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VARIATIONS IN VARIATION AND SELECTION: THE UBIQUITY OF THE VARIATION-AND-SELECTIVE-RETENTION RATCHET IN EMERGENT ORGANIZATIONAL COMPLEXITY

Part II: Quantum Field Theory

ABSTRACT. If the general arguments concerning the involvement of variation and selection in explanations of "fit" are valid, then variation and selection explanations should be appropriate, or at least potentially appropriate, outside the paradigm historistic domains of biology and knowledge. In this discussion, I wish to indicate some potential roles for variation and selection in foundational physics – specifically in quantum field theory. I will not be attempting any full coherent ontology for quantum field theory – none currently exists, and none is likely for at least the short term future. Instead, I wish to engage in some partially speculative interpretations of some interesting results in this area with the aim of demonstrating that variation and selection notions might play a role even here. If variation and selection can survive in even as inhospitable and non-paradigmatic a terrain as foundational physics, then it can survive anywhere.

KEY WORDS: quantum field theory, quantum mechanics, variation and selection

QUANTUM FIELD THEORY

At first glance, variation and selection forms of explanation seem quite unrelated to the foundations of physics. They originated in evolutionary biology, and physics just doesn't seem to have the requisite properties for such kinds of processes to take place. This view is more correct for the Newtonian view of the world, but I will suggest that variation and selection can be deeply involved in contemporary physics.

Newtonian mechanics. In Newtonian mechanics, the motions of particles are fixed and determinate, given initial conditions. Trajectories of motion do not split into two or more possibilities, and

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trajectories from differing initial conditions never merge, no matter how close those initial conditions might be.

In such a linear "clock-work" view of the world, there is no choice, no variation. Limitations of human knowledge can force a statistical treatment of systems of many particles – as in classical statistical mechanics – and this, in turn, can introduce non-linear mathematics with its possibilities of bifurcation and other "un-clock-work" phenomena. But the underlying reality is still viewed as linearly determinate, and the appearances to the contrary are dismissed as mere consequences of human ignorance of the full determinative conditions.

In this view, there is no domain of variations, except with respect to human ignorance, and, therefore, no domain in which potential selections could function. Variation and selection forms of explanation are nugatory.

Quantum field theory: Quantized fields. Contemporary quantum field theory yields a vastly different view. In accordance with the uncertainty principle in quantum mechanics, it is possible for pairs of particles to come into existence and then vanish, as long as their energies and durations do not violate the uncertainty principle. Such a fleeting virtual existence would seem to be a pointless superfluous notion, but such virtual particles do have empirically testable consequences which have in fact been experimentally supported (Aitchison, 1985; Sciama, 1991).

Quantum mechanics focuses on particles and their mechanics. The introduction of the requirement that the physics be consistent with special relativity forces a shift from particles to fields. An intuition of this shift can be derived by noting that, if an electron oscillates in one place and thereby elicits a force on an electron in another place, that force must be felt only after a delay that honors the limitations of the speed of light. But the influence of the first electron on the second involves a transmission of energy from the first to the second, and, if energy is to be conserved, then a field notion is required to "hold" and transmit that energy during the delay of transmission. Fields in this sense are distributed and dynamic in space-time. Quantization of fields, rather than of particles, yields quantum field theory (Kaku, 1993; Ryder, 1985).

Vacuum foam. The uncertainty principle in quantum field theory yields not just virtual particles, but a vastly different notion of the basic vacuum in which the phenomena of physics are conceived of as taking place. In particular, the vacuum becomes a sea of continuous creation and annihilation of field quanta in accordance with the uncertainty principle – a foam of such creations and annihilations. The dynamics of quantum fields can be crudely conceptualized as waves of excitation moving in this sea of background activity (Hiley, 1991; Misner, Thorne and Wheeler, 1973; Saunders and Brown, 1991).

The notion of particle disappears in this view, in that, while the properties and interactions of fields are quantized, this is more akin to the "quantization" of waves in a guitar string than to any trajectories of substantial particles. In fact, the number of "particles" is not a constant in quantum field theory, but depends on the state of the observer (Birrell and Davies, 1982; Davies, 1984; Hiley, 1991; Sciama, 1991; Unruh, 1989; Wald, 1986). The fundamental perspective is that of process rather than substance or particle (Brown and Harré, 1988; Teller, 1990).

