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THE ABANDONMENT OF SIMULTANEITY*

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ABSTRACT

Some recent investigations in linguistics, communication, and social organization have found that progress can be made only by abandoning the concept of simultaneity in favor of a multicomponent hierarchical description of overlapping times. It is suggested that the same approach might offer a clue to the solution of the problem of joining relativity theory to quantum mechanics, which has resisted more conventional approaches for forty years.

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Although the atomic hypothesis that phenomena can be analysed into discrete elements with fixed properties has proved enormously fruitful in many different sciences, it conceals a fundamental paradox. If the atoms so isolated are in fact independent of their surroundings, how is it possible for them to influence those surroundings? This problem is already present with the hard impenetrable material atoms of Democritus; he held that there are only atoms and the void, and that all phenomena reduce to the collisions of these atoms. It was learned during the nineteenth century that one can, in fact, explain the relation between pressure, temperature, and volume of a gas with such a model, up to a point, but this is a far cry from explaining sounds and colors as experienced by human minds. The atomic hypothesis taken literally produces a dichotomy between mind and matter, primary and secondary qualities, and so on; philosophers have struggled with this problem from time to time without resolving it.

Up to a point, the quantum mechanical description of the structure of matter gets around these difficulties in an ingenious way.[1] It starts (at the level of description which first concerns us) with a system of electrons and nuclei with fixed and stable properties, but because of the uncertainty principle, asserts that we are unable to predict anything more than probability distributions for these particles. Thus an isolated hydrogen atom consists of one proton and one electron; if we observe that atom in such a way as to locate these particles, we will find only the two particles named. However, the locations of the particles will differ from hydrogen atom to hydrogen atom, even though hydrogen atoms interacting in ways that do <u>not</u> allow the localization of the particles behave in identical ways. This is accounted for in the theory by calculating a probability distribution for the electron in the hydrogen atom, and showing that, to about

1 part in 137, we will get the correct answer in such cases if we treat the charge of the electron, not as a point, but as if it were smeared out into this probability distribution. Even though the theory in a sense is built on point particles, it also is capable of a description resembling an extended structure in space.

With this understanding, we can, to a certain approximation, talk about a hydrogen atom in its ground state as having a spherically symmetric charge distribution, the radius of the sphere being about 0.5×10^{-8} cm in length. If two hydrogen atoms join together to form a hydrogen molecule, this charge distribution does not remain spherical. It forms an elongated structure with rounded ends. At rather accurately defined positions along the axis of this structure, it is possible to make measurements which will localize one or the other of the two protons, or both of them, and within the extended charge cloud one can, by suitable measurement, localize either or both of the two electrons. Thus quantum mechanics allows changes in the effective structure of atoms when they join to form molecules, even though the constituent electrons and nuclei retain their particulate character. In this way, one aspect of the atomic decomposition is retained, while at the same time allowing the actual spatial structure of the atoms to change with the molecules in which they are imbedded. Similarly the structure of the molecules will be altered by whether they are in free space or surrounded by other atoms of a liquid. Ultimately, then, there will be subtle differences (according to the theory) depending on whether the molecule is in a muscle fiber or in a brain, what the species of the organism is, and what its past history has been. Thus there is no hiatus or barrier as one extends the chain of hierarchical organization upward. It is this subtlety of description which is at the root of the considerable success which molecular biology has had in accounting for the mechanism of life.

Of course the chain does not stop there. As Polyani has pointed out,[2] this molecular biological description, no matter how complete, still does not account for the purposeful aspects of life. To give explanation for these, we must extend our universe of discourse to include the evolutionary processes which through natural selection have fitted the gene pool of the species to the environment and interlocked the different species into ecological systems. Ultimately this description must extend backward in time over the full $4\frac{1}{2}$ billion years the earth has existed and include the steps by which self-replicating systems developed from nonliving matter. Even so we are still not up to the level of discussing consciousness, which involves not only the neural currents in the brains of individuals, but the processes of learning by which they become associated with distinguishable aspects of the surroundings, and the social organizational structures without which these learning processes could not exist, and which shape them.

