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THE LAW OF EVOLUTION AS A MAXIMAL PRINCIPLE

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UNDOUBTEDLY fundamental to the concept of evolution is the idea that it is in some significant sense a *directed* process. As soon, however, as we seek to define in precise terms its presumably characteristic direction we meet with difficulties. To say, as some have said or implied, that the direction of evolution is the direction of progress, is merely to substitute for an undefined term another at best ill defined,[1] and contaminated with anthropomorphic flavor. Such phrases as "passage from lower to higher forms" which are sometimes used to describe the direction of evolution, are open to the same objection. If, on the other hand, it is stated that evolution proceeds from simpler to more complex forms, from less specialized to more specialized forms, the direction of evolution is but poorly defined, for the rule is one with disturbing exceptions, and what we seek is not an empirical rule, but a law of nature that brooks no exceptions.

One description of the direction of evolution which has a certain superficial appearance of greater scientific precision is that evolution

[1] B. Petronievics (*Science Progress,* 1919, p. 407) expressly distinguishes *progressive, regressive,* and *mixed* evolution. I cite this, not in evidence for, or refutation of, progress as a characteristic of evolution, but merely to show that the term "progress" is itself too indefinite to be used to characterize the direction of evolution.

proceeds from less probable to more probable states. That this appearance of precision is fallacious can be seen from a simple example. In a new pack of cards the first thirteen cards are the Ace to Ten, Knave, Queen, King, of Spades, arranged in that order. If we shuffle the cards thoroughly, we shall presently find the suit of spades distributed approximately evenly throughout the pack. We can express this by saying that in the original arrangement the spades had a density of *one,* or *100 percent,* in the first quarter of the pack, and a density *zero,* in the rest of the pack, whereas at the end of the shuffling they approached much more nearly a uniform density of 13/52 or 25 percent throughout the whole pack. In an actual trial the following distribution was observed after thorough shuffling:

	Spades	
	Number	*Density* (per cent)
First quarter of pack	3	23.1
Second quarter	3	23.1
Third quarter	2	15.4
Fourth quarter	5	38.4

In a certain sense it can here be said that the pack of cards, in the shuffling process, has passed from a less probable to a more probable state. But this is not an objective property of either the pack or the process of shuffling. It is a subjective property of the shuffler, or the observer, who takes a special interest in the suit of spades picked out for observation, and who uses two fundamentally different modes of description for the initial and the final state of the pack: In describing the initial state he tells us specifically what the first 13 cards are; he describes the final state only in terms of a density. There is only one specification that correctly describes the arrangement of the new pack; there are a great many different arrangements that would have the particular density observed in the shuffled pack. If the final state is defined with the same detail as the initial state, namely by indicating each card and its position in the pack, then the final state is just as probable or improbable as the initial state. In the shuffling of the cards the passage is not from a less probable to a more probable state, but from a precisely known to a less well known state. The distinction is not objective but psychological. The future is here known only statistically because we deliberately shuffle in such manner as to have only statistical knowledge of the course of events.

Evidently, then, the statement that evolution proceeds from less probable to more probable states is, not so much a false statement, as it is a statement devoid of meaning, unless it is further supplemented by a specification as to how and in what respects the probabilities of these states are measured.[2]

The example of the card shuffling is also suited to illustrate another point. It has been remarked by various writers[3] (including the present),[4] that evolution is an *irreversible* process: Now the term *irreversible process* has acquired a very special meaning in the vocabulary of the physicist, and not every process that might be described in ordinary speech as irreversible falls into the category of irreversible processes as the physicist understands the term. The suffling of the pack of cards is an irreversible process in the sense that never *by mere shuffling* could the initial state of the pack be restored. The cards would be worn to rags before the spades ever appeared in order at the top of the pack.

But note that, except for the peculiar psychological effect which the marks on the cards have upon certain human minds, the 52 cards of the pack are physically as good as identical. Except again as through their peculiar action on human minds, the particular order of the cards is practically without effect upon the course of physical events. Such shuffling as this is physically in the same category as the interdiffusion of two quantities of the same gas when intercommunication is established between the two vessels containing them at the same temperature and pressure. This is not the type of process which the physicist terms irreversible; it is thermodynamically indifferent. An irreversible pro-

[2] The significance of the particular kind of passage from less probable to more probable states which plays a role in statistical mechanics arises from its connection with certain energy relations, namely from the fact that processes so characterized can be made to yield a balance of work. The shuffling of a pack of cards is devoid of this characteristic.

[3] In particular, L. Dollo. See B. Petronievics, Sur la loi de l'évolution irréversible, *Science Progress,* 1919, p. 406. See also pp. 418-419 for bibliography.

[4] A. J. Lotka, *Elements of Physical Biology,* 1925, pp. 23 *et seq.* But the concept of irreversibility is there introduced mainly to distinguish an evolutionary process from a purely periodic process and to characterize the forward direction in time.

cess, as the physicist uses the words, is associated with decrease in thermodynamic potential, with capacity for yielding a balance of work, as when one gas diffuses into *another* gas. By a purely physical device (semipermeable membrane or porous partition) such diffusion can be made to operate, for example, a pointer moving over a graduated dial, to warn of the presence of an explosive gas mixture.

Now it may be objected that the shuffling of the pack of cards, though it cannot affect the course of events through the action of any *simple* physical device, could indeed be made to do so by the aid of a sufficiently intricate "purely physical" contrivance, such as an electric eye (as distinguished from psychological interference). This is true, but the fact is itself instructive. For there is an important difference between the operation of the danger signal pointer under the influence of gaseous diffusion, for example, and the automatic door opener actuated by the aid of an electric eye: The energy for the operation of the former is furnished by the diffusing gas itself, whereas the electric eye acts merely as the "trigger" or "key" to release energy supplied by a separate source. In this it truly copies the human eye, and indeed all our sense organs, the role of which, in their part in human behavior, is typically to act as "triggers,"[5] operated, as a rule, by the application of a very small dose[6] of external energy, the "stimulus," to set in action a wholly disproportionate amount of energy drawn from the total sources available in the living body, or, by secondary trigger action, from still more abundant sources outside the body. These are cases of "relay" action, of which probably the most advanced example, in contrivances of human construction, is the amplifier of a radio set.

The fact is, in the last analysis irreversibility is a relative thing, and is due to restrictions placed naturally (by physical or economic

[5] The significance of trigger action seems to be have been first pointed out by N. L. S. Carnot, and more specifically by Barré de Saint Venant, who speaks of it as *travail de décrochement,* as in the pulling of a *déclic* (trigger). See Boussinesq, *Cours de physique mathématique,* Tome III, p. XXXII (in section "Conciliation du véritable déterminisme avec l'existence de la vie et de la liberté morale"). Paris, Gauthier-Villars, 1922, but referring to original publications in 1872, 1878.

