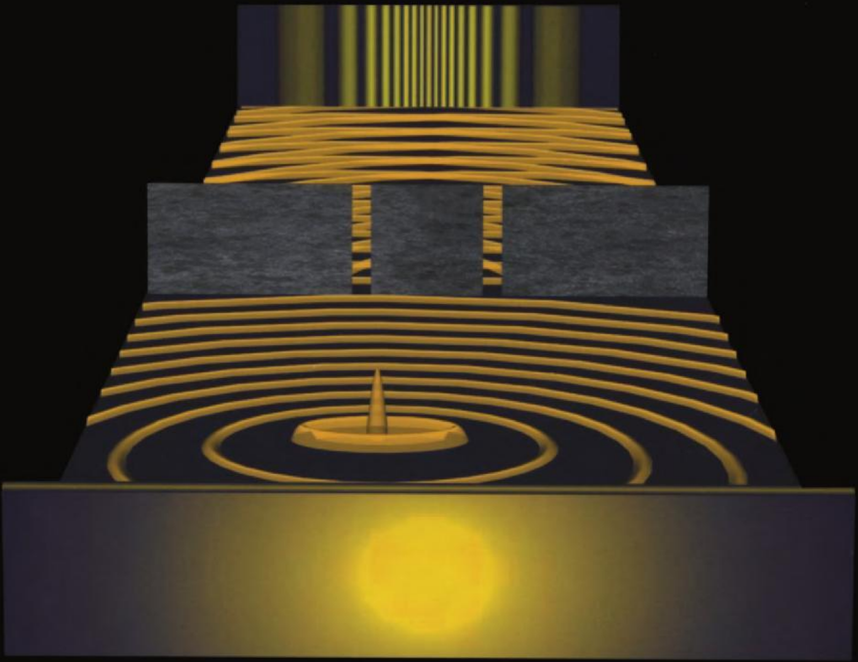

QUANTUM CYBERNETICS

Toward a Unification of Relativity and Quantum Theory via Circularly Causal Modeling

Gerhard Grössing

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With 25 Illustrations

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Gerhard Grössing
Austrian Institute for Nonlinear Studies
Parkgasse 9
Vienna A-1030
Austria
ains@telekabel.at

Cover illustration: Simplified scheme of a quantum system, where a "particle" is actually represented by the nonlinear part of an elsewhere linear, wavelike medium ("aether").

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Introduction: The Return of the Aether

Nicht *wie* die Welt ist, ist das Mystische, sondern *dass* sie ist.
(It is not *how* the world is that is mystical, but *that* it is.)

Ludwig Wittgenstein
Tractatus Logico-Philosophicus

Most of theoretical physics in the twentieth century can be characterized by a reductionist attitude that has revealed a hierarchical structure of the physical world. However, instead of being "radically" reducible to *one* "basic" level only, each layer of the hierarchy has turned out as largely autonomous. The great success of this approach consists in a huge amount of often very precise knowledge about each of these layers, unified in the "fundamental" descriptions via "universal" laws. The successful strategy of reduction and unification is due to a quite remarkable *level independence*, such that, for instance, the effective Lagrangian on the level of molecular interactions is for all practical purposes decoupled from the one on the level of quarks constituting the molecules' individual nuclei.

However, level independence is not only a "fact of nature" that we observe; it is also to some degree a consequence of the reductionist strategy per se [Primas 1983], which actively closes its eyes upon other, *level – connecting* phenomena, like self-organization, emergence, etc. According to Sam Schweber, "it is not enough to know the 'fundamental' laws at a given level. It is the *solutions* to equations, not the equations themselves, that provide a mathematical description of the physical phenomena. 'Emergence' refers to properties of the solutions — in particular, the properties that are not readily apparent from the equations" [Schweber]. Thus, one can say that toward the end of the twentieth century, physicists, and scientists in general, although (necessarily) still remaining "reductionists" in a weaker sense, increasingly tend to direct their attention from level independence toward "holistic" phenomena. This is done in very diverse areas such as, e.g., quantum theory (where holism has — "philosophically" — always been an issue, but in recent years has also become of operational importance), or the transdisciplinary study of *self-organized criticality* [Bak *et al.*].

In general, holistic phenomena cannot be described by linear, monocausal reasoning. Rather, whichever element on some particular level is chosen for investigation, it must be considered in its context involving other levels, with circularly causal relations between them. Contextuality and circularly causal (or feedback-based) reasoning nowadays can be found in practically all fields of knowledge. Although not always explicitly stated as such, in practice they are a matter of course in the humanities, as in sociology or psychology. In evolutionary biology, one speaks of "evolutionary landscapes" (e.g., in "fitness space"): if classical Darwinism today resembles the study of the flow of a river's water by tracing the trajectories of individual droplets back to their origins, the new systemic approach to evolution has to consider also the river bed and the constant interactions between the "water" and its surroundings. In other words, there exists a circularly causal relationship between the trajectories of individual evolutionary units (such as species) and their surrounding ecologies. A very similar systemic relationship can be found on the level of the genes: Formerly having been considered as constituting the "atoms of heredity," genes now are rendered to assume new roles within "autocatalytic networks" [Kauffman].

