside those buildings all the scraps of Europe are piled up in confusion. Those admirable large rectangles, in plan or elevation, make the teeming chaos to which they are basically unrelated particularly intolerable. The magnificent grid is artificially imposed upon a continent that has not produced it; it is a law one endures [18, p.354].

Furthermore, order is a necessary condition for making a structure function. A physical mechanism, be it a team of laborers, the body of an animal, or a machine, can work only if it is in physical order.

The mechanism must be organized in such a way that the various forces constituting it are properly attuned to one another. Functions must be assigned in keeping with capacity; duplications and conflicts must be avoided. Any progress requires a change of order. A revolution must aim at the destruction of the given order and will succeed only by asserting an order of its own.

Order is a prerequisite of survival; therefore the impulse to produce orderly arrangements is inbred by evolution. The social organizations of animals, the spatial formations of travelling birds or fishes, the webs of spiders and bee hives are examples. A pervasive striving for order seems to be inherent also in the human mind-an inclination that applies mostly for good practical reasons.

2. REFLECTIONS OF PHYSICAL ORDER

However, practicality is not the only consideration. There are forms of behavior suggesting a different impulse. Why would experiments in perception show that the mind organizes visual patterns spontaneously in such a way that the simplest available structure results?[1] To be sure, one might surmise that all perception involves a desire to understand and that the simplest, most orderly structure facilitates understanding. If a line figure (Figure 2.1a) can be seen as a combination of square and circle, it is more readily apprehended than the combination of three units indicated in Figure 2.1b. Even so, another explanation imposes itself when one remembers that such elementary perceptual behavior is but a reflection of analogous physiological processes taking place in the brain. If there were independent evidence to make it likely that a similar tendency toward orderly structure exists in these brain processes also, one might want to think of perceptual order as the conscious manifestation of a more universal physiological and indeed physical phenomenon.

The corresponding activities in the brain would have to be field processes because only when the forces constituting a process are sufficiently free to interact can a pattern organize itself spontaneously according to the structure prevailing in the whole. No known fact prevents us from assuming that such field processes do indeed take place in the sensory areas of the brain.[2] They are quite common in

[1] For the literature on perceptual organization see [8, Ch.2].

[2] This continues to be true even though an important group of recent experiments has shown that the smallest units subjected to perceptual organization are not necessarily the single point-sized receptors in the retina and their equally elementary counterparts at the various processing levels, especially in the cerebrum. Instead, animal experiments indicate that groups of special receptors cooperate to

(a) (b)

FIGURE 2.1. Line figure of a square and circle.

physics. It was Wolfgang Kohler who, impressed by the gestalt law of simple structure in psychology, surveyed corresponding phenomena in the physical sciences in his book on the "physical gestalten," a naturphilosophische investigation published in 1920 [38]. In a later paper he noted:

> In physics we have a simple rule about the nature of equilibria, a rule which was independently established by three physicists: E. Mach, P. Curie, and W. Voigt. They observed that in a state of equilibrium, processes-or materials-tend to assume the most even and regular distributions of which they are capable under the given conditions [40, p.500].

Two examples may convey an idea of this sort of physical behavior. The physicist Sir Joseph J. Thomson once illustrated the equilibrium of corpuscles in a plane by the behavior of magnetized needles pushed through cork discs that float on water . The needles, having their poles all pointing the same way, repel each other like the atomic corpuscles. A large magnet is placed above the surface of the water, its lower pole being of the opposite sign to that of the upper poles

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signal the presence of certain basic shapes, movements, or spatial orientations in the visual field. The best known examples are the "bug detectors" in the frog's retina, which respond only to moving, dark, convex objects in the field. [For a survey of the findings and their possible application to human vision see Weisstein [68].] These are biological short cuts to perceptual organization. The perception of certain standard items of the environment is delegated to local and apparently quite independent organizational processes. The studies show that perceptual organization begins at a much more peripheral level than we were used to assuming; but by no means do they suggest that what an animal or person perceives comes about as the sum of standardized subunits. Typical perceptual organization, of which Figure 2.1 is an elementary example, continues to require field processes, in which *the parts are determined by the structure of the whole*.