[6] According to S. Hecht, under the most favorable conditions, the smallest amount of light which the human eye can detect is 58-148 quanta, representing an energy of $2\text{-}6 \times 10^{-10}$ ergs. Actually only about one-tenth of this is absorbed by the retina; the rest is lost by corneal reflection, absorption by ocular media and passing on beyond the retina. (Abstract in *Nature,* July 1, 1944, p. 13)

constraints) or arbitrarily upon operations permitted. Just as the trisection of an angle is or is not an impossible feat, according as we prohibit or allow the use of instruments other than straight edge and compass, so a process may be described as irreversible or not, according as we are restricted (by physical or economic constraints) to operations in bulk, or are allowed to operate separately upon individual elements.

While these facts bear an important relation to the central problem of organic evolution, the vagueness of the concept of irreversibility in its broader interpretation demands very special caution in its application to the general problem of evolution. It is quite true that a species of irreversibility very like that contemplated in thermodynamics, as applied to processes on a molecular scale, plays an important role also in large scale processes, in which our faculty of "sorting," or "unshuffling," i. e. reversing the spontaneous "mixing" processes of nature, gives us a material advantage. But merely to state that "a biological species never retraces its steps," or that "when a race has lived its term it comes no more again," does not characterize an "irreversible" process in any useful sense, for this does not distinguish the chain of events from a mere "changeful sequence." If the world's events taken in historical order *A, B, C,* . . . are a changeful sequence, the same would be true of the inverted sequence . . . *C, B, A*. This kind of "principle of irreversibility" has no prognostic value. It tells us at best that if the sequence *A, B, C* happens, then the sequence *C, B, A* will not happen, and vice versa; but it does not tell us which of the two actually will happen. *After* the event it calls the one that *has* happened "irreversible."[7]

Another characterization of the direction of evolution that has been given is that it is the direction of increasing organization. Those who have in the past propounded this view have not told us how to measure organization, as would be necessary in order either to establish or to refute such characterization.[8] But assuming that an appropriate measure were forthcoming, this could at best lead to an empirical ob-

[7] "Dollo's Law of Irreversibility, even in its modern phrasing: Evolution is reversible in that structures or functions once gained may be lost, but irreversible in that structures once lost can never be regained," is not borne out by facts. A. J. E. Cave and R. Wheeler Haines, *Nature*, Nov. 4, 1944, p. 579.

[8] C. C. Lienau has presented an interesting suggestion for the mathematical treatment of this problem. But this applies to special cases. It does not enable us, for example, to appraise quantitatively, and to compare with each other, as to degree of organization, the elephant, the frog, the housefly, the oyster or amoeba.

servation that evolution in a large number of cases has proceeded along the line of increasing organization. While such studies have a definite interest, they belong in the domain of descriptive science. What we seek is a deductive scheme in which the law of evolution is seen to flow as a *necessary* consequence from fundamental laws, as a result of the physical properties of the organisms and the system of which they form part.

The standards of the exact sciences look beyond mere description. They aim at establishing coherent disciplines within which, by the application of relatively few fundamental principles, the course of events can be rigorously *deduced* for innumerable specific situations. So, for example, an application of the first and second laws of thermodynamics (the laws of conservation and of dissipation of energy) to a system composed of *any* liquid and its saturated vapor enables us to deduce the latent heat of vaporization of the liquid if three characteristic properties of the substance are known, namely its specific volume in the liquid and vapor form, and the temperature coefficient of its vapor pressure.

The phenomenon of increasing organization, which in a somewhat loose qualitative sense may be admitted to be a common characteristic of organic evolution, is far too complicated and too inexactly defined[9] a conception to be classed with such basic principles as the two laws of thermodynamics, for example. It is rather the sort of thing that we might hope to derive as a consequence of the properties of living organisms and some other more basic principle or principles.

To accept a "law" of increasing organization as a basic principle would be to shut the door to further important analysis by prematurely pronouncing as solved a problem that actually is hardly even approached: to establish the fundamental law governing the course of evolution in a system composed of aggregations of energy transformers of a

[9] To speak vaguely of increasing organization, without indicating any method of measuring, is merely another way of stating the obvious fact that certain of the most successful competitors owe their success to adaptation enabling them to deal with a greater and greater variety and diversity of circumstances. This is achieved by the acquisition of certain structures performing certain functions—that is, by organization. But this is only *one* direction in which evolution may proceed. While certain species have thus moved in the direction of greater and greater capacity for individual survival under varied conditions, others have assured race survival by great fertility of the species in the face of a lower degree of adaptation of the individual. These two types survive together, the one, in many cases, depending on the other for food. A shining example of this bilateral adaptation is man and certain domestic animals kept for slaughter.

peculiar type, competing for the substances and energies requisite for their continued existence and operation. In this search we are looking, not for a new *empirical* formulation, but for *necessary* relations deduced from known universal principles.

From a purely formal[10] statement in mathematical symbols of the fact that in general the rate of growth of each organic species is "some function" of the amounts of coexisting species, it is possible, on rather broad assumptions, to set up a function (or, indeed, a whole class of functions) of the amounts (masses) of the several species, which has the property of approaching a maximum or a minimum as the several coexisting species proceed toward a stable adjustment. Such purely formal expressions have been indicated by Lotka,[11] and in greater detail and perfection by Volterra.[12] The latter author names the function thus established by him the "demographic potential" of the system. This use of the term "potential" cannot be commended. Potential is a

[10] Such a purely formal statement does not necessarily have any deeper significance. *Cf.* G. D. Birkhoff, "One can manage to obtain a variational principle appropriate to almost any physical or mathematical theory," *Scientific Monthly,* 1944, vol. 58, p. 54.

[11] A. J. Lotka, Evolution and Irreversibility, *Science Progress,* 1920, vol. 14, pp. 406, 412.

[12] V. Volterra, Principes de biologie mathématique, *Acta Biotheoretica,* 1937, vol. 3, part 1. See especially pp. 18, 20, 30, where also the terms *énergie démographique* and *principe de moindre action en biologie* are used in a sense not conforming with their strict usage in physics. Other authors who have employed the term "potential" in similarly loose fashion are R. N. Chapman, *Animal Ecology,* 1926, p. 145, and L. Hersch, *Publications des sciences économiques et sociales de l'Université de Genève,* 1944, p. 64.

