Foundations of Probability and Physics-3: Preface of Proceedings and Round Table on Quantum Foundations and Computing

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Abstract
This preprint contains a detailed Preface to Proceedings of the International Conference “Foundations of Probability and Physics-3” held in Växjö, Sweden, 7-12 June 2004; table of contents and round table. The main theme of the round table was “Fundamental problems in quantum mechanics, probabilistic description of reality, and quantum information.” The topics that were specifically discussed were that of Quantum Cryptography, Quantum computing, and Quantum Macroscopic Structures. For each of these topics, the participants were asked to discuss which are the crucial Quantum features required among the following: violation of Bell’s inequality, Entanglement, Complementarity, and Interference of Probabilities. Finally, the connection between Mental states and Quantum states was discussed.

PREFACE
This volume constitutes the proceedings of the International Conference “Foundations of Probability and Physics-3” held in Växjö, Sweden, 7-12 June 2004 (see also: [http://www.msi.vxu.se/icmm/fpp3/]). The organizing committee of the Conference included: S. Gudder (University of Denver), H. Rauch (Atominstutit, Vienne), A. Yu. Khrennikov (Växjö University, Sweden). The conference was supported by the Swedish Research Council, Profile
Mathematical Modeling of Växjö University, and the EU-network "Quantum Probability and Applications in Biology, Economy, and Physics." This conference is one of a series of Växjö conferences on the foundations of quantum mechanics (with emphasis on probability theory).\textsuperscript{1} The conference started with an opening lecture by Alain Aspect, who presented the conventional viewpoint on the EPR-Bohm experiment, Bell’s inequality and experimental tests of Bell’s inequality. \textsuperscript{2}

This first talk induced stormy debates, which where stopped only by the announcement that participants were about to miss lunch. Debates continued during lunch. There were many questions and strong comments from people who doubt the conventional interpretation of Bell’s inequality. In particular, A. Khrennikov pointed out that it seems that the problem which is well known in experimental circles under the rubric of “detector efficiency,” is in fact, essentially a more general problem of “matching” measurements taken on two parts of composite systems. In particular, time-factors play a crucial role. It seems, that it is a fundamental problem, which will not be solved in a purely experimental framework. A. Aspect disagreed with such a viewpoint and expressed the belief that the problem of detector efficiency will be solved in the future via technological advancements.

There was a heavy discussion between A. Aspect and I. Volovich. The latter pointed out that the conventional description of the EPR-Bohm experiment (in Bell’s formulation) does not contain space as a variable at all. I. Volovich claimed that without additional experiments on the role of spacial separation of the detectors in EPR-Bohm experiments, Bell’s conclusions are not justified. A. Aspect responded to Volovich’s contention by pointing out

\textsuperscript{1}See: Proceedings of International Conferences (ed.: A. Yu. Khrennikov): Foundations of Probability and Physics, Ser. Quantum Prob. White Noise Analysis, 13, 201-218 (WSP, Singapore, 2001); Quantum Theory: Reconsideration of Foundations, Ser. Math. Modeling, v. 2 (Växjö Univ. Press, 2002); Foundations of Probability and Physics-2, Ser. Math. Modeling, v. 5 (Växjö Univ. Press, 2003); Quantum Theory: Reconsideration of Foundations-2, Ser. Math. Modeling, v. 10, Växjö Univ. Press, 2004; see also [http://www.msi.vxu.se/forskn/quantum.pdf](http://www.msi.vxu.se/forskn/quantum.pdf)

\textsuperscript{2}There was an interesting deviation from the usual presentation: Instead of simultaneous measurements of commuting observables on parts of a composite quantum system, he considered conditional measurements: i.e., given the first subsystem as a condition, what state does the second subsystem exhibit. However, he did not regard this as a new viewpoint on the relation between realistic and quantum models. He was sure that this is just a convenient way to present the EPR-Bohm experiment.
that suitable experiments have been done; and, they did not demonstrate substantial influence by such separation on the observed correlations.

During this lunch discussion involving A. Aspect, A.Khrennikov, I. Volovich and A. Grib, A. Khrennikov asked about arguments supporting the anti-photon interpretation of, say, Willis E. Lamb and Alfred Lande, who, although among the founders of quantum mechanics, nevertheless totally rejected Einstein’s photon. A. Aspect presented a detailed recounting of attempts to use a classical description of light in quantum theory to explain experiments, which, he said, show that such attempts can not be successful.