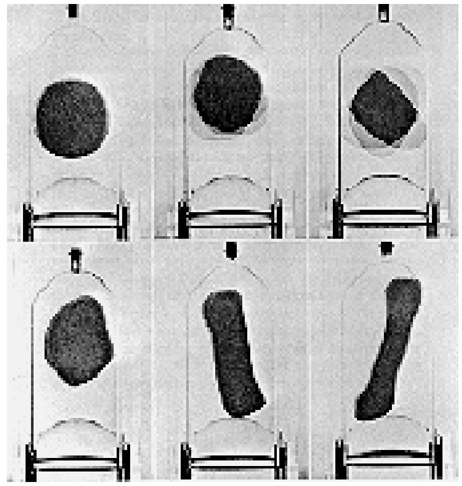

FIGURE 2.2. Fuel tank filled with clear oil and colored water of equal density.

of the floating magnets. Under these conditions, the needles, which repel each other but are attracted by the larger magnet, will arrange themselves on the surface of the water around the center of attraction in the simplest possible form: three needles in a triangle, four at the comers of a square, five at the comers of a pentagon. Thus orderly shape results from the balancing of the antagonistic forces [65, p.110].[3] The same kind of effect can be observed in another demonstration (Plate 2.2), intended to simulate the behavior of propellant gases and liquids under conditions of zero-gravity. A lucite model of the Centaur fuel tank is filled with clear oil and colored water. Both are of equal density and do not mix, "and the natural surface of the water forms an interface of constant equal tension between them, which is almost like a membrane."[4] Variously agitated or rotated, the segregating surface assumes all sorts of accidental shapes. But when outside interference ceases, the forces inherent in the two liquids organize themselves to constitute an overall state of equilibrium or minimum tension, which results in perfectly regular spherical shape-the simplest shape available under the circumstances.

[3]The same illustration is used by Sir William Bragg [16, p.38]. Thomson mentions that the method was "introduced for a different purpose by an American physicist, Professor Mayer." I am indebted for this reference as well as for other valuable suggestions to Professors Gerald Holton and Thomas von Foerster of the Department of Physics at Harvard University.

[4]Advertisement in the Scientiflc American, from which Plate 1 has been adapted by permission of General Dynamics/Astronautics, San Diego, California.

Such demonstrations show that orderly form will come about as the visible result of physical forces establishing, under field conditions, the most balanced configurations attainable. This is true for inorganic as well as organic systems, for the symmetries of crystals as well as those of flowers or animal bodies.[5] What shall we make of this similarity of organic and inorganic striving? Is it by mere coincidence that order, developing everywhere in organic evolution as a condition of survival and realized by man in his mental and physical activities, is also striven for by inanimate nature, which knows no purpose? The preceding examples have shown that the *forces constituting a physical field* have no alternative. They *cannot cease to rearrange themselves until they block each other's movement by attaining a state of balance*. The state of balance is the only one in which the system remains at rest, and balance makes for order because it represents the simplest possible configuration of the system's components. A proper version of order, however, is also a prerequisite of good functioning and is aspired to for this reason also by organic nature and by man.

3. DISORDER AND DEGRADATION

The vision of such harmonious striving for order throughout nature is disturbingly contradicted by one of the most influential statements on the behavior of physical forces, namely, the Second Law of Thermodynamics. The most general account physicists are willing to give of changes in time is often formulated to mean that the material world moves from orderly states to an ever-increasing disorder and that the final situation of the universe will be one of maximal disorder. Thus Max Planck, in his lectures on theoretical physics delivered at Columbia University in 1920, said:

> Therefore, it is not the atomic distribution, but rather the hypothesis of elementary disorder, which forms the real kernel of the principle of increase of entropy and, therefore, the preliminary condition for the existence of entropy. Without elementary disorder there is neither entropy nor irreversible process [56, p.50].

[5]The term "order" is used here not, or not only, in the sense of what works best in our particular environment but as an objective description of the simplest, most symmetrical, most regular form. The shape of a chicken egg is less simple, and in this sense, of a more complex order than that of a sphere; but it is better adapted to its mechanical function than a spherical egg would be. Most animal bodies are adapted to the one-sided stress of the earth's gravitational field by being symmetrical only about a plane, not about the center.

And in a recent book, Angrist and Hepler formulate the Second Law as follows: "Microscopic disorder (entropy) of a system and its surroundings (all of the relevant universe) does not spontaneously decrease" [3, p.151]. In this sense, therefore, *entropy* is defined as the *quantitative measure of the degree of disorder in a system* - a definition that, as we shall see, is in need of considerable interpretation.

Modern science, then, maintains on the one hand that nature, both organic and inorganic, strives towards a state of order and that man's actions are governed by the same tendency. It maintains on the other hand that physical systems move towards a state of maximum disorder. This contradiction in theory calls for clarification. Is one of the two assertions wrong? Are the two parties talking about different things or do they attach different meanings to the same words?

Apparent paradox

The First Law of Thermodynamics referred to the conservation of energy. It stated that energy may be changed from one form to another but is neither created nor destroyed. This could sound unpleasant if one took it to mean (as one of the leading physicists of the time, John Tyndall, actually did [66]) that "the law of conservation excludes both creation and annihilation" [34, p.1062].