Another loose transference of a verbalism from the domain of physics to that of biological phenomena, made without adequate critical examination of the underlying assumptions and the conditions for its validity, is the tentative application of the *Principle of Le Chatelier* by various authors (e. g., O. D. Chwolson, F. Le Dantec, W. D. Bancroft). How incautious such applications are can be seen from the fact that even in the domain of physical systems, where conditions are much simpler and more clearly defined, erroneous applications have been common, as pointed out by P. Ehrenfest (*Zeitschr. f. phys. Chemic.,* 1911, p. 735). An analysis of the conditions for the valid application of the principle cannot be entered into within the scope of this article. For such the reader must be referred to my *Principles of Physical Biology* (1925), Chapter XXII, Displacement of Equilibrium, especially pp. 281 *et seq.,* and the references there cited, in particular, A. J. Lotka, The General Conditions for the Validity of the Principle of Le Chatelier, *Proc. Amer. Acad. Arts and Sciences,* 1922, vol. 27, p. 21; The Principle of Le Chatelier in Biology and Medicine, *Am. Jl. of Hygiene,* 1923, vol. 3, p. 355.

technical term in physics, of the dimensions of an energy, and Volterra's analysis nowhere introduces considerations of energy or of the peculiar mechanical properties of the organism. If we were dealing in problems wholly unconnected with energetics, the borrowing of a term from that field in a purely figurative sense might be condoned. But, quite on the contrary, the energy relations of the system of organic nature are a deeply fundamental feature, in which potentials of some kind, in the physicist's meaning, may be expected to play a role. To christen a function as a potential, which does not have the dimensions and qualities of a potential in the physicist's meaning, is to create the impression that a problem has been solved which, actually, still awaits solution. This does not make for the advancement of science.

A better signpost to point us in the right direction is given in Bertrand Russell's *An Outline of Philosophy*:[13]

> Every living thing is a sort of imperialist, seeking to transform as much as possible of its environment into itself and its seed . . . . We may regard the whole of evolution as flowing from this 'chemical imperialism' of living matter. Of this man is the last example (so far). He transforms the surface of the globe by irrigation, mining, quarrying, making canals and railways, breeding certain animals and destroying others; and when we ask ourselves, from the standpoint of an outside observer, what is the end achieved by all these activities, we find that it can be summed up into one very simple formula: to transform as much as possible of the earth's surface into human bodies . . . . And in pursuing the simple purpose of maximizing the amount of human life, we have at any rate the consolation of feeling at one with the whole movement of living things from their earliest origin on this planet.

Now a good signpost points the way, but it also tells us that we have not yet arrived. If each species seeks to maximize its own mass, what is the over-all result? It is, of course, conceivable that ultimately one single species (perhaps man) might dominate the scene to the exclusion of all others. But short of this eventuality, or at any rate until it is attained, the problem is one of distribution. What determines the distribution of the total matter of the system among the several species and individual organisms, and the successive changes in this distribution? Is there some significant physical quantity which these competing organisms maximize by their collective activities?

[13] Bertrand Russell, *An Outline of Philosophy*, London, 1927, p. 27.

Problems of distribution are not new to the physical sciences. The whole topic of *Change of State* deals with precisely such problems: The distribution of a mass of water between the liquid and the vapor phase, or between the solid and the liquid phase, under specified conditions of volume, temperature, etc.; the distribution of hydrogen and oxygen between the three components of a system composed of these substances in elementary form, H_2 and O_2 on the one hand, and in combination as water, H_2O, on the other, again under specified conditions, etc. As applied to these cases the law of evolution is well known and clearly defined. It states that for an isolated system, for example, the entropy of the system increases to a maximum as the system approaches equilibrium; or, more generally, that certain clearly defined functions of the parameters specifying the state of the system—its thermodynamic potentials—approach a minimum.

A special example which has often been cited, because of a certain superficial analogy to the growth of a colony of bacteria in a suitable nutrient medium, is that of the crystallization from a supersaturated solution, upon the introduction of a crystal "germ" of the dissolved substance. So long as the supersaturated solution is left undisturbed it may remain as such for long, perhaps indefinite periods, though seemingly spontaneous crystallization may also take place. This restricted type of stability has sometimes been spoken of as the *metastable* state. Its thermodynamic potential is not at the minimum possible for the system, and hence, as soon as an available "path" is presented (by the introduction of the crystal germ), the transformation to the crystal form is initiated. It continues until that particular amount of the solid has formed which is required to bring about *stable* equilibrium, that is, to make the thermodynamic potential a minimum.

If this were merely outward appearance of analogy, the oft repeated example would hardly be worth quoting again here. But it is literally true that the nutrient solution is "metastable" in the absence of a germ of an organism capable of growth in it. Whether in primordial nature somewhere locally such a state presented itself, and whether the metastable state could pass over into some kind of elementary "living" matter without the presence of a preexisting germ, just as crystallization of a supersaturated solution can take place even in the absence of a crystal germ, that is today still one of the unsolved problems of science.[14] But if such was the origin of life, we know that it was followed by a long chain of evolutionary development. And just as the continued growth of the crystal, from the first germ to the completely formed solid phase, is governed by the law that this process proceeds with continuous diminution of thermodynamic potential of the system solution plus crystal, so we may expect that the law of organic evolution takes the form that it is accompanied in the long run with diminution of some function, analogous to thermodynamic potential, of the parameters defining the physical state of the system as a whole.

While the problem of organic evolution, as a problem in the distribution of matter among the components of a material system, is formally in the same general category as these problems of distribution in physico-chemical systems, it differs, of course, in certain important respects from the specific problems considered in physico-chemical dynamics and statics. What are actually the significant points of difference?

First, that the ultimate individual components recognized in physico-chemical transformation—molecules and atoms—escape direct observation by any of the ordinary methods. It is the bulk properties and effects, such as volume, pressure, temperature, etc., of the massive components, which are directly accessible to observation, and in terms of which thermodynamics receives its data and states its conclusions. The investigation of the detailed actions of individual molecules and atoms requires altogether different, highly refined techniques.

The establishment of the statistical relations between the individual actions and the bulk effects is an additional discipline of great interest—statistical mechanics—but is not primarily necessary for the knowledge of the bulk effects, since they are directly observed with greater ease than the individual actions.

Diametrically opposite is the situation when we study organic evolution. Here it is the individuals, the separate organisms, that are accessible to direct observation, while the collective or bulk effects of aggregates of organisms, *as a whole,* (in terms of which we must ex-

[14] This observation, casually introduced by Ostwald in one of his lectures in 1902, was the "trigger" that set off the train of thought developed in my subsequent publications, and summarized, in part, in my *Elements of Physical Biology* (1925) and *Théorie Analytique des Associations Biologiques* (1934, 1939).

pect the law of organic evolution to be primarily expressed) will necessitate the development of a special branch of statistical dynamics.

Secondly, physico-chemical transformations, in all their variety, are nevertheless limited by certain narrow restrictions which hold *for all time*. These transformations run, as it were, along a single track. So for example in the case already cited, in a system composed of specified amounts of hydrogen and oxygen, the relative amounts of H_2, O_2 and H_2O may undergo a progressive change (toward an equilibrium if external conditions are constant), but they will never give rise to hydrochloric acid, for example. This may be expressed by saying that ordinary physico-chemical transformations (exclusive of transmutations of elements) are bound by certain equations of constraint (the "reactions equations") which are fixed for all time.

