Free Will, Information, Quantum Mechanics, and Biology

It Pays to Distinguish Different Forms of Free Choice and Information

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Attempts to make use of quantum physical indeterminism in interpretations of the origin of free will are almost as old as quantum mechanics itself [1]: Human free will can be traced down to and is a result of Heisenberg's uncertainty relation. A recent version of the hypothesis of a physical origin of human freedom has been published by Conway and Kochen [2, 3]. They invert the conventional argumentation and assign "free will" even to elementary particles: The uncertainty relation provides room for free decisions at the atomic level or "if indeed humans have free will, then elementary particles already have their own small share of this valuable commodity." According to [3], the strong free will theorem is based on three different phenomena:

i. Relativity theory predicts that the time order of two events at space-like separation, $c^2\Delta t^2 < \Delta r^2$, is not absolute, or in other words, if event A appears to occur before event B in one reference frame there exist other reference frames in which the inverse order of events is observed.
ii. The Einstein–Podolsky–Rosen paradox of two spatially distant entangled particles allows for manipulation of one particle through changing the state of the other particle, and
iii. The Kochen–Specker theorem states that there is no context-free model with hidden quantum mechanical variables.

Combining the three empirically supported predictions from relativity theory and quantum mechanics Conway and Kochen present a rigorous proof for the strong free will theorem that is cast into popular terms by the authors: "If the experimenter can freely choose the directions in which to orient his apparatus in a certain measurement, then the particle's response is not determined by the entire previous history of the universe."

Consciousness and free will were, are, and will be central to the interplay of neurobiology, brain research, and psychology. Benjamin Libet's pioneering work on decision making by the brain [4, 5] made clear that purely conscious free decisions are a subjective illusion. In Libet's experiments, individuals were asked to

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flick their wrist at a random moment consciously decided by them and to monitor the time when they felt that they did the decision, while Libet recorded the EEG activity in their brains. Brain activity in form of the so-called readiness potential did not only precede the motor action but occurred also before the consciously felt intention to move. The time lag between the rise of the readiness potential and the consciously felt decision was approximately half a second. In a refined experiment by Haggard and Eimer [6], the persons were asked to decide also which hand to move. The experimenter recorded the difference in the EEG readiness potential between the left and the right hemisphere with the result that the unconscious lateral readiness potential preceded the consciously felt decision, which hand to move. Many experiments followed and eliminated possible unwanted and uncontrollable perturbations, but the major finding remained unchanged. As an example, a recent very careful study [7] is mentioned using a much more sophisticated decision scheme and spatially resolved functional magnetic resonance imaging (fMRI) for recording of brain activity. The authors find a whole hierarchy of brain activities—related and unrelated, which precede the consciously felt decisions. As much as 10 s time can elapse from the unconscious onset of brain activity to the consciously intended act. Apparently, the free will addressed here, is something completely different from Conway's free will. Rational choice and conscious self-control of action by a human brain are qualities different from the "freedom" to flicker within a cone with a certain angle. Certainly, a rather complicated brain structure is needed for consciousness and the ongoing heavy debate about when it appeared in the evolution of the animal kingdom—if it appeared at all—is proof for this suggestion [8, 9].

Free will would deserve a long and detailed discussion that would go far beyond my competence and the intentions of this essay. In particular, the questions related to freedom of decision, responsibility, and legal consequences have seen and are currently seeing endless discussions. Instead, I would like to mention ideas on the evolution of free will and quote from the abstract of a recent article by Roy Baumeister [10] who touches on the evolutionary importance of free will in human phylogeny: "Human evolution seems to have created a relatively new, more complex form of action control that corresponds to popular notions of free will. It is marked by self-control and rational choice, both of which are highly adaptive, especially for functioning within culture. The processes that create these forms of free will may be biologically costly and therefore are only used occasionally, so that people are likely to remain only incompletely self-disciplined, virtuous, and rational." Unconscious and conscious decision-making work together though we are aware of the latter only. Only occasionally, the conscious brain activity overrules the unconscious. The evolutionary aspects of a highly developed unconscious mind preceding the conscious mind were recently accentuated by Bargh and Morsella [11] and it is hard to resist the temptation of citing Theodosius Dobzhansky in this context: "Nothing in biology makes sense except in the light of evolution."

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What is the role of quantum mechanics in biology? Quantum mechanics provides the basis of chemistry in two fundamental aspects: (i) molecular structures can only be understood within the frame of quantum mechanics and (ii) the empirically established chemical reaction kinetics found its deeper explanations in quantum mechanical collision theory. Structural biology makes use of the principles of molecular structures, which were ultimately derived from quantum mechanics, although most of the theoretical models for biological structures have a combined quantum chemical and empirical basis, because the size of biological macromolecules is prohibitive for full ab initio calculations. Most modeling of dynamical phenomena in biology is done by means of differential equations, which for molecular descriptions have their roots in chemical reaction kinetics. Molecular systems biology bridging the gap between holism and reduction is in essence chemical reaction kinetics of metabolic or genetic modules or even whole cells. Quantum mechanics—in the form of Heisenberg's uncertainty, delocalization, etc.—is invisibly incorporated into biological models as it is in the conventional approach to chemical reactions. There are exceptions where direct applications of quantum physics are indispensable for understanding phenomena in biology, the three most important of them are: (i) interaction of electromagnetic radiation with matter as it occurs, for example, in photosynthesis or in vision, (ii) electron transport, for example, in the redox chain, and (iii) proton transfer through tunneling.