The popular connotations of the Second Law of Thermodynamics were quite different. When it began to enter the public consciousness a century or so ago, it suggested an apocalyptic vision of the course of events on earth. The Second Law stated that the entropy of the world strives towards a maximum, which amounted to saying that the energy in the universe, although constant in amount, was subject to more and more dissipation and degradation. These terms had a distinctly negative ring. They were congenial to a pessimistic, mood of the times. Stephen G. Brush, in a paper on thermodynamics and history, points out that in 1857 there were published in France Benedict Auguste Morel's "Traité des dégénérescences physiques, intellectuelles et morales de l'espèce humaine" [50] as well as Charles Baudelaire's "Les fleurs du mal" [17, p.505]. The sober formulations of Clausius, Kelvin, and Boltzmann were suited to become a cosmic memento mori, pointing to the underlying cause of the gradual decay of all things physical and mental. According to Henry Adams' witty treatise, *The Degradation of the Democratic Dogma*, "to the vulgar and ignorant historian it meant only that the ash heap was constantly increasing in size" [1, p.142]. The sun was getting smaller, the earth colder, and no day passed without the French or German newspapers producing some uneasy discussion of supposed social decrepitude; falling off of the birthrate; decline of rural population; lowering of army standards; multiplication of suicides; increase of insanity or idiocy, of cancer, of tuberculosis; signs of nervous exhaustion, of enfeebled vitality, "habits" of alcoholism and drugs, failure of eyesight in the young and so on, without end... [1, p.186].

This was in 1910. In 1892, Max Nordau had published his famous *Degeneration* - a book most symptomatic of the fin de siecle mood, although it cannot be said to imply that mankind as a whole was on its way out [51]. In his diatribe of nearly a thousand pages, the Hungarian physician and writer, basing his contentions on the work of Morel and Lombroso, denounced the wealthy city dwellers and their artists, composers, and writers as hysterics and degenerates. For instance, he thought that the pictorial style of the Impressionists was due to the nystagmus found in the eyes of "degenerates" and the partial anesthesia of the retinae in hysterics. He attributed the high incidence of degeneration to nervous exhaustion produced by modern technology as well as to alcohol, tobacco, narcotics, syphilis. But he predicted that in the twentieth century mankind would prove healthy enough to either tolerate modern life without harm or reject it as intolerable [51, p.508].

Today we no longer regard the universe as the cause of our own undeserved troubles but perhaps, on the contrary, as the last refuge from the mismanagement of our earthly affairs. Even so, the law of entropy continues to make for a bothersome discrepancy in the humanities and helps to maintain the artificial separation from the natural sciences. Lancelot L. Whyte, acutely aware of the problem, formulated it by asking: "What is the relation of the two cosmic tendencies: towards mechanical disorder (entropy principle) and towards geometrical order (in crystals, molecules, organisms, etc.)?" [69, p.27].

The visual arts have recently presented us with two stylistic trends which, at first look, may seem quite different from each other but which the present investigation may reveal to have common roots. On the one hand, there is a display of extreme simplicity, initiated as early as 1913 by the Russian painter Kasimir Malevich's Suprematist black square on a white ground [21, p.342]. This tendency has a long history in the more elementary varieties of ornamentation as well as the frugal design of many functional objects through the ages. In our own day, we have pictures limited to a few parallel stripes, canvases evenly stained with a single color, bare boxes of wood or metal, and so forth. The other tendency, relying on accidental or deliberately produced disorder, can be traced back to a predilection for compositions of randomly gathered subject matter in Dutch still lifes, untidy scenes of social criticism in the generation of Hogarth, groups of unrelated individuals in French genre scenes of the nineteenth century, and so on [4]. In modern painting we note the more or less controlled splashes and sprays of paint, in sculpture a reliance on chance textures, tears or twists of various materials, and found objects. Related symptoms in other branches of art are the use of random sequences of words or pages in literature, or a musical performance presenting nothing but silence so that the audience may listen to the noises of the street outside. In the writings of the composer John Cage, one finds observations such as the following:

> I asked him what a musical score is now. He said that's a good question. I said: Is it a fixed relationship of parts? He said: Of course not; that would be insulting. [19, p.27]

Magazine and newspaper critics often discuss these phenomena with the bland or tongue-in-cheek objectivity of the reporter. Or they attribute to elementary signs the power of consummate symbols, for instance, by accepting a simple arrow as the expression of cosmic soaring or descent, or the crushed remains of an automobile as an image of social turmoil. When they condemn such work, they tend to accuse the artists of impertinence and lack of talent or imagination without at the same time evaluating the work as symptomatic and analyzing its cause and purpose. Aesthetic and scientific principles do not seem to be readily at hand.