The transformations between and within organic species are of a different order, because they are in the main transformations of *structure,* which is capable of infinite variation. It is true that here also there are equations of constraint. An eagle is not hatched from a duck's egg. But a white duck may have parti-colored ducklings. Again, it is not possible at the present epoch of the world's history for grass or hay to be converted into mammoth. But some tens or hundreds of thousands of years ago this transformation, or something very much like it, was not only possible, it was a daily occurrence. Thus the equations of constraint that delimit the possible transformations of organic evolution are not only more liberal than those of physico-chemical evolution, they are distinguished by the fact that they are functions of the time, whereas the physico-chemical equations of constraint (e. g. the "reaction equations" of chemistry) are rigidly fixed for all time.

One consequence of this distinctive character of the equations of constraint in organic evolution is that the process is one that never ends, since structure is capable of infinite variation. In contrast to this, a reaction such as that already cited between hydrogen and oxygen proceeds (under given condition) to an equilibrium, often reached within a short space of time.[15]

The fact that the equations of constraint in organic evolution are functions of the time is closely related to a third characteristic. Whereas the components of the systems considered in physico-chemical

[15] That is, for all practical purposes. Theoretically the end state may never be fully reached, but only approached to within a negligible distance.

dynamics—elements, compounds, "phases"—are strictly homogeneous, the component biological species in the system of nature are only *relatively* homogeneous. In comparison with the discontinuous gaps that separate different species, the variations within each species, describable in terms of frequency distributions of characteristics among its individuals, are either practically continuous, or, if discontinuous, proceed by steps much less extreme than those that separate the several species.

In accordance with this, analytic formulation distinguishes two aspects of organic evolution: changes in the distribution of matter among the different species—*inter-species* evolution; and changes in the distribution of the individuals within each species, as defined by suitable frequency functions of their characteristics—*intra-species* evolution.

It is the changing character of organic species that imparts to the equations of constraint their dependence on time. This feature has no counterpart in physico-chemical evolution, since there the components are homogeneous and invariable and present no opportunity for intra-species evolution. On the contrary, in the system of organic nature, intra-species evolution has so prominently engaged the attention of biologists, that attempts to indicate the direction of evolution have commonly been couched with reference to individual species. Actually, as already hinted, any adequate treatment of the problem must envisage the evolving system as a whole—the aggregate of coexisting species and their inorganic environment.[16] Anyone accustomed to the discipline of physico-chemical dynamics knows that it would be quite out of the question to formulate the law of evolution of the system by reference to one of the components alone. The law of organic evolution, likewise, must undoubtedly be formulated in terms of the system as a whole evolving under the flood of light received from the sun.

And this brings us to the fourth typical difference that distinguishes organic evolution from most of the physico-chemical transformations usually considered (adiabatic or isothermal reactions), namely that the latter are envisaged as taking place under conditions leading to an *equilibrium.* Absolutely fundamental to organic evolution is that it takes its course in a system exposed to a continuous stream of energy from the sun, so that the approach is not towards equilibrium, but to-

[16] For a particularly illuminating survey of the planetary relations involved, see W. Vernadsky, *La Géochimie,* Paris (Alcan), 1924.

wards a *stationary state* maintained with continuous expenditure of free energy.[17]

And directly related to this is the fact to which reference has already been made in passing, namely that trigger action plays an important role in organic evolution. For trigger action presupposes a fund of free energy ready to be released, and, as was pointed out years ago by Boltzmann, the life struggle is primarily a competition for available energy. What we have before us in organic nature is a system composed of aggregates of energy transformers adapted by their composition and structure to guide available energy into such channels as lead to their maintenance and growth. A special branch of physics needs to be developed, the *statistical dynamics of systems of energy transformers.* In the development of this it will not be necessary or even desirable to deal primarily with specific living organisms, but rather with transformer *types* possessing certain properties characteristic of the physical *modus operandi* of living organisms. The kind of problem then to be studied will be the relation between the distribution of matter in the system on the one hand, and on the other the particular properties and variation in properties of the several types of transformers of which the system is composed. In so far as the system of organic nature is subject to physical law, certain at least of the relations deduced for the systems studied in this branch of physics should be found applicable to the system of organic nature and its evolution, just as that system is, for example, subject to the law of conservation of energy which is usually thought of as applicable primarily to inorganic systems.[18]

Among the transformers which this branch of physics will have to consider, one important class obtains its supply of available energy from sources distributed discontinuously, in separate masses, through the system in which they operate. This necessitates structures or "apparatus" whereby "collisions" or "encounters" between those transformers and their energy sources are rendered probable. The more perfect the functioning of this apparatus, the greater will be the prob-

[17] In this respect it is similar to photochemical reactions, and indeed, it might be regarded as a photochemical reaction on a heroic scale, accompanied by important structural changes. However, in organic evolution, owing to intra-species changes, the state is only *relatively* stationary; it resembles rather what has been (inaccurately) termed a "moving equilibrium."

[18] Though the principle was originally recognized by J. R. Meyer on the basis of physiological observations.

ability of these encounters, and the less the energy expended in proportion to the energy captured in the encounter, so as to yield a net balance of gain.

In the apparatus by which the probability of favorable encounters is ensured or enhanced four typical elements are to be distinguished, as follows:

1. *Receptors.* The action of the transformer must be a function of the position of the sources. But that action is primarily a function of the state of the transformer itself. Hence there must be apparatus to provide that the state of the environment is in some manner "represented" or "depicted" in the transformer. This may be by optical image formation by a lens, as in the human eye or in an automatic door opener operated by a photoelectric cell; but more generally, the process of "depicting"[19] may take a variety of forms. What is characteristic is that the amount of energy involved in the process may be very small.

2. *Free energy.* Associated with the transformer is a *fund of free energy*[20] ready to be released by trigger action, that is, by an expenditure of an amount of energy bearing in general no quantitative relation to the energy released, which can thus be far in excess of the energy applied at the "trigger."

3. *Effectors,* that is, structures by which the energy released by trigger action from the available fund is applied to react upon the environment so as to bring about an encounter with an energy source to be captured, or so as to avoid an encounter in which the transformer itself will be captured or injured, i. e., made more or less inoperative.

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[19] That is, of establishing a one-to-one correspondence between certain features of the environment and certain appropriate features of the transformer. It is no mere accident of language that we speak of this generalized process of "image formation" in ourselves as *information.* By it we are *informed* of conditions in the environment.

In the case of man the primary representation (depiction) of the environment in the individual is further supplemented or elaborated by a faculty or a set of faculties which we may designate as the elaborators. Their most refined product is the scientific world picture.