Even in the physical sciences of "inanimate matter," contextuality and circular causality abound. For example, in General Relativity, a massive body influences the spacetime curvature of its surroundings, and vice versa: the curvature of spacetime determines the trajectories of the massive bodies. Moreover, in the Maxwell–Lorentz theory of the electron, particles and field mutually influence each other. Furthermore, in energetically open systems, processes of self-organization are characterized by a mutual relationship between the dynamics of individual entities and the boundary conditions of the whole system.

So, if the context of a research topic is not chosen too narrowly, circular causality is state-of-the-art, even in the (classical) physics of matter. But what about quantum theory? Apparently, this seems to be the only field of physics where causality is seriously questioned, and with respect to local monocausal explanations this is certainly justified. However, it is also justified to enquire whether the behavior of quantum systems really differs so much from all the other systems studied in the sciences. On the contrary, I shall try here to indicate the use of systemic thinking in quantum theory as well: the key issue will be contextuality and a circularly causal, i.e., a cybernetic viewpoint.

There may be several reasons why such an approach has not been considered extensively so far.[2] One of them is certainly given by the many successful applications of quantum theory without any serious need for refined viewpoints. Moreover, the implications of the quantum phenomena may also be seen as being so radical for our whole understanding of the material world we live in, that it may well take at least decades to fully realize them. In fact, the development of quantum mechanics in the twentieth century does show a steady increase in awareness of its central feature, i.e., of *nonlocality*.[3] While Albert Einstein referred to the corresponding phenomena only as a "spooky action at a distance," John Bell was able to show that no *local* hidden variable model whatsoever can reproduce the predictions of quantum mechanics. Rather, quantum mechanics violates his famous inequalities which are today named after him [4] [Bell]. Later, Alain Aspect's group [Aspect *et al.* 1982a, Aspect *et al.* 1982b] was the first to experimentally verify the violations of Bell's inequalities (although with a small caveat, later to be overcome, as mentioned by [Zeilinger]), and nowadays a whole series of experiments makes direct use of the nonlocal nature of quantum theory [Aspect].

In other words, during the last decades of the twentieth century we have become witnesses of what I call "the end of the twentieth century atomism," i.e., the end of "the belief (put into practice with the atom bomb, nuclear reactors, or particle accelerators) that the world, in its deepest essence, is composed of tiniest entities — these 'atoms' today being some kind of 'elementary particles' — such that any object can be considered, at least in principle, as a spatially limited collection of a finite number of such entities" [Grössing 1993a]. In contrast, it has become feasible to speak about dynamical "holistic" networks where "particles" are embedded in a relevant (i.e., irreducible) environment or "context." In this regard, I have already mentioned the demise of the concept of genes as the "atoms of heredity" above, giving way to the framework of autocatalytic networks. Similarly, atoms, electrons, neutrons, etc., which have once been considered as "fundamental particles," now have to be described in modern quantum theory within the framework of nonlocal holism, viz., the phenomenon of *entanglement* [Schrödinger 1935], for example.

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[2]Exceptions discussing different aspects of a hypothesized quantum "control theory" include [Guerra and Morato, Santamato, Rosenbrock, MacGregor, Yasue].

[3]In general, I refer to "nonlocality" in the sense that spacelike separated regions of spacetime are correlated or can influence each other. I will thus retain this nomenclature even in the case where superluminal propagations are made responsible for the experimental results, which one might then consider as elements of a "local" but "holistically" causal theory.

[4]Naturally, the remaining proponents of locality insist that there are a few holes in the present experimental evidence [Selleri], but the latter will most likely soon be filled.

This amounts to nothing less than a "Copernican revolution" on the level of "objects." Instead of being separate entities "centered in themselves," — like some massive object with its gravitational field — with the rest of the world somewhere around them, quantum "objects" are not necessarily "centered" anywhere, but rather connected to different and distant parts of the world that are simultaneously parts of the quanta themselves. So, if we speak about quantum "objects" at all, we must be aware that thereby we already introduce a "de-finition" (or delimitation) that excludes parts of the correlations of the quantum system with the rest of the world: as Hans Primas has repeatedly pointed out, quantal "objects" do not exist in an absolute sense, but only in a contextual one, i.e., in the framework of our chosen delimitations. In this sense, "observable phenomena are created by abstracting from some EPR correlations" [Primas 1983, p. 253]. From ontological and epistemic points of view, this has an interesting corollary:

> According to quantum mechanics the electrons of the moon are entangled with their radiation field. If we are not willing to abstract from the quantum mechanical structure of this radiation field on the grounds that it is irrelevant for the problem under discussion, then the moon becomes entangled with the sun, etc. and cannot be said to possess an individuality. So without abstracting from the quantum structure of the radiation field, the moon cannot be an object [Primas 1983, p. 292].