Occasional explicit references to entropy can be found in critical writing. Richard Kostelanetz, in an article on "Inferential Arts," quotes Robert Smithson's *Entropy and the New Monuments* as saying of recent towering sculptures of basic shapes that they are "not built for the ages but rather against the ages" and "have provided a visible analogue for the Second Law of Thermodynamics" [42, p.22]. Surely the popular use of the notion of entropy has changed. If during the last century it served to diagnose, explain, and deplore the degradation of culture, it now provides a positive rationale for "minimal" art and the pleasures of chaos.[6]

[6]Cf. Monroe C. Beardsley's ironical comment: ". . . because the Second Law of Thermodynamics promises an inexorable downhill march to a statistical heat-death, what else can a conscientious artist do but play along with nature by maximizing the entropy of his work?" [11, p.196].

4. WHAT THE PHYSICIST HAS IN MIND

Tuming from the bravura of the market place to the theoretical issues, one may want to ask first of all: What is it that induces physicists to describe the end state of certain material systems as one of maximal disorder, that is, to use descriptive terms of distinctly negative connotation? For the answer one must look at their view of (a) the shape situations and (b) the dynamic configurations prevailing in early and late states of physical systems. Here one discovers, first of all, that the processes measured by the principle of entropy are perceived as the gradual or sudden destruction of inviolate objects - a degradation involving the breaking-up of shape, the dissolution of functional contexts, the abolition of meaningful location. P. T. Landsberg in a lecture, *Entropy and the Unity of Knowledge*, chooses the following characteristic example:

> Tidy away all your children's toys in a toy cupboard, and the probability of finding part of a toy in a cubic centimeter is highly peaked in the region of the cupboard. Release a randomizing influence in the form of an untidy child, and the distribution for the system will soon spread [45, p.16].

The child's playroom can indeed serve as an example of disorder - especially if we do not grant the child a hearing to defend the hidden order of his own toy arrangements as he sees them. But the messed-up room is not a good example of a final thermodynamic state. The child may have succeeded in breaking all the functional and formal ties among his implements by destroying the initial order and replacing it with one of many possible, equally arbitrary arrangements. Thereby he may have increased the probability that the present kind of state may come about by chance, which amounts to a respectable increase of entropy. He may even have dispersed the pieces of a jigsaw puzzle or broken a fire engine, thereby extending disintegration somewhat beyond the relations among complete objects to include the relations among parts.

Nevertheless, the child is a very inefficient randomizer. Failing to grind his belongings to a powder of independent molecules, he has preserved islands of untouched order everywhere. In fact, it is only because of this failure that the state of his room can be called disorderly. *Disorder "is not the absence of all order but rather the clash of uncoordinated orders"* [5, p.125].[7]

[7]W. Kohler: "The word disorder applies suitably to physical states in which a multiplicity of elements pursue mostly independent paths but, for short times,

Randomness is order!

The random whirling of elementary particles, however, does not meet this definition of disorder. Although it may have come about by dissolution, it is actually a kind of order. This will become clearer if I refer to another common model for the increase of entropy, namely *shuffling* [23, Ch.4]. The usual interpretation of this operation is that by shuffling, say, a deck of cards one converts an initial order into a reasonably perfect disorder. This, however, can be maintained only if any particular initial sequence of cards in the deck is considered an order and if the purpose of the shuffling operation is ignored. Actually, of course, the deck is shuffled because all players are to have the chance of receiving a comparable assortment of cards. To this end, shuffling, by aiming at a random sequence, is meant to create a homogeneous distribution of the various kinds of cards throughout the deck. This homogeneity is the order demanded by the purpose of the operation. To be sure, it is a low level of order and, in fact, a limiting case of order because the only structural condition it fulfills is that a sufficiently equal distribution shall prevail throughout the sequence. A very large number of particular sequences can meet this condition; but it is an order nevertheless, similar, for example, to the sort of symmetry of a somewhat higher order that would exist in the initial set-up of a game in which every player would be dealt one card of each kind systematically.

Before shuffling, the initial sequence of the cards in the deck, if considered by and for itself, may have been quite orderly. Perhaps all the aces or all the deuces were lying together. But this order would be like the false windows in Pascal's example. It would be in discord with the very different order required for the game, and the false relation between form and function would constitute an element of disorder.

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come into physical connection." [38, p.180]. Cf. also James K. Feibleman: "Disorder depends on the random dispersion of limited orders" [43, p.11]. In medical language, diseases are often called "disorders," meaning the lack of coordination among partial systems of the body or the mind. The British psychiatrist R.D. Laing comments on the case of one of his patients: "The overall unity of her being had broken up into several 'partial assemblies' or 'partial systems' (quasi-autonomous 'complexes,' 'inner objects') each of which had its own little stereotyped 'personality' (molar splitting). In addition, any actual sequence of behavior was fragmented in a much more minute manner (molecular splitting)" [44, p.196]. A visual parallel can be found in works of art that appear to consist of unrelatable units. The components strain to adapt to one another, fight each other, come apart. The disorderly pattern is perceived as a combination of independent units locked in unreadable conflict.