[20] It can be noted here only in passing that the possession of such a fund of free energy is what gives the opportunity for purposive action and the exhibition of the phenomenon of *will,* that is, action teleologically aimed at future effects. For a discussion of this the reader may be referred to Chapters XXVIII *et seq.* of my *Elements of Physical Biology,* and, for a more recent review, to A. J. Lotka, Evolution and Thermodynamics, *Science and Society,* 1944, vol. 8, p. 161.

For since these transformers possess a fund of free energy they can themselves become objects for capture by competing transformers. The avoidance of capture is made possible by the existence of refuges scattered through the topography over which they operate.

4. *Adjustors*. Lastly, in order that the receptors and effectors may function successfully in ensuring the probability of encounters with energy sources and in warding off unfavorable encounters, the transformer must comprise apparatus by which the action of the effectors upon the environment is suitably adjusted to the "information" supplied by the receptors.

Since it is characteristic of trigger action that the energy released may far exceed the energy spent in working the trigger, while the energy captured may still further exceed the energy expended from the available fund of the transformer, it follows that a transformer or an aggregate of transformers equipped with apparatus of the type described is capable of continued functioning, obtaining sufficient energy from captured sources to defray the energy cost of capturing further sources. In fact, there may be a balance left over for accumulation, which may take the form of growth of the transformer or of the aggregate of transformers.

In this discussion it has been assumed that there exist "discrete" sources available for capture, scattered through the field of operation of the transformers of the type so far considered.

That such sources exist and are continually replenished in nature is due to the existence of another type of energy transformers, which themselves draw their supply of energy and substance from sources continuously distributed in space, namely sunlight on the one hand, and on the other, gaseous or dissolved substances which drift to them spontaneously by diffusion and seepage. These transformers can accordingly remain essentially passive and do not require the "ingenious" apparatus for capturing energy by trigger action. At the same time they lose the benefit of the power actively to avoid unfavorable encounters. They do, of course, possess various passive means of protection, some of which, incidentally, are available also to animals.

Such are the fundamental data with which the statistical dynamics of aggregates of energy transformers will have to deal. Indications of the direction in which the development of this branch of physics may be expected to move have been given by the writer elsewhere.[21] For our present purpose only certain broad observations will here be made.

While the transformers in nature are "living" animals and plants, it will be desirable to develop the discipline of statistical dynamics of aggregates of transformer irrespective of this fact. The results achieved must then be applicable to the world of organisms in so far as they are energy transformers having the physical properties taken in view in that discipline, just as the law of conservation of energy, is applicable to them.

Dealing with purely physical data affords certain important advantages. We have complete control of the particular properties which we may assign to the transformers under consideration, without raising the question whether such a transformer actually exists or ever has existed. As Karl Pearson has remarked: "In dealing with natural phenomena . . . . the mathematician has to simplify the conditions until they reach the attenuated character which lies within the power of his analysis."

This process can be carried much farther both experimentally and conceptually in purely physical than in biological systems. The relative simplicity and direction of physical laws is in no small measure due to the fact that experimentally we can control conditions so as to isolate the factors essential to our enquiry, from adventitious circumstances in which for the moment we are not interested.[22]

The fact that we ourselves are of the dimensions of the units (transformers) contemplated in this discipline gives us an inside view of

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[21] A. J. Lotka, *Elements of Physical Biology,* pp. 36, 37, and especially Chapters XXIV to XXXIV. Also, Families of Curves of Pursuit and Their Isochrones, *American Mathematical Monthly,* 1928, vol. 35, p. 421; Contribution to the Mathematical Theory of Capture, *Proceedings of the National Academy of Sciences,* 1932, vol. 18, p. 172. See also V. Lalan, *Compt. Rend.,* 1931, vol. 192, p. 468.

[22] The history of Science well illustrates the importance of this simplification for the progress, and especially the early progress, of a science. Thus astronomy was able to make a very early start because nature herself has simplified some of the basic problems by reducing the data practically to mathematical points, the position of stars (and for the naked eye also the planets) in the sky. At the other extreme we have the case of chemistry, one of the last sciences to develop effectively, because no considerable progress could be made until recognition and separation of the fundamental units of chemistry—elements and pure compounds—had been achieved.

the processes under discussion, and thus enables us to select the appropriate ensemble of properties to assign to the conventionalized models of the actual transformers presented to us in nature's organisms. At the same time we shall retain full freedom, in this process of conventionalization, to place the development of the subject on a postulational basis, if we conduct the enquiry solely in terms of physically defined transformers, since we thus avoid carrying on the discussion in terms of "hypothetical animals and plants," to which some biologists might take exception.

An admittedly primitive illustration of the mode of approach to the problem is the case of a "pursuing" transformer of velocity v_1 seeking encounter with a "pursued" transformer of velocity v_2 while the latter flees in a straight line toward a refuge of safety. The pursuer, constantly directed toward the pursued, then follows a so-called "curve of pursuit." Whether capture occurs or not then depends on the relative position of the pursuer and the pursued at the time when first stage of the pursuit, the "stalk," begins (that is, when the pursuer first directs his course toward the pursued); and depends further on the time when the second stage begins, namely when the pursued first reacts by "flight" to the "attack" of the pursuer. The problem thus conventionalized resolves itself into a problem of geometry. Capture certainly occurs, or does not occur, according as a certain circle does or does not fall within a certain ellipse of dimensions depending on the efficiency of the receptor-effector apparatus of the two types of transformers. If the circle and the ellipse intersect, capture occurs for some initial positions and does not occur for others. In this conventionalized case we can, for example, discuss the influence, upon the probability of capture, of variations in the velocities v_1 and v_2 or in the degree of perfection of the receptors, etc. Carrying the model somewhat further, the influence of the density of distribution of refuges in the territory may be discussed.[23]

It may be objected by some that such primitive—not to say naive—conventionalizations of the natural phenomena of pursuit and capture observed among living organisms, are too far removed from any realities to be of any value.

To this the answer is, first, that the case described is used merely as a simple example of the *kind* of procedure to follow, with appropriate

[23] For details the reader is referred to my two papers cited above, on curves of pursuit and on the theory of capture.

refinements and extensions. And second, that it is well to be very cautious in pronouncing useless a conventionalization merely because it is a seeming over-simplification. Such highly attenuated conventionalizations have done excellent service in certain fields.

The Carnot heat engine, with its perfectly conducting and perfectly insulating parts, is a case in point, and so is the use of a "perfect gas"[24] in illustrating the derivation of the second law of thermodynamics by a Carnot cycle. As is well known, the results so derived are of far-reaching consequence and of the widest applicability.

While the future development of such a discipline of statistical dynamics of aggregates of energy transformers should eventually prove of great interest and importance in relation to the problems of organic evolution, certain broad observations with which its result presumably will conform may be stated even now.

It has been remarked[25] that the influence of living organisms is to retard the dissipation of energy. So far as the plant world is concerned this seems essentially true. Green plants act as accumulators storing sunlight which would otherwise shortly be converted into heat at terrestrial temperatures.