Information in physics is seen as our knowledge of reality and as such is related to the outcome of an experiment. In quantum mechanics, the distinction between reality and information is jeopardized by indeterminism because there are details of the system under consideration that in principle cannot be determined and hence Anton Zeilinger suggests that reality and information are two sides of the same coin [12] and a distinction between reality and our knowledge of reality is futile. This "lesson from quantum theory" has been questioned by a group of mathematicians and the-

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oretical physicists [13] who strongly attack the view that "the physical world is just information." Without further digression into this discussion, it seems important to stress that the notion of "information" in the context of reality in a quantum world is radically different from information in biology commonly—but not always—thought to be tantamount to genetic information stored in a nucleic acid molecule. Biological information is of a different quality. Without the information stored in macromolecules of a certain class, biology would be nothing more than a funny chemistry with a restrictive selection of atoms—C, H, N, O, P, S, and a few metal ions. What makes biology different from chemistry and physics is Nature's invention of digital information. The great problem that had to be solved was to find a molecule that is capable of storing and multiplying information in digitally encoded form. Since Watson and Crick's correct proposal of the molecular structure of deoxyribonucleic acid (DNA) [14] Nature's trick has been disclosed. It consists of the usage of digits that are combined in complementary pairs through fitting into the rigid geometry of a double helix. In the cell, biological information is processed by means of a complex molecular machinery producing thousands of biomolecules whose highly specific structures and functions are encoded in the digital sequence of DNA molecules.

The same structural principle that allows for encoding information for the synthesis of biomolecules provides the basis for the multiplication of information. Multiplication together with the occurrence of mutations—commonly interpreted as replication errors—is the basis of evolution. Multiplication introduces a nonlinearity into the system that allows—in open systems—for progression away from thermodynamic equilibrium. Expressed in other words, multiplication leads to exponential growth—even single DNA molecules can be amplified routinely to 10^{10} copies or more—and selection of the best adapted variants, a phenomenon that cannot occur near equilibrium. Against the approach toward thermodynamic equilibrium of simple systems, evolution based on multiplication or mutation has the tendency to produce more efficient and more complex entities. In contrast to thermodynamic processes leading to equilibrium, where all memory of specific developments is lost, evolution is characterized by both history and contingency. Replication and evolution require open systems at conditions away from thermodynamic equilibrium, which have their own rules being different from the laws governing near equilibrium thermodynamics.

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Finally, I accentuate that the relation between biology and quantum physics is not essentially different from the relation between biology and thermodynamics: There is no reason to believe that the laws of thermodynamics or quantum physics are broken in biology and both provide the frame within which biology unfolds, however, they contribute very little to an understanding and to a solution of the problems in biology—with exception of the aforementioned cases. Although physicists and biologists are unlikely to confuse Conway's free will with popular free will or Zeilinger's information with encoded information, it pays to make clear for the nonspecialists what is actually meant. Even more fortunate would be the usage of different notions for different phenomena.

REFERENCES

1.. Lillie, R.S. Physical indeterminism and vital action. Science 1927, 66, 139–144.
2. Conway, J.H.; Kochen, S. The free will theorem. Found Phys 2006, 36, 1441–1473.
3. Conway, J.H.; Kochen, S. The strong free will theorem. Notices of the AMS 2009, 56, 226–232.
4. Libet, B.; Gleason, C.A.; Wright, E.E.; Pearl, D.K. Time of conscious intention to act in relation to the onset of cerebral activity (readiness–potential). The unconscious initiation of a freely voluntary act. Brain 1983, 106, 623–642.
5. Libet, B. Unconscious cerebral initiative and the role of conscious will in voluntary action. Behav Brain Sci 1985, 8, 529–566.
6. Haggard, P.; Eimer, M. On the relation between brain potentials and the awareness of voluntary movements. Exp Brain Res 1999, 126, 128–133.
7. Soon, C.S.; Brass, M.; Heinze, H.J.; Haynes, J.D. Unconscious determinants of free decisions in the human brain. Nat Neurosci 2008, 11, 543–545.
8. Dennett, D.C. Animal consciousness and why it matters. Soc Res 1995, 62, 691–710.
9. Dennett, D.C. Kinds of Minds: Towards an Understanding of Consciousness. Basic Books (Science Masters Series): New York, 1997.
10. Baumeister, R.F. Free will in scientific psychology. Perspect Psychol Sci 2008, 3, 14–19.
11. Bargh, J.A.; Morsella, E. The unconscious mind. Perspect Psychol Sci 2008, 3, 73–79.
12. Zeilinger, A. The message of the quantum. Nature 2005, 438, 743.
13. Daumer, M.; Dürr, D.; Goldstein, S.; Maudlin, T.; Tumulka, R.; Zanghi, N. The message of the quantum? AIP Conf Proc 2006, 844, 129–132.
14. Watson, J.D.; Crick, F.H.C. A structure for deoxyribose nucleic acid. Nature 1953, 171, 737–738

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