The orderliness inherent in the homogeneity of a sufficiently large random distribution is easily overlooked because the probability statistics of *the entropy principle is no more descriptive of structure* than a thermometer is of the nature of heat. Cyril S. Smith has observed: "Like molecular structure earlier, quantum mechanics began almost as a notational device, and even today physicists tend to *ignore the rather obvious spatial structure* underlying their energy-level notation" [62, p.642]. Pure *thermodynamics*, in the words of Planck, "*knows nothing of an atomic structure* and *regards all substances as absolutely continuous*" ([56, p.41];[39]). In fact, the term disorder, when used by physicists in this connection, is intended to mean no more than that "the *single elements*, with which the statistical approach operates, *behave in complete independence from one another*" [55, p.42]. It follows that the ***entropy principle*** *defines* ***order*** *simply as an improbable arrangement of elements*, regardless of whether the macro-shape of this arrangement is beautifully structured or most arbitrarily deformed; and it calls *disorder* the *dissolution of such an improbable arrangement*.

5. INFORMATION AND ORDER

The *absurd consequences of neglecting structure but using the concept of order* just the same *are evident if* one examines the present terminology of *information theory*. Here *order* is described as the *carrier of information*, because information is defined as the *opposite of entropy*, and entropy is a measure of disorder. To transmit information means to induce order. This sounds reasonable enough. Next, since entropy grows with the probability of a state of affairs, information does the opposite: it *increases with its improbability*. The less likely an event is to happen, the more information does its occurrence represent. This again seems reasonable. Now what sort of sequence of events will be least predictable and therefore carry a maximum of information? Obviously a totally disordered one, since when we are confronted with chaos we can never predict what will happen next. The conclusion is that total disorder provides a maximum of information; and since information is measured by order, a maximum of order is conveyed by a maximum of disorder. Obviously, this is a Babylonian muddle. Somebody or something has confounded our language.[8]

[8] In his editorial Preface to the new edition of *Aspects of Form* [70, p.XVI], L.L. Whyte criticizes the neglect of "processes leading towards spatial order" and adds: "In my view Schrodinger insulted this pre-eminent class of processes by giving them a negative and, in certain technical respects, misleading name: negative entropy (now structural neg-entropy)."

The cause of the trouble is that when we commonly talk about order we mean a property of structure. In a purely statistical sense, on the other hand, the term order can be used to describe a sequence or arrangement of items unlikely to come about by mere chance. Now in a world of totally unrelated items, which has the throwing of dice as its paradigm, all particular sequences or arrangements of items are equally unlikely to occur, whether a series of straight sixes or a totally irregular but particular sequence of the six digits. In the language of *information theory, which ignores structure,* each of these sequences carries a maximum amount of information, *i.e.*, of order, unless the procedure happens to be applied to a world that exhibits regularities. Structure means to the information theorist nothing better than that certain sequences of items can be expected to occur.

Suppose you watch a straight line growing a vapor trail in the sky or a black mark in an animated film or on the pad of an artist. In a world of pure chance, the probability of the line continuing in the same direction is minimal. It is reciprocal to the infinite number of directions the line may take. In a structured world, there is some probability that the straight line will continue to be straight. A person concerned with structure can attempt to derive this probability from his understanding of the structure. How likely is the airplane suddenly to change its course? Given the nature of the film or the artist's drawing, how likely is the straight line to continue? The information theorist, who persists in ignoring structure, can handle this situation only by deriving from earlier events a measure of how long the straightness is likely to continue. He asks: What was the length of the straight lines that occurred before in the same situation or in comparable ones? Being a gambler, he takes a blind chance on the future, on the basis of what happened in the past. If he bets on the regularity of straightness, it is only because straightness has been observed before or has been decreed by the rules of the game. A particular form of crookedness would do just as well as the straight line, if it happened to meet the statistical condition, in a world in which crookedness were the rule. Naturally, most of the time such predictions will be laborious and untrustworthy. Few things in this world can be safely predicted from the frequency of their previous occurrence alone; and the voluntary abstinence by which pure statistics of this kind rejects any other criterion, that is to say, any understanding of structure, will make calculations very difficult.

Any predictable regularity is termed redundant by the information theorist because he is committed to economy: every statement must be limited to what is needed. He shares this commitment with

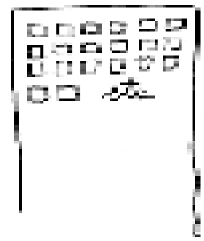

FIGURE 5.1. The economy of redundancy.

scientists and artists; its meaning, however, depends on whether one chops up patterns into elementary bits or whether one treats them as structures.[9] A straight line reduced to a sequence of dots for the purpose of piecemeal analysis or transmission can be highly redundant; in the drawing of a geometrician, engineer, or artist it is not. The processions of almost identical human figures on the walls of San Apollinare Nuovo in Ravenna are not redundant. They are intended to impress the eyes of the beholders with the spectacle of a multitude of worshipers united in the same religious function. In our own day, Andy Warhol has presented one photograph in rows of identical reproductions in order to explore connotations of mechanical multiplication as a phenomenon of modern life. Structural redundancy does, of course, exist; but it depends entirely on how much repetition is required by the visual nature of the total pattern. The effect and meaning of the single unit varies with the number of its repetitions.