But the influence of animals is essentially in the opposite direction, since their activities are conducted with dissipation of energy, catabolism exceeding anabolism.

At first sight there is something perplexing about these two opposing tendencies. But this perplexity exists only so long as we seek to express the drift of organic nature in terms of a retardation or a promo-

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[24] As to this, it is admitted that both logically and for didactic reasons it is preferable to avoid the use of an unreal working substance in this derivation of the efficiency of a reversible heat engine. It is not the ideal way of treating the subject, though it has a certain heuristic and illustrative value. I have noted that some who had so been initiated into the foundations of thermodynamics gained the impression that the use of a "perfect" gas was a necessary point of the argument—whereas just the opposite should have been impressed upon them—that the argument and its conclusions are independent of the working substance, and that therefore, in the interest of simplicity of the mathematical manipulations *it is permissible* to conduct the argument on the basis of a fictitious working substance—the conclusion is independent of the fact that such a particular substance does not exist.

[25] See J. Johnston, *The Mechanism of Life,* 1921, pp. 220, 221, especially the footnote on page 221.

tion of the dissipative process. As soon as we frankly accept the fact that both are going on side by side the perplexity vanishes.

A simile may be helpful in illustrating the situation. Consider a reservoir constructed to collect rainwater. Now let there be two agencies at work, one tending to enlarge the catchment area, the other tending to enlarge the outlet or outlets from the reservoir. In one sense these two influences seem antagonistic, one tends to increase the volume of water in the reservoir, the other tends to decrease it. But in one thing they cooperate: *Together they increase the total flow through the reservoir.*

From this illustration by analogy, let us return to the actual case before us. The argument, as I have presented it elsewhere,[26] runs as follows: As already noted, "it has been pointed out by Boltzmann that the fundamental object of contention in the life struggle, in the evolution of the organic world, is available energy." In accord with this observation is the principle that in the struggle for existence the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable for the preservation of the species.

> "The first effect of natural selection thus operating upon competing species will be to give relative preponderance to those most efficient in guiding available energy in the manner indicated. Primarily the *path* of the energy flux through the system will be affected.
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> "But the species possessing superior energy-capturing and directing devices may accomplish something more than merely to divert to its own advantage energy for which others are competing with it. If sources are presented, capable of supplying available energy in excess of that actually being tapped by the entire system of living organisms, then an opportunity is furnished for suitably constituted organisms to enlarge the total energy flux[27] through the system. *Whenever such organisms arise,* natural selection will operate to preserve and increase them. The result, in this case, is not a mere diversion of the energy flux through the system of organic nature along a new path, but an increase of the total flux through that system.
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> "Again, so long as sources exist, capable of supplying matter of a character suitable for the composition of living organisms, in excess of that actually embodied in the system of organic nature, so long is

[26] A. J. Lotka, Contribution to the Energetics of Evolution, *Proceedings of the National Academy of Sciences,* 1922, vol. 8, p. 147.

[27] The term *energy flux* is here used to denote the available energy absorbed by and dissipated within the system per unit of time.

opportunity furnished for suitably constituted organisms to enlarge the total mass of the system of organic nature. *Whenever such organisms arise,* natural selection will operate to preserve and increase them, provided always there is presented a residue of untapped available energy. The result will be to increase the total mass of the system, and, with this total mass, also the total energy flux through the system, since, other things equal, this energy flux is proportional to the mass of the system.

"Where a limit, either constant or slowly changing,[28] is imposed upon the total mass available for the operation of life processes, the available energy per unit of time placed at the disposal of the organisms for application to their life tasks and contests, may be capable of increase by increasing the rate of turnover of the organic matter through the life cycle. Suppose, as a simple, though rather extreme illustration, that man found means of doubling the rate of growth of crops, and of growing two crops a year instead of one. Then, without changing the average crop actually standing on the fields, the land would be capable of supporting double the present population. If this population were attained, the energy flux through the system composed of the human population and the organisms upon which it is dependent for food, would also be doubled. This result would be attained, not by doubling the mass of the system (for the matter locked up in crops, etc., at a given moment would be, on the average, unchanged) but by increasing the velocity of circulation of mass through the life cycle in the system. Once more it is evident that *whenever a group*[29] *of organisms arises* which is so constituted as to increase the rate of circulation of matter through the system in the manner exemplified, natural selection will operate to preserve and increase such a group, provided always that there is presented a residue of untapped available energy, and, where circumstances require it, also a residue of mass suitable for the composition of living matter.

"To recapitulate: In every instance considered, natural selection will so operate as to increase the total mass of the organic system, to increase the rate of circulation of matter through the system, and to increase the total energy flux through the system, so long as there is presented an unutilized residue of matter and available energy.

"This may be expressed by saying that *natural selection* tends to make the energy flux through the system a maximum, so far as compatible with the constraints to which the system is subject.

[28] As, for example, if the total mass of the system is capable of accretion, but only at a limited velocity, in which case the phenomenon of a "moving equilibrium" may present itself. Compare Lotka, A. J., *Proc. Nat. Acad. Sci.,* 1921, vol. 7, p. 168.

[29] Owing to the fact that in existing organisms the anabiotic and catabiotic functions are very largely segregated in different types (plants and animals), evolution will here operate upon systems or groups of at least two species, one species of autotrophic anabions, and one of heterotrophic catabions.

> "It is not lawful to infer immediately that *evolution* tends thus to make this energy flux a maximum. For in evolution two kinds of influences are at work: selecting influences, and generating influences. The former select, the latter furnish the material for selection.
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> "If the material furnished for selection is strictly limited, as in the case of a simple chemical reaction, which gives rise to a finite number of products, the range of operation of the selective influences is equally limited.
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> "In the case of organic evolution the situation is very different. We have no reason to suppose that there is any finite limit to the number of possible types of organisms. In the present state of our knowledge, or rather our ignorance, regarding the generating influences that furnish material for natural selection, for organic evolution, an element of uncertainty enters here. It appears, however, at least *a priori* probable that, among the certainly very large (if not infinite) variety of types presented for selection, sooner or later those will occur which give the opportunity for selection to operate in the direction indicated,[30] namely so as to increase the total mass of the system, the rate of circulation of mass through the system, and the total energy flux through the system. If this condition is satisfied, the law of selection becomes also the law of evolution:
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> "Evolution, in these circumstances, proceeds in such direction as to make the total energy flux through the system a maximum *compatible with the constraints*."[31]

As for these constraints, over relatively short periods of time, when we are dealing mainly with inter-species evolution, they are defined essentially by transformation coefficients indicating in what ratio the mass added in the growth of one species stands to the masses captured from other species or from the environment. For, growth in *mass* of organisms takes place by the assimilation of food, though growth in *numbers* takes place by reproduction (births), which thus acts as pacemaker for the growth in mass.