...Nor can a single tree, or a single electron, for example. Of course, in our lives of daily routine, this does not change much — just as for us the sun still "rises" in the east and "sets" in the west, despite the heliocentric revolution of Copernicus and others. But if we are really interested in how the world is, we have to face the "Copernican revolution" of quantum theory in its full extent: that in its "deepest essence" (and as far as we can talk about it today), there are no "atoms" of the physical world separable from the rest; rather, the world has to be considered as a whole, with "parts" constituting only (more or less viable) simplifications of the actual ongoing dynamics, or of what David Bohm has called the "holomovement" [Bohm 1980]. The fascinating perspective of this new world view is, however, that under particular circumstances the "wholeness" of the physical world can be used to show nonlocal correlations that under our old atomistic perspective could only be qualified as "magic." It is clear that such a sweeping revolution literally affecting our fundamental concepts of the whole universe cannot be fully grasped within short periods of time, or be accepted by a scientific community with firm roots in an "atomistic" world view to be overcome. This situation today is, in fact, very similar to the cosmological "Copernican revolution" during the times of the Renaissance, of which Alexandre Koyré has pointed out, that it, too, did not succeed in one great step, but took decades, or even centuries to become settled into the minds of individuals [Koyré].

This book is structured as follows. In Chapter 1, some of the problems concerning the compatibility of quantum theory and the special theory of relativity are discussed. It is shown that a hitherto ignored consequence from the principle of relativity has a wide range of implications even for the quantum domain. Specifically, it is shown how upon the assumption of a relativistic "aether," both Born's rule for calculating probabilities of events and nonlocal correlations follow from the principle of relativity. Although not necessarily based on the idea of quantum cybernetics, but in perfect agreement with it, a calculation scheme is presented with which the results of quantum theory can be obtained without invoking complex-numbered "probability amplitudes." A brief review of the de Broglie–Bohm interpretation of quantum theory and problems concerning relativistic formulations thereof rounds up the first chapter. In Chapter 2, the approach of quantum cybernetics is presented, i.e., the idea of a circular causality between waves and "particles." A relativistic quantum cybernetics is proposed that can avoid problems of other relativistic formulations of the causal interpretation. Furthermore, it is shown how the rules to calculate probabilities in quantum theory can be understood in principle. Chapter 3 presents a discussion of experiments relevant for the approach of quantum cybernetics. In particular, it is shown how superluminal velocities and perhaps even signaling might occur. With regard to special relativity, a solution of an apparent conflict between different observers' descriptions of nonlocal effects is given within a realistic framework, as well as a discussion of "causal paradoxes" associated with eventual superluminal signaling. In Chapter 4, Einstein's equations for the gravitational field are derived from quantum cybernetics, thereby providing a close link between circular causality at the quantum level and Mach's principle. Finally, in Chapter 5, circular causality at the quantum level is discussed, both with respect to the historical context and future perspectives.

To complete this introduction, I want to point out what this book is not about. Although the term "cybernetics" may evoke associations with computing devices in the reader, I do not deal with the field of quantum computing here. Also, the recently increasing interest in controlling the performance of quantum precision experiments by using feedback processes against decoherence effects [Anderson, Dunningham *et al.*] is not covered. With the latter being rather of the type of a "quantum control theory," I would like to reserve the term *quantum cybernetics* for the proposed feedback processes *constituting* any quantum system. Finally, let it be said here that I have no intention whatsoever to propose an "alternative" to quantum theory. Cybernetics, as I understand it, is a way of looking at things, with a particular focus on feedback processes that are describable as circularly causal ones. This does not mean that any description via the usual linearly causal approaches must be wrong. In effect, we know that quantum systems are to be seen holistically, and any type of description, which by its very nature is "reductionist" to some degree, will be only of some limited value. Still, I hope to be able to show that some central issues of quantum mechanics can in fact be illustrated very aptly with cybernetic concepts. In particular, the establishment and changes in nonlocal correlations shall be a primary focus of my explorations. Thus, quantum cybernetics *is* quantum theory from a cybernetic point of view.

Actually, quantum theory is so complex and rich of curious phenomena that, to grasp it fully, no single canonical theory could highlight all its features optimally. In this sense, quantum cybernetics is an attempt to draw attention to some aspects of quantum processes, which may explain some central questions of today's theory, but simultaneously opens many new ones.

1

Quantum Theory and the Special Theory of Relativity

> It may well be that a relativistic version of the (quantum) theory, while Lorentz invariant and local at the observational level, may be necessarily non-local and with a preferred frame (or aether) at the fundamental level.
>
> John Bell
> *Speakable and Unspeakable in Quantum Mechanics*

1.1 Compatibility of Nonlocal Correlations with the Principle of Relativity

1.1.1 Introduction

One of the main unresolved problems in the foundations of physics is the compatibility of quantum theory with the theory of relativity: although the latter seemingly excludes the propagation of information with velocities faster than the speed of light c in the vacuum, the nonlocality of quantum theory (as given by the EPR correlations, for example) is — at least in the opinion of the big majority of physicists, which I share in this regard — an experimentally confirmed fact [Aspect, Tittel *et al.*]. This apparently proves that there exist "quasi-instantaneous effects" over very large distances such that the latter could be viewed as propagating with