Andrey Grib recounted the origin of the Copenhagen interpretation of the wave functions (i.e., assigning a wave function to an individual quantum system, e.g., to a single electron, vice an ensemble). He pointed out that one of the strongest supporters of this interpretation was Vladimir A. Fock, and that even though Bohr himself had doubts about its consistency, he, Fock, demonstrated to Bohr inconsistency in the Einsteinian ensemble interpretation.

A. Aspect and A.Khrennikov discussed the so-called Växjö (contextual statistical realistic) interpretation of quantum mechanics. A. Khrennikov claimed that by taking into account dependence of probabilities on complexes of physical conditions (contexts) one can reconstruct the probabilistic structure of quantum mechanics. The latter was considered as just a special (complex Hilbert space) projection of a realistic pre-quantum model. A. Aspect supported the contextual viewpoint to quantum mechanics, but he expressed his doubts regarding the possibility to reconstruct quantum mechanics solely on the basis of classical (even contextual) probability theory. A. Aspect was certain that negative probabilities would always arise.

A. Aspect’s opening presentation provided considerable stimulation; and, it was discussed in numerous coffee-breaks and during the round table. It was the first in a series of excellent talks on experiments with quantum systems. In particular, Oliver Benson presented results of single photon experiments with applications to quantum information. His talk induced a discussion regarding the justification for the claim, that single photon experiments really have been done. H. Rauch spoke about the foundations of quantum mechanics in light of quantum interferometry. One of his messages was, that in real experiments it is actually impossible to split microscopic systems from macroscopic experimental devices, e.g., a neutron from the crystal in the interferometer. H. Takayanagi described a wide domain of experimental research at the NTT Corporation (Kanagawa, Japan). This talk, among others, emphasized
how truly amazing the breadth of advanced experiments in so many directions on quantum information theory is in fact. G. Jaeger described experimental research in quantum information at the Boston University Photonics Center concentrating on entanglement and symmetry in multi-qubit states.

These experimental talks on quantum information matched very well with fundamental theoretical talks on foundations of quantum information, computing and cryptography. In particular, we can mention the lectures of Masanori Ohya and Noboru Watanabe on characterization of quantum entangled states, quantum entropy and capacity; Igor Volovich on the role of space in quantum cryptography; Sebastian Ahnert on optical implementation of Hardy’s paradox; Jan-Ake Larsson on the possibility of a coincidence-time loophole. There was also a series of talks on probabilistic foundations of quantum mechanics and measurement theory, e.g., Stan Gudder—fuzzy quantum probability theory, Andrei Khrennikov—contextual probability theory and contextual interpretation of interference of probabilities, Olga Nánásiova—dependence on orthomodular lattices, Paolo Rocchi—reversibility and irreversibility of stochastic systems, Inge Helland—quantum theory as a statistical theory under symmetry and complementarity, Marcos Perez-Suarez—subjectivist Bayesian approach to quantum information.

As always, much was said about Bell’s inequality. Luigi Accardi and Massimo Regoli presented graphical results from numerical experiments employing a classical, local realistic model reproducing the EPR-Bohm correlation function. These graphical results demonstrated clearly the essence of their so-called chameleon effect. This effect induces losses of particles due to influence by measurement devices. Therefore, it seems that the old bet\footnote{In 2002 at Madeira, after a good lunch, we (L. Accardi, R. Gill, V. Belavkin, I. Helland and I) took a walk on the beach where L. Accardi and R. Gill made a bet on the possibility of a computer simulation (local and realistic) reproducing the EPR-Bohm correlation function. Others (V. Belavkin, I. Helland and I) were chosen to serve as the jury. The first bet was for 1000 Euro. Next year the ante was raised to 2500 Euro. Polemics between Accardi and Gill, however, diverted the dispute to an ancillary issue: namely, the correctness of the computer program used by Accardi-Regoli.} between L. Accardi and R. Gill should be adjudicated in favor of Accardi, as it really is possible to reproduce the EPR-Bohm correlations. The chameleon effect is local, and chameleons arereal. The only problem is, that some chameleons die, and these chameleons would not be taken into account. The latter possibility was not discussed at Madeira, but Accardi’s model does fulfill reality and locality conditions. But R. Gill might, of course, reply that he had in
One may say, that this story really is just about detector efficiency. However, it would be unreasonable to reduce the chameleon effect to only a matter of detector efficiency, because it involves a more general problem. In fact, a similar issue was discussed in the talk by Guillaume Adenier and Andrei Khrennikov, who reproduced the EPR-Bohm correlation function by taking into account the influence of polarization beam splitters. Adenier also designed an experimental scheme to test for the effects of such an influence. I would like to comment on these investigations by saying, that in fact they match very well with Bohr’s thesis, that the whole experimental arrangement must be taken into account. Moreover, I think that the influence of devices plays the fundamental role, and they will not be eliminated through technological developments. This viewpoint was defended in our paper with I. Volovich at the Växjö conference two years ago.\textsuperscript{4} It is interesting, that in fact people (using the conventional interpretation of Bell’s inequality) have very strong disagreements with N. Bohr, but still, many people criticizing Bell’s arguments actually are just follow N. Bohr. In any case, I think that until we are able to present at least a computer simulation of the whole EPR-Bohm experiment, which would model effects of all measurement devices (source, polarization beam splitters, phase shifters and so on), it is too early to come to definite conclusions.