Over extended periods of time, as already noted, the constraints are functions of the time, and the empirical data which define them are sup-

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[30] One is inclined here to give at least qualified assent to the saying of Herodotus: "If one is sufficiently lavish with time, everything possible happens." (Cited by C. E. Guye, *Physicochemical Evolution,* Methuen & Co., London, 1925, p. 30. This is essentially a republication in English of a series of papers originally appearing in various French journals, 1917 to 1920.)

[31] A further analytical development based upon this principle has been suggested by N. Rashevsky, Outline of a New Mathematical Approach to General Biology, II, *Bulletin of Mathematical Biophysics,* 1943, vol. 5, p. 49.

plied mainly—but with one highly significant exception—by the findings of genetics.

The one outstanding exception is the human species. Here evolution, especially in more recent times, has followed an entirely new path. In place of slow adaptation of anatomical structure and physiological function in successive generations by selective survival, increased adaptation has been achieved by the incomparably more rapid development of "artificial" aids to our native receptor-effector apparatus, in a process that might be termed *exosomatic* evolution.[32]

Until recently the net effect of these new implements of evolution has been essentially in the same direction as the main current. Man, one of the latest, and in his own judgment the highest product of evolution, has hitherto signally conformed with the principle of increasing energy flux.[33] By ingenious contrivances he has immensely refined and multiplied the operation of his receptor-effector apparatus. The excess of energy captured, over the energy barely sufficient for mere maintenance, has in his case grown to a wholly unparalleled magnitude. Normally this leaves him with a large balance available for "play" activities and luxuries. And some of his play activities have turned out to be a most profitable reinvestment. For among them must be classed scientific research indulged in primarily out of curiosity, but resulting among other things in that complete recasting of methods of production which is known as the industrial and agricultural revolution. Aside from its direct benefits this "has made it possible to spend relatively large amounts on sanitary improvements, on medical education and research, and, above all, on better living among the masses of the people. This in-

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[32] I have elsewhere (*Proceedings of the American Philosophical Society,* 1939, vol. 80, p. 625) graphically represented in quantitative measure the rocket-like ascent, in modern times, of human knowledge and technical skill. See also, the editorial "Forty Years of Plenty" in the *Bulletin of the American Association for the Advancement of Science,* 1944, vol. 3, no. 10, p. 73.

[33] Of this the exploitation of solar energy stored up from past ages in coal is in the present era the outstanding, though perhaps transitory, example. "The problem of economy in husbanding resources will not rise to its full importance until the available resources are more completely tapped than they are today. Every indication is that man will learn to utilize some of the sunlight that now goes to waste. The general effect will be to increase the rate of energy flux through the system of organic nature . . . ." (A. J. Lotka, *Elements of Physical Biology,* 1925, pp. 357-358). Compare also F. H. Pike, The Driving Force in Evolution, *Ecology,* 1929, p. 167. This also contains bibliographical notes.

crease in the productivity of human labor may, therefore, very properly be called the basis of the decline in the death rate which has taken place in almost all parts of the Western World during the last century."[34]

This is one side of the picture. But there are also less pleasing aspects. The same ingenious contrivances that extend our view, that speed our travel, and multiply our strength in beneficent pursuits, are equally potent to destroy. Then, in a world at war as today, contending armies exchange death against death,[35] while among the inhabitants of the occupied countries "a disproportionate expenditure of energy is required merely to maintain life and satisfy the most elementary demands of food and cleanliness, with the almost inevitable result that in many cases habits of personal hygiene are relaxed and all interests beyond the mere struggle for existence are stifled."[36]

It is not only in war that the trend of human evolution has brought special problems. With the vastly multiplied efficiency of modern industry, as compared with primitive labor, the necessities of life can be produced in much less than the full working time of the gainfully employed population.[37] Hence, to secure full employment much of the industrial activity must be expended on the production of luxuries and near-luxuries. This in itself would be no disadvantage. Quite on the contrary, if continued full or approximately full productive activity were assured, this would mean the enjoyment of these luxuries by the consumers, among whom are the producers themselves. But there is

[34] W. S. Thompson, *Plenty of People,* Jaques Cattell Press, 1944, p. 64.

[35] The latest development in this field is the unlocking of atomic energy for purposes of war. It remains to be seen whether this new channel for the flux of energy through the evolving system of which human society forms part, will in the course of time be put to constructive use. In that case this will be the superlative example of the principle of maximum energy flux as characterizing the direction of evolution.

[36] International Labour Office, *The Health of Children in Occupied Europe,* Montreal, November 1943, p. 28.

[37] Compare W. B. Kaempffert, Technological Advance in Relation to Population Trends, *Proceedings of the American Philosophical Society,* 1939, vol. 80, p. 563: "In the decade from 1920 to 1930 . . . . the nation's output increased 46 percent, but the labor force only 16 percent." Compare also the editorial "Forty Years of Plenty," *Bulletin of the American Assoiation for the Advancement of Science,* 1944, vol. 3, no. 10, p. 73. In the four decades 1900 to 1940 the population of the United States increased 70 percent, while the number of farm workers *decreased* more than 10 percent.

this serious drawback: While the necessities of life, from their very nature, insistently demand continued production, no such powerful inherent drive exists for the luxury trades. And so, with our present economic system, when from time to time periods occur during which the production of luxuries and near luxuries is depressed, this results in a plague of unemployment, since idleness at such times is quite unevenly divided, some retaining full time employment, while others are wholly without work. Then we have the incongruous spectacle that in the midst of plenty there is widespread want.[38]

While the occurrence of the more severe economic fluctuations are, to say the least, annoying and do cause much hardship, it cannot be said that they offer any serious threat to the maintenance of the species, and it may reasonably be hoped that in time better adjustments of production, distribution and consumption may be achieved, with reduction or elimination of at least the more extreme fluctuations.

But the effect of the greatly increased productivity of labor in shifting the center of gravity of the total activity toward luxury production has other more serious results. It is obviously in the interest of producers to stimulate demand for luxuries. This demand, unlike that for necessities, is very elastic. The demand for personal necessities needs no particular stimulation—that is what we mean by necessities—nor could it be very greatly enhanced by any attempt at stimulation. People's appetite for food is limited. Their appetite for automobiles, radios, fur coats, jewelry, actually seems to follow the rule of the French proverb *l'appétit vient en mangeant.* At any rate it is highly susceptible to suggestion, which our advertising fraternity has developed, if not to a fine art, at least to an importunate technique.