The uncertainty principle as constraint. The uncertainty principle is *permissive* relative to Newtonian physics in that it permits phenomena that are impossible on classical accounts. In quantum field theory, however, the basic character of a field is one of process and creation, and the uncertainty principle plays a constraining, or *selecting*, function on the dynamics and interactions of such creative processes. The propagation of a quantum field is essentially a propagation of potentialities, a generation of variations, which are selected from in accordance with the uncertainty principle and the various laws of interaction.

Invariance constraints. Still more deeply, the quantum fields themselves can be viewed as consequences of constraints on underlying dynamics of the vacuum. In accordance with Noether's theorem, every generator of a form of symmetry in the laws of action yields a conserved quantity in the dynamics of the vacuum (Aitchison and Hey, 1989; Kaku, 1993; Ryder, 1985; Sudbery, 1986): the action determines the time course of a physical system, and an invariant of the action, therefore, yields a time invariant of physical systems

– a conserved quantity. Forms of symmetry are forms of invariance, or forms of constraint, on those dynamics, and conserved quantities are what yield an excitation of a quantum field moving through the underlying sea of vacuum activity – a current carrying that conserved quantity. A symmetry, or form of invariance, is in this sense a specification of some property that cannot be arbitrarily annihilated or introduced *de novo* into the underlying vacuum dynamics. Such properties will be quantized because the vacuum dynamics is already quantized.

Collapse as selection. The propagations of potentialities for interaction in a quantum field are irreversibly collapsed when certain interactions, such as a measurement, take place. This amounts to a selection of one of those potentialities. It is in fact one of the lacunae of modern physics to be able to explain what the crucial selective conditions are for such collapses, but, even though no explanation for such selections are currently consensually available, it is clear that they occur. (There are attempts to eliminate such notions of collapse or projection, but so far without success.)

The point of this rehearsal of some aspects of contemporary physics is to demonstrate that notions of variation and selection, and variation and selection as a form of explanation, are not alien to the fundamentals of contemporary physics. This should certainly be so if variation and selection forms are in fact logically necessary to account for regular satisfactions of constraints. At minimum, then, contemporary physics does not offer a counterexample to this general point. More strongly, it suggests an involvement of variation and selection principles in the foundational dynamics of the vacuum. The fundamental regularities of quantum field theory can be construed as selection constraints on the creative, variational, dynamics of the vacuum. This point will be further elaborated below in the discussion of intrinsic-constraint forms of explanation.

Quantum tunneling. In accordance with the uncertainty principle, the position of an electron is not fully determinate – it is smeared or spread out in space. If the energy barrier that forms an energy well is thin enough, then the spatially distributed uncertainty of location of the electron may actually cross over the energy barrier and have nonzero probability on the "other" side of the boundary of the energy well. Electrons, in this manner, can “tunnel” out of an energy well that they do not have enough energy to simply overcome. Similarly, electrons could also “tunnel” *into* such an energy well.

If there is a potential across the energy barrier that selects for movement out of the well (by reducing the probability of tunneling back into the well relative to the probability of tunneling out) then there will be a net movement of electrons across the energy barrier – a current. Such tunneling, then, occurs as a result of the probabilistic selections that set the rate of change in one direction higher than that in the other direction. In this respect, it is quite similar to the rate differentials that yield crystal formation, or the formation of atoms and molecules.

In general, in fact, energy well stabilities are not the result of elements coming to rest, with inertia holding them in their stable positions. Energy well stabilities always occur with respect to sometimes high levels of thermal and quantum fluctuations, and they result from selection effects that alter the rates of transition out of the stable configurations of process relative to the rates of transition into the stable configurations. Tunneling phenomena offer one more realm of illustration of this point.

QUANTUM FIELD THEORY AND INTRINSIC CONSTRAINTS

Quantum field theory presents a framework of interrelated intrinsic constraints. Earlier, the uncertainty principles were discussed as constraints on the underlying vacuum activity. Here, I present a perspective in which the uncertainty principles themselves arise as conjunctions of intrinsic constraints.