In his talk, W. Philipp criticized existing derivations of Bell’s inequality. He considered two main approaches to derive Bell-type inequalities: 1) measure-theoretical; 2) frequency. It was emphasized, that one could proceed in the first approach only by assuming (as J. Bell did) that there exists a joint probability distribution of observables. This assumption has no real physical justification, since some observables are incompatible. This argument was discussed many times during previous conferences by L. Accardi, W. De Baere, W. De. Muynck, A. Khrennikov. The new feature was the rediscovery by W. Philipp of an old paper by the Russian probabilist Vorobjev, who described random parameters which do not have a joint probability distribution; he used such parameters in game theory. Thus, there is not hinge specially ‘quantum’ in such situations. W. Philipp also criticized frequency derivations, because, in his opinion, one should not mix, into the same arithmetic

\textsuperscript{4}A. Yu. Khrennikov, I. V. Volovich, Local Realism, Contextualism and Loopholes in Bell's Experiments. Proc. Conf. Foundations of Probability and Physics-2, Ser. Math. Modeling , vol. 5, 325-344, Växjö Univ. Press, 2002; quant-ph/0212127
expression, statistical data from different (even incompatible) experiments. This thesis was strongly criticized by practically all participants (including experimentalists).

In principle, I presented similar arguments a few years ago (such a viewpoint was introduced by W. De Baere already in the 70’s). However, I have been disappointed by the fact, that I am unable to find examples in the macro world that exhibit effects similar to those seen in quantum mechanics and caused by such data mixing.

There were many interesting talks on philosophical problems in quantum mechanics, e.g., Arcady Plotnitsky on complementarity, quantum probability and information; Gerard Emch on models of dynamics in mathematics and theoretical physics, Harald Atmanspacher on epistemic and ontic realities. Theo Nieuwenhuizen showed that, contrary to a rather common opinion, one can construct realistic models for many quantum measurements. He also criticized strongly the orthodox Copenhagen interpretation and gave various arguments in favor of the so-called statistical interpretation of quantum mechanics. In a discussion after his talk, Luigi Accardi and Andrei Khrennikov pointed out that, although in general they support his views, the situation is not so simple. In particular, A. Khrennikov emphasized that explaining interference of probabilities in the statistical approach is a complex matter. Ingemar Bengtsson gave the talk on finite geometries, polytopes and double stochastic matrices. Luigi Accardi pointed out the connection of these structures with some complex problems in quantum probability. Andrey Grib discussed the appearance of quantum non distributive structures in macroscopic games and possible applications of such games. There were a few talks on applications to acoustic and signal analysis (Thomas Biro, Borje Nilsson and Sven Nordebo) and to financial mathematics (Roger Pettersson).

A strongly ‘contrarian’ presentation was made by A. F. Kracklauer, who first surveyed several critical studies of Bell’s analysis, including Edwin Jaynes’ argument that Bell misapplied the chain rule for conditional probabilities, and an argument originated by Brody et al. in the early 1970’s, to the effect that data satisfying the conditions of derivation of Bell inequalities, physically can not be acquired. He then proceeded to present candidate, local-realistic numerical models (unrelated to the chameleon effect) that exhibit EPR correlations. Altogether, this threefold complementarity between

Khrennikov A.Yu., *Interpretations of Probability*. VSP Int. Sc. Publishers, Utrecht/Tokyo, 1999 (second edition, 2004).
experimental, theoretical, and philosophical talks was very fruitful and hope-
fully stimulated discussions further than the conference boundaries, until
next year.