I remember seeing a child's drawing that represented a skyscraper building. The child had begun to put in the rows of windows but lost patience after a while and avoided further labor by the expedient shown in Figure 5.1. From the point of view of information theory, the child is to be applauded. He has recognized the redundancy of the window pattern and has practiced economy by a shortcut in communication. If his procedure strikes us as amusing, it is because we realize that to display structure to the eyes is the very purpose of

[9]A beautiful observation of the composer Arnold Schonberg is reported by John Cage, his disciple. When Schonberg, whose generation still believed in structure, was told that someone threatened to cut one of his works, he maintained that such cuts would not shorten the composition. It would still be a long piece, which would be too short in various places [19, p.48].

a picture. The child's procedure would be quite proper if the drawing were to be dictated over the telephone. One would say: "Make sixty rows of twelve windows each!"

In dealing with structure, as is constantly done in the arts, regularity of form is not redundancy. It does not diminish information and thereby diminish order. On the contrary, *for the purposes of structure, regularity is a mainstay of order*, and this order is the basic requirement for any adequate information about structured things. The word "information," taken literally, means to give form; and *form needs structure*. This is why the tempting prospect of applying information theory to the arts and thereby reducing aesthetic form to quantitative measurement has remained largely unrewarding. The more adequate the attempts to account for a sequence of items, *e.g.*, in a piece of music by calculating the probability of its occurrence, the more necessary is it to consider complex structural factors; and this complexity of order tends to make the calculation impracticable [48, 49, 11].

Information Theory is about sequences, arrangements of items.

At this point, a significant difference between information theory and the entropy principle must be cleared up. The *information theorist*'s object of inquiry is an *individual sequence* or some other *arrangement of items* reduced to such a sequence. He investigates the probability of its occurrence by establishing the number of possible sequences, one of which is the present one. He asks how likely is a particular melody written by Mozart to continue in a certain way, given the tone sequences Mozart is known to have written on previous occasions. The less predictable the sequence, the more information the sequence will be said to yield, and if information is identified with order, the paradox I mentioned will occur and the least structured sequence will be called the most orderly.

Entropy Theory is about the overall distribution.

Entropy theory, on the other hand, is not concerned with the probability of succession in a series of items but with the *overall distribution* of kinds of items in a given arrangement. The more remote the arrangement is from a random distribution, the lower will be its entropy and the higher its level of order. This implies the following difference between the two approaches: a highly randomized sequence will be said to carry much information because information is concerned with the probability of this particular sequence; a similarly randomized distribution will be called highly probable and therefore of low order by the entropy theorist because innumerable distributions of this kind can occur.[10] A sequence of fifty white

[10]The fact that in an unstructured combination of elements the particular sequences or arrangements employed do not matter but lead structurally always

balls followed by fifty black ones will be said to contain much redundancy, little information, low order, if it occurs in an orderly world; the opposite will be true for a random sequence of white and black bars. The entropy theorist, on the other hand, will call the first distribution quite orderly because most unlikely to occur by chance. He will say of the random one that innumerable distributions of its kind can occur and that therefore it has low order and high entropy.

6. PROBABILITY AND STRUCTURE

The difference, then, is due to the fact that the entropy theorist is not concerned with sets of individual items. Such sets would be treated by him as microstates, which constitute nothing but "complexions" of overall situations. The particular nature of any one such state does not matter. Its structural uniqueness, orderliness or disorderliness does not count, and its entropy cannot be measured. What does matter is the totality of these innumerable complexions, adding up to a global macrostate.[11]

Think of a glassful of water, into which a tablet of aspirin has just been dropped. Microscopically, molecules are in constant motion in

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to one and the same condition is brought home forcefully by certain avant garde attempts in film editing or the multiplication or mixing of media to combine disparate elements more or less at random. They are all different but they all say the same thing: chaos! which is very close to saying nothing. These new techniques, when handled with a competent sense of form, can develop new valid and perhaps beautiful structures. They are likely to be quite complex; but mere randomness of combination does not suffice to create readable complexity.