Position and wavelength. First, there is an intrinsic indeterminancy – a mathematical indeterminancy – between the wavelengths involved in a waveform and the position of that waveform (Sudbery, 1986). If the waveform is located precisely, that specifies a geometric point, but the wave*length* is not a determinate notion for a point. Conversely, if the wavelengths of the waveform are determined precisely, then those waves extend throughout the manifold or space that they exist within, and the location is not determinate. This relationship can be expressed quantitatively as a minimum bound on the product of the indeterminancies involved (Körner, 1988).

Oscillatory ontology. To this mathematically intrinsic constraint, I now add two more considerations: (1) that the inherent dynamics of the vacuum are oscillatory, thus waveform, in nature, and (2) that the dynamics *among* these vacuum processes are themselves oscillatory. Waves in the underlying vacuum foam or froth of activity, then, will propagate and interfere in at least metaphorically familiar ways.

The action. Feynman's postulate proposes that the phases of such activity are related to a property of the underlying vacuum activity called the Langrangian (Aitchison and Hey, 1989; Kaku, 1988, 1993; Ryder, 1985; Townsend, 1992; Ward and Wells, 1990). When waves of activity come together, then, the constructive and destructive interferences among the waves involved will depend on the Langrangian. The result of this relationship is that the overall dynamics of the system satisfies a constraint on the integral of this Langrangian over space-time – over those dynamics – called the action, such that the action of the resultant dynamics is necessarily stationary.

Invariances of the action. The Langrangian, thus the action, and thus the dynamics, are invariant with respect to a number of possible changes that could be made. These invariances, in turn, require certain conserved quantities and currents. A classic example is the invariance of the dynamics with respect to changes in spatial reference frame. The conserved quantity resulting from this spatial or translational invariance is called momentum.

Invariances and reference frames. An invariance of the action constitutes an impossibility of the existence of a privileged zero point of a class of reference frames (Lee, 1988) – here is yet another constraint. If the action were not invariant with respect to position, for example, if space-time were not dynamically homogeneous, then some location could be differentiated as an absolute zero of location. There would be a dynamically privileged spatial reference frame, and space would not be dynamically homogeneous. Invariances of the action, then, constitute various forms of dynamic homogeneity with respect to the relevant fields.

Gauge fields. There are similar conserved quantities for other invariances with respect to other global changes to the Langrangian –

temporal dynamic homogeneity, for example, yields energy conservation. And there are also conserved quantities for Langrangian invariances in which the variations themselves can smoothly vary – a non-zero *meta*variation – across the field involved. Such "local" metavariational invariances of the Langrangian involve shifts in the phases of underlying activity that vary across that activity, and, thus, themselves form a field of variations. In order for the Langrangian, and thus the dynamics, to remain unchanged from such alterations in how the phases of activity are defined, there must again be a compensating field. Such fields are called gauge fields; the conservation of electric charge is a classic example of conservation necessitated by invariance with respect to phase frames for the underlying electromagnetic field (Aitchison and Hey, 1989; Kaku, 1993; Ryder, 1985; Nakahara, 1992).

Invariance constraints and indeterminancies. Such conservations, in turn, constrain the overall vacuum fluctuations; the vacuum activity cannot violate those conservations without violating the relevant invariances of the action. But those conservations can constrain the vacuum activity only insofar as the properties to which the conservations apply are themselves well defined. Momentum, for example, is a property of wavelength, and wavelength and position are involved in an indeterminancy with respect to each other. When the momentum conservation is imposed up to the limit of this indeterminancy, the familiar position-momentum uncertainty principle results. When the time dimension of space-time is selected instead of a spatial dimension, the general indeterminancy combines with the invariance constraint on the action to yield the energy-time uncertainty principle: energy must be conserved if time shifts are to leave the dynamics unchanged, and energy is also a property of waveform. (The action can be formulated in such a way that it is relativistically invariant itself, and, thus, does not differentiate in such an absolute manner between spatial and temporal dimensions. Deriving momentum-position or energy-time uncertainties, then, involves specifying reference frames in which these dimensions can be differentiated out of the basic indeterminancy at the level of the oscillatory action principle per se.)