Andrei Yu. Khrennikov,
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ROUND TABLE

The main theme of the round table was “Fundamental problems in quantum mechanics, probabilistic description of reality, and quantum information.” The topics that were specifically discussed were that of Quantum Cryptography, Quantum computing, and Quantum Macroscopic Structures. For each of these topics, the participants were asked to discuss which are the crucial Quantum features required among the following: violation of Bell’s inequality, Entanglement, Complementarity, and Interference of Probabilities. Finally, the connection between Mental states and Quantum states was discussed.

1 Quantum Cryptography

**Gregg Jaeger:** The no-cloning theorem is the essence. If perfect cloning were possible then eavesdropping would be possible and the special physical security of quantum key distribution would be lost. Bell’s theorem does not play that crucial a role, but without Bell’s theorem what becomes of Quantum Mechanics? In any case, there can be a practical benefit in using entanglement such as in the Ekert protocol.

**Luigi Accardi:** Yes, but no-cloning theorem is just a theorem. It’s more Heisenberg uncertainty principle that plays a crucial role. There is no first kind measurement for photons.

**Andrei Khrennikov:** I agree that the no-cloning theorem is just a theorem. Any theorem is valid only for a fixed system of axioms. The no-cloning theorem was proved in the conventional (Dirac-von Neumann) axiomatic of quantum mechanics. This axiomatic provides a rather special interpretation some Hilbert space structures. In particular, it is crucial that the superposition of states can be considered as a superposition of states for an individual system. During the last hundred years numerous arguments have been presented both for and against the conventional axiomatic. One cannot exclude however that another axiomatic of quantum mechanics could be created (with another interpretation of the superposition principle), and in which the no-cloning theorem would no longer be valid.

**Igor Volovich:** It is in any case possible to make an approximate cloning. The main danger actually comes from an attack from space.

**Jan-Ake Larsson:** Bell inequalities and no-cloning theorem are impor-
tant. What is important is that the devices introduce something quantum into the play. The violation of Bell inequalities provides a test of the devices as being truly quantum or not.

Andrei Grib: In some versions of quantum cryptography breaking of Bell’s inequalities plays a crucial role. If there is intervention of Eve into communication of Alice and Bob they can learn it because of validity of Bell’s inequalities. If they are broken then Alice and Bob are sure in the secrecy of communication. Breaking of Bell’s inequalities shows that no Eve read their message.

Karl Svozil: Complementarity is the key. Propositional structures fitting complementarity. A type of quantum cryptography with classical objects and a kind of complementarity. Non distributive.

Arkady Plotnitsky: Complementarity preserves all the basic structures of quantum mechanics and hence it preserved the no-cloning theorem.

Oliver Benson: Single photons are crucial (violation of Bell inequalities is not). Quantum repeaters for long distances are needed and therefore quantum entanglement or teleportation.

Luigi Accardi: I think one should distinguish the case of weak coherent state cryptography and the case of entangled state cryptography: in the former case security is only statistical (although with reasonably high probability); in the latter the crucial role is played not by the impossibility of cloning, but by the impossibility of interacting with the photon without breaking the entanglement.

Andrei Khrennikov: If violation of Bell inequalities are not that crucial, then why do all talks on quantum cryptography start precisely with Bell inequalities?

Gregg Jaeger: Quantum Mystique!

2 Quantum computing

Andrei Khrennikov: Suppose we can go beyond quantum mechanics and create a realistic pre-quantum model, then what becomes of quantum computers?

Al Kracklauer: Quantum computing exploits superposition of states. This is okay for ensembles, but what about for ontological single systems in
such a superposition? Experiments always involve ensembles. Is superposition really needed for quantum computing?

Andrei Khrennikov: If one uses the ensemble interpretation of quantum mechanics and the corresponding interpretation of superpositions, then it is really impossible to explain the origin of quantum parallelism in computations. If everything can be described by purely classical probability distributions then the advantages of quantum algorithms over classical vanishes. In this case the whole quantum computing business would only remain as a model demonstrating the possibilities of coherent manipulation of quantum states.

