BOOK REVIEW

A review of *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*, by John D. Barrow, Paul C. W. Davies, and Charles L. Harper, Jr. (Eds.), 2004. New York: Cambridge University Press, xx + 742 pp. ISBN 0-521-83113-X. $79.00 USD.

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In Donald's (1991) previous book *The Origin of the Modern Mind: Three Stages in the Evolution of Cognition and Culture*, he criticized the idea of the homunculus, the little man inside our heads that calls the shots, arguing for the role of culture in the development of consciousness. In *A Mind So Rare: The Evolution of Human Consciousness*, he considered the relationship between consciousness and culture in greater detail, for example, arguing against Chomskians. In this review, I shall consider the relevance and articulation of Donald's contention that there is a socio-cultural basis of consciousness.

Donald's book, like most stories, begins with a problem: we have tended to consider consciousness that private place that no one else can reach. Indeed, as he pointed out, in modern Western culture, influenced by psychology, even our romantic arts sought to tell of things no one else had access to: our experiences; he challenges this picture, emphasizing the functional and social role of consciousness.

This book is an excellent resource on quantum theory, emergence, and our complex world. It developed as an edited collection of papers originally presented in June 2002 at a conference of research leaders and promising young thinkers in the physics community to honor John Archibald Wheeler. Known for investigating and challenging many of the most fundamental issues in physics, Wheeler addressed the "really big questions" of reality and cosmology. Conference presenters were encouraged to do the same and fearlessly tackle important questions and advance new explanations from reasonable principles that could be understood by non-specialists. Wheeler's work on black holes brought quantum mechanics to rescue the second law of thermodynamics by swallowing heat and reducing the entropy of the universe. Finding that matter, space,

and time are obliterated in gravitational collapse, Wheeler stated: "There is no law other than the law that there is no law." Perhaps, in fact, there are no ultimate laws of physics, only chaos and emergent properties. Paul Davies reviewed Wheeler's work on gravitation, the standard formulation being Einstein's theory of relativity. Relativity is a description of space, time, and gravitation; quantum mechanics is a theory of matter. Quantum theory and Einstein's theory of relativity are, however, seemingly incompatible. Wheeler described quantum space-time dynamics as "quantum geometrodynamics," which is not only dynamical, but subject to quantum rules like Heisenberg's uncertainty principle. From experiments, he concluded that an experimenter not only participates in the present unfolding of a given phenomena, but participates in the nature of the phenomenon as it was. Past states are less than real, having no definite mass, position, and motion, etc. The definiteness comes from the observer ("observer-participancy"). "It from Bit": It (molecules) are determined from Bit (information). By choosing the apparatus, the observer can determine whether particle or wave is manifest in the experiment—this "collapse of the wave packet" determines reality. It is tempting to envision how human beings may change the world through consciousness. Zeilinger cautions against the subjective interpretation that the consciousness of the observer can influence the particle (p. 209). Further, while quantum systems appear to communicate faster than the speed of light, "this cannot be used in a practical way by humans" (p. 217) because humans cannot know the state of the particle instantly but must receive the information in a classical manner.

Quantum Reality

How come the quantum? Hardy points out that quantum theory can be applied to many different situations and disciplines. Quantum theory has an underlying mathematical structure similar to probability theory. A physical system prepared in some initial state is subject to transformation and measurements are made on it. The probability of an outcome is used to define the state of a system, the smallest number of measurements needed to fix the state being the degrees of freedom. In quantum theory, unlike classical probability theory, there is a continuous path through pure states (no jumping between states). "Qubits" compose subsystems of elementary systems (such as particles like photons or electrons) with both discrete and continuous aspects. An atom of quantum information, the qubit, is exactly one bit. There is no elementary entity in nature corresponding to a bit; there are only qubits in nature. Isolating a set of qubits and causing them to interact for a fixed period—"Passing through a quantum gate"—allows them to strongly affect each other while remaining isolated from the environment. The complementary particle-like and wave-like behavior disappears when efforts to measure the position (particle aspect) disturb the momentum and, consequently, the interference pattern (wave aspect). Quantum weirdness requires the various parts of the waves of matter to maintain their relative phases (coherence). If the phases are scrambled in the environment the quantum qualities are suppressed. The decoherence destroys large quantum superpositions (the response at a place and time caused by the summation of

two or more stimuli) transforming them into mundane classical mixtures of states that we see. How does the (classical) world we observe emerge from the quantum? What is the quantum-classical boundary where quantum features vanish and why? What does a quantum superposition of a virus look, smell, taste, and sound like? Do we need a whole new sensory world we have yet to imagine to understand?

A quantum computer uses quantum interference effects at a macroscopic scale to perform massive parallelism achieving an exponential speed-up in computation. To build such a device decoherence must be overcome, slowed or capitalized upon somehow. Large ensembles of "quantum bits" (made of atoms, molecules, or photons) evolve in a superposition of two states (0 and 1) (p. 280). The bits, tangled together by quantum gates, exploit electromagnetic interactions between them. Two entangled particles, separated by a large distance, manifest themselves at the macroscopic scale. What is done to one particle immediately correlates with what happens to the other, even though they are far apart, e.g., thousands of miles, termed non-locality, and supported by Einstein-Podolsky-Rosen (EPR) effects and Bell inequalities (p. 258). Decoherence becomes faster and faster as the number of particles (photons) and the information on the system path increases. Today, efforts to make a quantum computer include altering environmental coupling, e.g., supercooling, in an effort to preserve the superpositions.