Clearly the whole explanatory process sketched above is far from complete at the present time, but there is no longer a logical reason why it cannot be continually expanded in scope and power as we learn more of molecular biology, neural structures, and intercommunicating social organizations. It also can be extended to a level of analysis below that of the electrons and nuclei showing that these too have structure which is subtly influenced by their surroundings. This comes about because of the combined effect of the $E = mc^2$ mass-energy equivalence of the special theory of relativity and the Heisenberg uncertainty relation $\delta E \delta t \geq \hbar$. Since massive particles must move at speeds less than c, the velocity of light, in a time interval δt they can move only distances shorter than $r = c\delta t$. If we attempt to localize a particle within this distance r, the uncertainty principle tells us that there will be an uncertainty in energy at least as large as $\hbar/\delta t = \hbar c/r$. But if r is less than $\hbar/mc$, this uncertainty is greater than mc^2, which then tells us that within distances $\hbar/mc$ of any particle it will be possible (i.e., with some finite calculable probability) to find an additional particle of mass m. In the particular case of electrons, since these carry electric charge, the appearance of a single electron would violate the law of conservation of charge, but within a distance of $\hbar/2m_e c$, we can expect to find a (negative) electron of mass m_e together with a positron (positively charged electron) also of mass m_e. Putting in the numbers this tells us that any particle which interacts with electrons will be surrounded by some probability distribution of electron-positron pairs of radius about 2×10^{-11} cm. Thus, once we include relativity, particles themselves have extended charge-current distributions, and since these in turn can interact, they will be affected by the structures in which they are imbedded. Hence, in principle, even the electrons and nuclear particles in the brain of one man differ in their space-time distributions from those in the brain of another. These effects can be calculated for an isolated hydrogen atom (Lamb shift, vacuum polarization, etc.) and are in agreement with experiment to high accuracy. Hence, if we look closely enough, even the particles of which the atomic and molecular distributions are composed themselves dissolve into modifiable structures, and all the structures in the universe are ultimately interlocked and interdependent, leaving no unbridgeable gap.

Unfortunately, this same line of reasoning leads to a new paradox. Since we can find an electron-positron pair within $\hbar/2m_e c$, we could find two such pairs within $\hbar/4m_e c$, three such pairs within $\hbar/6m_e c$, and so on. The smaller the scale on which we attempt a space-time description of the structure of particle charge-current (or mass) distributions, the larger the number of particles we encounter, and this number grows without limit. Dirac began struggling with the infinities this simple fact introduces into the theory nearly 40 years ago, and neither he nor succeeding generations of theoretical physicists have come up with a satisfactory resolution of the paradox, though we keep trying. In some cases it has proved possible to sweep these difficulties under the rug and come up with successful predictions which have been confirmed experimentally, but the basic paradox remains unresolved. As many people have realized, starting at least as early as Bohr and Rosenfeld[3] in 1933, the basic problem is that the special theory of relativity relies on an underlying space-time of points. The absolute simultaneity of two events which cannot be connected by a light signal cannot be defined; relative simultaneity defined by the Einstein convention still allows a unique ordering of events and an arbitrarily precise punctiform localization of any space-time event. Once this basic space-time is married to mass-energy equivalence and the uncertainty principle, infinite energy fluctuations at each of these points are inevitable; the mathematical consistency of the theory collapses. Attempts have been made to avoid this difficulty by giving a granular structure to space-time, or by other modifications of the theory at short distances which still allow it to reduce to the special theory of relativity in the macroscopic world. So far these have not commanded much enthusiasm in the community of theoretical physicists, and have not led to any striking successes. It might be worth while to look at other sciences trying to extricate themselves from the straitjacket imposed by a punctiform and unique space-time description, by building descriptions more in accord with the requirements of their data.

This possibility was suggested to me in a conversation with R. L.