[11]Is it really sensible to call information and entropy inversely related measures? as Norbert Wiener does when he says that "the amount of information is a quantity which differs from entropy merely by its algebraic sign . . ." [71, p.129]. The two measures could be reciprocal only if they referred to the same property of sets of items; but this they do not do, as I just pointed out. Entropy theory never leaves the world of pure chance, whereas information theory gets nowhere unless it does, because only then can it arrive at sequences varying in probability of occurrence. Its business is to predict likelihood of occurrence in a world in which sequences are not all equally likely to turn up. Ignoring these differences leads to much confusion. Wiener states, for example, that "a haphazard sequence of symbols can convey no information" [71, p.6]. This is by no means true, as any victim of lotteries or games of chance can testify. Information, as defined by the theory, is not "the measure of the regularity of a pattern," but rather the contrary. Nor can it be said that "regularity is to a certain extent an abnormal thing." It can be normal or abnormal, that is, likely or unlikely to turn up, depending on whether one is trying to predict the next hundred objects produced by an automobile factory or the next hundred items in a white elephant auction. Helmar Frank [28, p.40], as cited by Manfred Kiemle [37, p.30], has drawn attention to contradictions in Wiener's statements.

both, the water and the aspirin. The configuration changes from micromoment to micromoment. If we had nothing to work with but the situation at one of these micromoments, *i.e.*, if we had only a single complexion to look at, we could not tell whether the unevenness of distribution - aspirin molecules crowded in one area, water prevailing elsewhere - were highly unusual or typical for the state of affairs under investigation. Only by adding up a sufficient number of momentary complexions over a sufficient length of time can we tell something about the macroscopic state in the glass of water, *i.e.*, establish its entropy.

As an analytical method this approach to thermodynamics represented a ***revolution***. It meant a break with the century-old procedure of accounting for a whole by establishing the relations among its smallest parts. It drew the consequence of the fact that the swirling of molecules constituting a pool of water microscopically shows no kinship with the quiet sight of the pool looked at with the naked eye. Or, to use an example of Lecomte du Nouy: by mixing a white and a black powder one obtains a powder of medium grayness. This homogeneous grayness, however, would not exist for a microscopic insect, which would find itself crawling among black and white boulders [52, p.10].

Entropy theory is indeed a first attempt to deal with global form; but it has not been dealing with structure. All it says is that a large sum of elements may have properties not found in a smaller sample of them. In arithmetic, the assertion that innumerable sums of plus values and minus values add up to, for instance, plus ten or minus ten or zero is not a statement about structure but about the effect of summation. Similarly, an accumulation of building stones may, at a certain phase of the operation, produce a regular shape of the whole. As I pointed out earlier, the *statistical theory of thermodynamics presupposes a condition in which all particles are totally independent of each other, one in which the structure is zero*; and it applies its calculations to actual states of affairs in which this condition is met with some approximation. It predicts a steady increase of entropy in closed systems because among the permutations of a given number of elements the irregular ones are much more frequent than the regular ones, and therefore shuffling will increase irregularity until it reaches its maximum.

Under these circumstances it is difficult to agree with the physicist Arthur Eddington, who maintains that entropy, as it is treated today, is "an appreciation of arrangement and organization" and therefore deserves to be placed "alongside beauty and melody." Granted, he says, that entropy admits only the metrical aspects of such things as beauty and melody; but by this limitation it raises "organization" from a vague descriptive epithet to one of the measurable quantities of exact science [23, pp.73,95,105]. However, *what entropy theory measures is not the nature of organization but only its overall product*, namely, the *degree of the dissipation of energy it entails*, the *amount of "tension" available for work* in the system. It obtains the measure of this tension level by calculating the probability of its coming about by chance. With such an approach one might indeed be able to estimate the difference in the levels of interrelational tension between a Mozart sonata and the steady sound of an alarm clock, or conceivably even that between a Rubens and a Piero della Francesca, but how much would such an overall score tell about the structure of each of these objects or events?

For the purpose of structural analysis, the state of total independence among elements is not simply zero structure but the limiting case of structure, in which all constraints are absent and in which the action to which the system is subjected - by heat energy or shuffling - has an equal effect on all elements. All elements assume an equal position in the whole and therefore, to repeat what I said earlier about the shuffled deck of cards, they each fulfill the same function. Similarly in the sound of an alarm clock or on a uniformly stained canvas all elements do the same work and are therefore indistinguishable.

Needless to say, the entropy theory which has given rise to the notion of disorder I am discussing here is not necessarily the only way of dealing with thermodynamic events; nor does the theory's neglect of structure imply that no such structure actually exists at the molecular level. Kohler has pointed out that the structural aspects (Verteilungscharakter) of entropy-increase are most easily overlooked when, for scientific convenience, one concentrates on homogeneous states:

> Any system that attains the maximum of entropy not through a homogeneous state, but by differentiating itself spontaneously into discrete "phases" of very different makeup, demonstrates that aspect of thermodynamic happenings much more impressively [38, p.53].