Big Questions in Cosmology

Cosmologists are reporting puzzling findings that challenge physics including: very high energy cosmic rays, accelerating cosmological expansion, energy that is not conserved, and constants of Nature looking more like lawless dynamical variables. Observations show that evolution is a fact of life for the universe and some believe the laws of nature mutate with the universe-mutability (p. 530). Wheeler advanced the concept "mutability" where there are no fixed laws of physics at all. The baby universe, where anything went, cooled and collapsed to show some stability which humanity interpreted as knowable qualities. Are the laws of nature stable or do they change, mutating with the universe they describe? This would require a varying speed of light (VSL) where units like length, time and mass could be expected to vary as well. How many dimensions are there? Are there many more than three that are hidden from Newtonian scientific methods that we have only an intuition of during times of heightened awareness.

Emergence

Does nature manifest an inbuilt tendency to bring about increasing complexity? Increased diversity leads to phase transitions that lead to formation of collectively autocatalytic sets of molecules that speed up the very reactions by which they themselves are formed. From photons to living beings, autonomous parts are bound together for mutual benefit in a common state of localized complexity. According to Gleiser, Nature's complexity is necessary for its constant struggle to save resources

(Cosmic optimization principle). Gleiser examines how the identity of a structure is maintained and function emerges from the collective complexity of the structure. Complex structures have properties that cannot be predicted by knowing the properties of the individual constituents. Not only are the number of constituents in a structure needed to describe its physical state, but the functional complexity of the structure is important. In a complex system, how the many constituents function together is often difficult to determine and requires observation over time. A shift in focus from prediction to description is needed to gain knowledge of complex systems.

Living systems use information to control physical functions for higher-level goals. They learn by "capturing, storing, recalling, and analyzing information" using pattern recognition and predictive models (p. 610). Boundary conditions and structural relations effect top-down action (macroscopic directing how microscopic acts). Top-down and bottom-up are both important to understanding why the world behaves the way it does. Ellis stresses the distinction between "ontology (existence) and epistemology (what we can know about what exists)" making the point that we may not be aware of all that exists because our senses or measuring instruments do not "demonstrate clearly its existence to us" (p. 623). How can we become aware of what exists? Ellis lists four Worlds that are different "kinds of existence" related to each other through causal links: (1) Matter and forces, (2) Consciousness, (3) Physical and biological possibilities, and (4) Mathematical reality. Within 2) Consciousness is a world different from the world of material things and realized through human mind and society. Consciously we can never expect to understand (1), (3), and (4) completely because simultaneous multiple causality is always in operation in complex systems. What is observed depends on the questions we ask. Observers acquire information about "measured systems" indirectly by monitoring the environment. By pondering little intractable problems deep truths may be uncovered. These insights can be further explored using models of complex systems using computer hierarchical models plus heuristic understanding of the interplay of components, together with mathematical models of specific subsystems and networks. Kauffman's "new general biology" depends on physical and chemical regularities but is not reducible to them. Biological systems create and maintain order using energy input from the environment. Based on yet to be determined sets of laws of emergent ordering or self-complexification, a cell constructs constraints on the release of energy within, this propagates until the cell builds a copy of itself – the living state. Kauffman muses that someday we may create autonomous, novel life forms and a general biology different than the only one we know.

In "Emergence: Us from it," Clayton categorizes emergence into five types moving from: (1) use of the term in theories, (2) connections or laws as basis to new theory, (3) a heuristic that assists in recognition of common patterns between theories, (4) a common element in scientific transitions, and (5) a metaphysical theory that the world "produces continually more complex realities in a process of ongoing creativity (p. 602). Clayton sees four factors as key in biological emergence: Scaling (new whole-part relations), feedback loops (interacting mechanism from autocatalytic process), local-global Interactions (emerge from interlocked feedback loops), and nested hierarchies

(subsystems in "combinatorial explosion"). This broad pattern of interacting complex systems, shares common themes across disciplines and between theories, and forms an interdependent network with distinct elements contributing to an overall explanation from each scale. Emergence is particularly powerful in describing similar but not identical patterns in neighboring disciplines.

Finally

Chapters conclude with summaries connecting the content to the macroscopic, observable world and emphasize the importance of experiment and observation to create models for the systems we are interested in. Some chapters are easier with a physics background, but the editors really attained their goal of making the content understandable. The importance of the environment is clearer than ever. From the micro to the macro the environment cannot be ignored and must be considered in all of science. The authors and editors of this book took very important questions and advanced new explanations, that can be understood by many disciplines, opening new possibilities for shared micro, meso, macro understanding.

About the Reviewer

Dr. Davidson received her PhD in Nursing from the School of Nursing, University of Colorado, Denver. She assumed a dual role as assistant professor of nursing at the university and head of research at Boulder Community Hospital. In 1994, she was awarded a research fellowship at Harvard University, where she worked on a National Institutes of Health funded investigation of the role of environmental complexity in the physical and mental wellbeing of the elderly. In 2001, she received a research fellowship to travel to Pari, Italy to study with complexity science researchers at the Pari Institute. It is with sadness that we note that Dr. Davidson passed away on Dec. 3, 2009, at the age of 64, at her home in Seal Rock.