Birdwhistell, J. H. Crook, and K. L. Pike, at the Center for Advanced Study in the Behavioral Sciences. Birdwhistell[4] has been struggling for many years with kinesic aspects of communication – that is, behavior such as the eyeblink, head motion, eye focus, leg cross, etc., which accompany and often replace verbalizing. He could make little progress so long as he was hung up with the telecommunicative model derived from information theory – two individuals exchanging information back and forth along some channel in a uniquely ordered segmental time sequence. But a remark of Infeld's about the relativity of simultaneity freed him from this necessity and allowed him to start seeing the data as an overlapping laminated structure of events of varying lengths occurring along many channels; some of these units may be only a few milliseconds in length while other aspects of the communicative process may extend over four generations, and unitary events of any intermediate length also occur. For him the "information" described in the information theory model for communication can be interchanged along a limited channel only because of an enormous amount of social work preceding and succeeding this brief flow; one need only think of how difficult it is to enable children with a uniform culture to learn from a printed page, let alone to transmit this skill transculturally, to realize the force of his description. To use another analogy, communication starts with the installation of the phone system and not with the ringing of the bell; this fact should be obvious to the parent of any teenager sitting by a silent phone. By focusing attention on the flow of information in the lexical channel, one not only loses important aspects of the situation, but also makes it next to impossible to see the higher units of the hierarchical laminated structure; these longer events are just as real as any of the shorter units, and may often be much more significant.

Working with the linguistic channel itself, Pike[5] has come to a very similar structural picture. We are familiar in written English with the segmental decomposition into letters, words, sentences, paragraphs, and so on to higher units, but usually only trained linguists are familiar with the difficulties of recovering these structures from any particular example of spoken English, let alone making the equivalent analytic decomposition of spoken languages of different structure. A little reflection on the profound phonetic changes which occur in the speech of a child as it grows up, in voice tone of the same individual under various settings, or at various times during even the same speech, should convince the reader that the atoms of verbal communication are not unique physical structures with a defined distribution of frequencies and intensities occurring during a precisely defined interval of segmental time. Rather, they are a complicated hierarchical ordering of laminated relationships in which the units are subtly modified by these relationships. Otherwise it would be impossible to turn on a radio in the middle of a speech and realize almost immediately that a preacher is nearing the end of his sermon, or an orator building up to his peroration, as we obviously can. Again, the analysis of speech into segmental units successfully prevents the recovery of highly significant structural aspects of the ongoing process, and a multicomponent analysis such as that Pike uses is essential.

Field studies of the social structure of primate societies such as those being conducted by Crook[6] again reveal laminated hierarchical structured relationships rather than atomic encounters between individuals. For instance, among the Gelada baboons, the spatial relationships between all-male groups and the harem groups of dominant male plus females and young change through overlapping patterns from day to night and from season to season in ways that have an intimate connection with the exploitation of the available food supply, and hence are of fundamental evolutionary adaptive significance. These changes in both space and time are only very incompletely understood when the community is followed for only a year, even though the year contains the full range of seasonal variation. Equally significant is the way in which these relationships change as individuals mature and grow old and how the necessary accompanying changes in relationship are structured into the social organization. Clearly, these can only be guessed at until communities have been followed for generations, and this work is only beginning. The point to seize on here is that all this structure is missed if the data are viewed in terms of single segmental encounters rather than in larger units.

Clearly this rich material from the behavioral sciences can only be hinted at in an article of this length. It has taken the three individuals named above many years to come to this way of seeing their data, and there is by no means unanimity among anthropologists, linguists, or ethologists as to the importance of this type of approach. But it does appear significant that by abandoning simultaneity and punctiform units as a method of description,[7] significant new relationships become possible to observe. Unfortunately, the mathematical structures needed to give precision to this approach are yet to be worked out. One general area of mathematics in which to look is obviously set theory, as was realized long ago by von Neumann[8] in discussing economic behavior, or the axiomatic field theorists[9] in trying to come to grips with the infinities arising from the coupling of relativity and quantum mechanics. But it still seems to be beyond the current level of mathematical sophistication to go from a description in terms of overlapping sets, which does seem appropriate to the data, to a dynamical theory which would allow predictions as to how the relationships between these sets evolve in time. In the old punctiform theories, dynamics is supplied by equations of motion written in terms of rates of change (differential equations); but these seem to imply a continuous background space of points.[10] Since it is clear simultaneity and punctiform space must be abandoned,[11] this might imply that something equivalent to the calculus, but operating on the laminated set structure rather than on space-time, must be invented.[12] One purpose of this paper is to point up this necessity. A second purpose is to point out the similarity of structure between the problems of kinesics, linguistics, primate social organization, and elementary particle physics; this implies that advances in any one of these fields can offer fruitful suggestions for new insights into the others.