Actually, of course, even the molecular particles in a liquid or gas are not truly independent of each other. They hit and attract one another although their relations are loose enough to let the heat energy shuffle them freely. Under these conditions, processes of spatial distribution must take place, roughly comparable perhaps to what can be

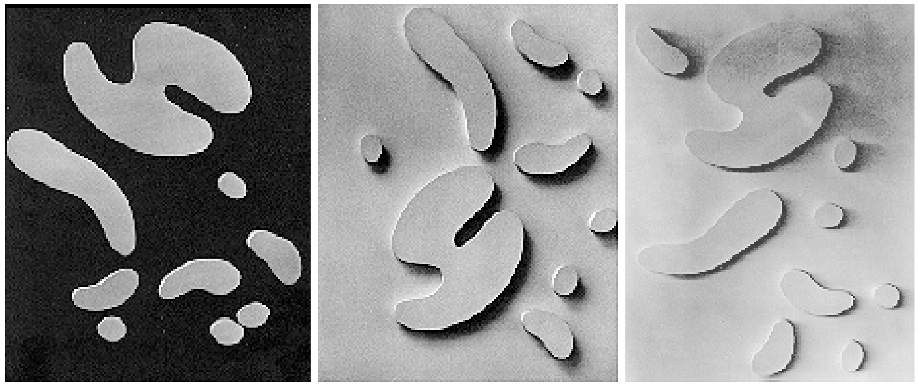

FIGURE 6.1. Jean Arp. Three Constellations of Same Forms. Triptych.

observed at the human level when a large crowd of people scrambles across an empty auditorium, train, or bathing beach to find suitable locations. Here the struggle for elbow room and breathing space results in an elementary order even under conditions approaching homogeneity of structure. In the arts, the more successful works of *Abstract Expressionism*, notably Jackson Pollock's paintings of the late 1940's, show a random distribution of sprinkled and splashed pigment controlled by the artist's sense of visual order. He "sees" to it that the overall texture is even and balanced and that the elements of shape and color leave each other sufficient freedom. And when Jean Arp experimented with the "laws of chance," which amounted sometimes to letting shapes fall on a surface and studying the result, he nevertheless worked with much care on the arrangement thus obtained. In a set of wood reliefs of 1942, *Three Constellations of Same Forms* (Figure 6.1) he presented a visual interpretation of the chance effect by placing a number of selfcontained forms on an empty ground in such a way that they did not fit any comprehensive compositional scheme but were kept in balance by their mutual weight and distance relations only. Also by showing that the same items could be put together in three different, but equally valid ways he stressed the fortuitous nature of their combination - all this with the delicate control of order he had come to recognize as indispensable.

It may seem that pure, uncontrolled randomness could produce by itself the sort of orderly homogeneity observed in the above examples. However, one must distinguish here between mechanically obtained randomness, such as is based on tables of random numbers or the throwing of dice, and the visual representation of randomness as a type of order. Since mechanically obtained randomness contains all kinds of possible permutations, including the most regular ones, it cannot be relied upon always to exhibit a pervasive irregularity. The skylines of cities, derived so largely from the lawlessness of private enterprise, are products of approximately random behavior but do not all give the visual effect of randomness to the same degree. Some happen to look attractively rhythmical, others have awkward bunches of buildings in some places, empty spots in others. They show neither free variety nor articulate organization but are chaotic. Alfred M. Bork, in an article on "Randomness and the 20th Century," discusses, among other examples of the modem taste, the growing practice in book and magazine design to abolish "justification," *i.e.*, to let the line of type run, without spacing it out in such a way as to obtain a right-hand vertical margin of uniform width [15]. Non-justified type creates instead a white strip of randomly varying width, pleasing to the eye by the free rhythm of its irregularity. But even here we find aesthetic freedom attained through control. Unless the printer avoids it by intuitive judgment, he is likely to get the same disorderly bunches and hollows that interfere with the effect of randomness in some skylines.

~~7. EQUILIBRIUM~~

~~The physicist's conception of order, I said earlier, must be considered in relation to his view of (a) the shape situations and (b) the dynamic configurations in physical systems. Having examined the former, I shall now refer to the latter by means of a familiar demonstration. A beaker may contain two different quantities of water, separated by a partition. The water level will be high on the one side, low on the other. The asymmetry of the distribution indicates a store of potential energy, which can be released to do work. If now the partition is pulled out, the water will go through pendulous motions of adjustment resulting in an even, horizontal surface. The system changes from a less probable to a more probable state and its entropy increases.~~

~~But something else has also happened. The system, freed from the constraint of the partition, has moved to a state of equilibrium. Naturally, physicists know full well that an *increase of entropy often leads to a state of equilibrium*. In fact, a leading textbook says of the idea of equilibrium that "in all thermodynamics there is no concept more fundamental than this" [46, p.16].~~

~~Now *equilibrium* is the very *opposite* of *disorder*. A system is in equilibrium when the forces constituting it are arranged in such a way as~~