The invariances to which the action of wave processes are subject impose conservation constraints on the vacuum activities, and those constraints apply only up to the limits of the intrinsic constraint on the joint determinancies of position and waveforms of oscillatory processes. Together, these two sources of constraint yield the classic uncertainty principles. Quantum field theory, then, explores crucial constraints imposed on vacuum activity: those constraints yield most of contemporary foundational physics.

Reversibility and irreversibility. There is still another sense in which principles of variation and selection are involved in this story. Basic vacuum activity is temporally reversible, except when certain conditions are satisfied. When these conditions occur, the underlying oscillatory wave processes irreversibly collapse into a new state – from which vacuum oscillatory wave processes again proceed. Measurements, for example, produce such irreversible changes. The nature of the conditions that yield irreversibility, however, and the reasons for it, constitute a major lacuna in quantum theory. There are proposals, but there is no clear answer (Bub, 2000; Cao, 1999; Huggett, 2000).

The relevance of this point is as follows. Not only do vacuum activities violate the conservations within the constraints of the uncertainty principles[1] (so that the uncertainty relationships act as selections on what vacuum activity can proceed), so also do the irreversibility conditions (whatever they may be) irreversibly select conditions of underlying reversible processes. These selections of states from which further vacuum activity can proceed are also subject to the conservation constraints. It is even possible that the constraints that give rise to the uncertainty relations and the constraints that generate irreversibility are one and the same constraints. In any case, we find here a relatively chaotic vacuum activity upon which several kinds of intrinsic constraint are imposed. The constraints function as selection principles for eliminating, forbidding, activity that violates the constraints.

I have carefully avoided a number of issues involved in quantum field theory. For example, the collapse of the wave processes (in measurements, for example) poses difficult questions of how spatially separated parts of the wave processes can jointly and "simultaneously" honor the various conservation constraints without violating the limitation of the speed of light of special relativity – how does one part of the wave process "know" what the other part is doing? Another avoided issue concerns the relationships between space-time itself and vacuum activities: space-time is, on the one hand, the setting in which vacuum activity takes place, yet, on the other hand, it too must be involved in such activity – space-time is itself dynamic. It is not clear that the perspectives presented could be consistently developed with respect to these issues. But, in fact, there is as yet *no* consistent model that can capture all of these properties and aspects of quantum processes (Cao, 1999; Huggett, 2000; cf. Bohm and Hiley, 1991; Hiley, 1991). My goal has not been to present an overall ontology for quantum field theory, but, rather, to illustrate that notions of variation and selection and constraint can participate in exploring these phenomena:

> The only natural alternative to an eternal law that I can imagine at present is an evolving one, along the lines suggested by C. S. Peirce in his theory of the First Flash (his term was significantly more accurate than "Big Bang", since light is older as well as faster than sound; I shall use it for the first quantum event of the Big Bang), and in other writings on his evolutionary cosmology. One first step toward an evolutionary dynamics is to move the law from its classical locus outside the dynamical theory to within the realm of evolving entities; this step is already taken in the diachronic quantum theories, where the ambient vacuum is the law. A next step, according to one speculation, is to organize the vacuum out of quasilocal genetic elements capable of reproduction and selection (Finkelstein, 1991, p. 272).

In general, contemporary physics has moved to a much more active conception of the vacuum – an intrinsic activity (Saunders and Brown, 1991). That activity, in turn, is subject to various intrinsic constraints, often simultaneously applicable, and the overall dynamics of the vacuum, and of excited fields in the vacuum, result from the honoring of and the interactions among these constraints. This is potentially a quite fertile domain for variation and selection conceptions. Again, if there are processes that satisfy constraints, there are likely to be variations and selections among, within, and with respect to, those processes.

NOTE

1. Better put: the conservations apply to properties of the vacuum dynamics that are only definable within the constraints of the uncertainty principles. These limits of definability, in turn, are themselves intrinsic constraints of the basic

oscillatory ontology of the underlying phenomena: position and wavelength are simply *not* simultaneously definable to indefinite precision – intrinsically.

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