REFERENCES

1. For a somewhat broader discussion of how quantum mechanics remains, from some points of view, an atomistic and particulate theory, cf. H. P. Noyes, American Scientist 45, 431 (1957).
2. M. Polyani, Science 160, 1308 (1968).
3. N. Bohr and L. Rosenfeld, Koenlige Danske Videnskaberns Selskab, Math-Fys. Medd. 12, No. 8 (1933); for a less technical discussion see the article by Rosenfeld in the Festschrift volume, Niels Bohr and the Development of Physics.
4. Since the full flavor of Birdwhistell's commentary has to be experienced along the nonlexical channels which he commands so thoroughly in order for really effective communication to take place, I prefer to acknowledge the importance of his providing me with this experience rather than to give necessarily inadequate lexical references.

5. K. L. Pike, Language in Relation to a Unified Theory of the Structure of Human Behavior (Mouton, the Hague and Paris, 1967).

6. J. H. Crook (ed.), Social Behavior and Ethology (Academic Press).

7. To "abandon simultaneity" in the easiest way is not a novel idea, as is evidenced by the folk wisdom that those who follow the analytic approach "cannot see the forest for the trees". It becomes somewhat more radical when the methodology becomes so ingrained that Birdwhistell can say that there are no trees (or baboons, or atoms, or . . .). This flies in the face of our culture-bound necessity for assuming that systems are built of discrete units, but becomes a methodological necessity in those fields where in fact the forest dissolves when analysed into trees. Philosophers are trained to accept a methodological description shorn of its metaphysical implications, but a scientist who becomes thoroughly committed to a methodology will follow it through to the implied metaphysical conclusion, just as Lucretius followed the opposite methodology through to the belief that there are only atoms and the void.

8. J. von Neumann and O. Morgenstern, Theory of Games and Economic and Economic Behavior (Princeton University Press, 1947).

9. A. S. Wightman, Phys. Today 22, 53 (September 1969).

10. Bertrand Russell, in the ABC of Relativity, was at some pains to construct the Minkowski space-time of special relativity out of the laminated structures of everyday experience by a limiting and abstracting process. He returned to this problem in his last epistemological work (Human Knowledge: Its Scope and Limits) with what strikes this author as an almost obsessive compulsion to establish not only space-time but also the causal chains of classical physics as a barricade against the Humean dilemma.

This is the reverse of the methodology suggested here, which rejects the classical limit as both irrelevant and misleading. Although Whitehead's attempt to construct space-time points from the extended events of everyday life has some similarity to Russell's he is more ready to recognize that the entities so constructed are hardly the elements of a naive punctiform geometry, and may not converge to that limit. He is still, however, concerned to reconcile his theory with the relativistic physics of his day, rather than to follow the implications of his metaphysics into the actual construction of a new type of dynamics.

11. T. D. Lee and G. C. Wick (private communication) attempted (c. 1969) to remove the infinities from quantum electrodynamics by a limiting procedure that still uses a punctiform mathematical space-time as a substrate. However, the expanded Hilbert space required to make their limiting procedure finite introduces particles of imaginary mass which cannot be directly observed, and runs into trouble with conventional ideas about causality. The experimenter has even less control over experimental study in their theory than in conventional quantum mechanics. In the conventional theory, the probability wave front retains its shape after scattering, but in theirs there is a precursor wave which is uncontrollable. Thus space-time recedes still further into the mathematical background. Other approaches to the problem of infinities introduce a granular structure to space-time, again avoiding the punctiform limit.

12. An alternative approach to the problem of infinities is the "bootstrap" theory in which every particle in the universe generates every other particle, and the universe exists because this is the only self-consistent solution to the equations. This is acausality with a vengeance, and even one of the

proponents of the (insoluble) theory questions whether it can be considered a "scientific" idea (G. F. Chew, Science 161, 762 (1968)). The lack of alternate solutions to the "true" one makes the issue of dynamical equations which determine the evolution of different systems starting with different conditions at some point irrelevant.