Now overstimulation of the demand for luxuries is not without its dangers. Necessities for the species are not always felt as necessities for the individual. Few persons may be tempted to go hungry in order to buy jewels. But many actually do go without children, or without an adequate number of them, in order to maintain certain standards of

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[38] The desperate measure adopted by Germany, of absorbing excess productivity by preparing for and waging aggressive war, has proved a catastrophic failure even from a criminally nationalistic point of view.

living.[39] Nature tricks the individual into doing things advantageous to the species, by linking the doing of them with pleasure for the individual. The trick works well, until the individual discovers ways of separating the links, and reaping the pleasure without accepting the cost. Here again man's ingenuity has worked against the advantage of the species, or at least of certain branches of the species, as the statistics show. The net reproduction rate, that is the ratio of total births in successive generations, has fallen well below unity, the required minimum, for many of the countries of Western civilization, as shown in Table 1.

TABLE 1

Net reproduction rate, according to age-specific mortality and fertility at specified dates*

COUNTRY	DATE	RATE
Austria	1935	.64
Belgium	1941	.67
Czechoslovakia	1935	.79
Denmark	1941	.96
England and Wales	1933	.73
	1938	.81
Finland	1938	.96
France	1939	.90
Germany	1933	.70
	1940	.98
Holland	1941	1.16
Norway	1939	.86
Sweden	1940	.79
Switzerland	1941	.90
United States (white persons)	1931–5	.98
	1939–41	1.01

* Ratio of total births in two successive generations.

The meaning of these figures is that certain contingents of mankind are headed for extinction, if present attitudes continue. This is not saying that in the case of the human species the principle of maxi-

[39] For a discussion of the social influences making for restriction in the size of families see J. J. Spengler, *France Faces Depopulation,* Duke University Press, 1938, especially pp. 157 *et seq.* Also the same author's article "Pareto on Population" in the *Quarterly Journal of Economics,* August, 1944.

mum energy flux is on the point of failing. For, in the first place, that principle contains a reservation: a maximum *compatible with the constraints*. The principle tells us what is selected; what is presented for selection is determined by other principles—just as in physico-chemical evolution the principles of thermodynamics tells us which of *possible* transformations actually take place. What transformations *are* possible is determined by the facts of stoichiometry.

Secondly, the principle of maximum energy flux presumably continues to be operative among the remaining components of the system of nature, if one of them drops out. Any species, or contingent of a species, that signally fails to keep in the current of the law of maximum energy flux is headed for elimination from the evolving system. Thus the law is preserved.

That such elimination of species occurs from time to time is a familiar fact engraved in the earth's fossil record, though the precise cause of these disappearances may remain unknown. One conjecture is that, in certain cases at least, the extinction was due to a certain fatal drift in the cumulative inheritance of certain characteristics from generation to generation by what has been termed orthogenesis. Whether physiologically speaking orthogenesis is fact or fiction is a matter of dispute, but the *exosomatic* evolution of the human species is indisputably subject to orthogenesis. Knowledge breeds knowledge, and with present-day methods of recording, this means unceasing accumulation of knowledge and of the technical skills based upon it.[40] But in a way hardly dreamed of by Tennyson, it is true that "knowledge comes, but wisdom lingers," if by wisdom we understand that adjustment of action to ends which is for the good of the species. It is precisely this that has gone awry in the schemes of men: The receptors and effectors have been perfected to a nicety; but the development of the adjustors has lagged so far behind, that the resultant of our efforts has actually been reversed. From preservation of life we have turned to the de-

[40] This property of knowledge has been much exalted by A. Korzibski (*Manhood of Humanity*, Dutton, 1921) who seemed to be under the impression that he had discovered a new principle. The idea was of course far from new. It had for example been clearly set forth by W. Ostwald in *Energetische Grundlagen der Kulturwissenschaften*, 1909, pp. 121, 122. Korzibski's characterization of man on this account, as "time binder," can hardly be praised either as a happy choice of terms or as altogether setting man apart from other species.

struction of life; and from expansion of the human race we have, in some of the most advanced communities, turned to its curtailment.

If certain contingents of the human species are to be preserved and perpetuated, a revision of prevailing valuations will be necessary. As R. S. Lillie has remarked, "The avoidance of useless conflict, and the subordination of individual interests to the integrated whole, which includes the individual, would seem to be a rational aim for conscious beings."[41] In particular, as procreation, from the essentially instinctive drive, is passing into the domain of deliberately controlled actions, it becomes necessary that the adjustment of reproduction be equally controlled in accordance with the needs of the species. This may be difficult to accomplish. For, as Whelpton has pointed out, "The average size of planned families has been substantially smaller than that of unplanned families in the past and will be smaller in the future, though perhaps in lesser degree. Any tendency for the average size of planned families to increase in the future will be more than offset by the increase in the relative frequency of planned families which will result from the continuing spread through the population of information about effective methods of contraception."[42]

We find ourselves at a most remarkable epoch in history. As never before, man looking back contemplates a vista of miraculous progress; and as never before he finds himself casting searching glances into the future. Our gratification in being at once spectators and participators in a captivating drama is considerably damped by the fact that the prospect does not please. In the solution of scientific and technical problems we have achieved brilliant results. Social problems, as conceived broadly from the point of view of the species, we have bungled.

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To us, at this critical period, the two-fold threat to the very existence of large sections of the human race dominates our immediate interest in world history. In the longer view all this is but an episode in the great drama of the evolution of the earth and its inhabitants. The

[41] R. S. Lillie, The Psychic Factors in Living Organisms, *Philosophy of Science,* 1943, vol. 10, p. 270. Similar reflections also are developed, especially in the closing chapters, in my *Elements of Physical Biology* (1925).

[42] P. K. Whelpton, War and the Birth Rate. Paper presented before the American Public Health Association, Oct. 2, 1944.

larger scientific outlook aspires to an objective survey of events quite aside from any peculiar relation which they may have to human affairs.

It is with this broader conception that we have viewed the evolution of life on our planet as the changing distribution of matter among the various organic species and their inorganic environment. Whatever line the development of this branch of science may ultimately take, this can be confidently asserted, that no treatment can be effective which fails to give a prominent place to the competition for substance and energy among the diverse organic species, in relation to the characteristic physical and dynamical properties which the individual organism possesses for waging the competitive struggle. We may further set it down that the formulation of the law of evolution must unquestionably be made in terms of the evolving system as a whole; that it cannot be adequately expressed by reference to only one component, such as a single species. It is the system as a whole, under the flood of light energy received from the sun, that evolves. From our experience in the disciplines of the physics of change of state and physical chemistry we know that it would be quite out of the question to formulate the law of evolution of a physico-chemical system by reference to one of the components alone. No more can we expect to express the basic directional principle of organic evolution in terms of the "organization" or any other property or assemblage of properties of individual species considered separately. It is in the collective activities and effects of the organisms that we must look for an indication of the direction of evolution. These collective effects tend to maximize, on the one hand, the energy intake of organic nature from the sun, and on the other, the outgo of free energy by dissipative processes in living and in decaying dead organisms. The net effect is to maximize in this sense the energy flux through the system of organic nature.

Such, it seems, is the shape of the basic principle defining the direction of organic evolution.