Arkady Plotnitsky: Quantum Computing indeed depends on superposition.

Hans Grelland: Molecules and chemistry depends exactly on this idea of cat states. The geometrical form of orbitals, which are wave functions and not just probability densities, determine the chemical properties of the molecule Thus the wave function is demonstrated to be real by the chemical behavior of individual molecules.

Al Kracklauer: Quantum tomography yields just a reconstruction. If one reconstructs a Beethoven symphony from signals of an incomplete set of filters, the result would be far from the original, and might well have nonintuitive properties.

Karl Svozil: Quantum parallelism is just a metaphor—Young’s double slit experiment can be considered to have this feature as well. The problem is that there is no powerful enough algorithms. The existing ones are ingenious but not extremely convincing. There are many important NP-complete problems, and we have only at our disposal two algorithms which are not in this class.

Stanley Gudder: I agree. Superposition and entanglement are crucial. Quantum cryptography is today technology, quantum computing is but for the future.

Gregg Jaeger: Grover’s algorithm does not need entanglement, however. Of course decoherence comes into play for all algorithms.

3 Quantum Macroscopic Structures

Andrei Khrennikov: What is the upper bound for cat states? Anthony Leggett for instance sees no limit; Anton Zeilinger did already beautiful ex-
Igor Volovich: Quantum Macroscopic Structures exists already: superfluids, superconductors, etc. There is no problem in creating a quantum macroscopic structure, and quantum mechanics is actually the only way to explain these phenomenon.

Andrei Khrennikov: But if there are no interferences here, how come quantum mechanics be the only possible theory for these phenomenon?

Gregg Jaeger: GRW put forward one. But where does this collapse occur? Nobody has been able to answer that.

Helmut Rauch: There are no boarders. Quantum objects are combined with macro-objects (the measurement device). It just becomes more and more difficult to shift the experimental boarder to more macroscopic objects. It’s a technological problem.

Andrei Grib: Some people like Penrose and others have hope on quantum gravity to solve the problem of the collapse. For any macroscopic system in spite of the fact that it consists of quantum particles, movement of it’s center of mass must be described as movement of large mass, much larger than a Planckian mass. If one will use quantum mechanics for this degree of freedom one can think about quantum gravity. Some experiments were proposed in CERN by Ellis and Nanopoulos to look for breaking of unitarity in these cases, but there are still no definite results. Superstring theorists also have hopes on these experiments because even before quantum gravity scale superstrings can manifest their existence due to breaking of unitarity for macroscopic degrees of freedom.

Luigi Accardi: This dualism Micro-Macro is not very accurate. We should go further than historical tradition. There are more than just two scales, a continuum in fact. Micro, Macro (and Meso, which begins to be quite fashionable nowadays) are but schematizations. The natural scales are infinitely many in a double sense: (i) that there are infinitely many scales (of magnitude - for masses, of distances, of energy, of wave length, of time, ...); (ii) within each scale there are infinitely many gradations. Any finite categorization necessarily introduces some arbitrariness, in the sense that the boundary between two scales is not sharply defined. In the case of the micro-macro scale this was already pointed out by the Greek philosophers with the famous “argumentum acervi”.

Karl Svozil: But there are even some deterministic rules and finite automata which could mimic complementarity.

Arkady Plotnitsky: It depends on one’s definition of complementarity.
Complementarity in Bohr’s sense applies to the measuring devices involved and not to the quantum objects ("particles") themselves. As such, it establishes a mutually exclusive character of certain measurements and predictions, for example, in the EPR case, where what kind of measurement we perform on the first object of the EPR pair strictly defines what we can or cannot predict concerning the outcomes of possible measurements on the second. If it is a momentum measurement (manifest in the apparatus), we can only predict the outcome of a momentum measurement, but never a position measurement, on the second object (a measurement, again, to be manifest in the apparatus used to verify the prediction), and vice versa. How do you yourself define complementarity?

**Karl Svozil:** Complementarity can be characterized by the non distributivity of the associated propositional structure; e.g., of the quantum logic.

**Andrei Khrennikov:** I think that the only quantum feature that can be tested experimentally is the interference of probabilities. In my contextual probabilistic approach, interference is a consequence of a combination of statistical data obtained for different complexes of physical conditions – contexts —, and therefore I totally agree with Arcady Plotnitsky. In principle, combinations of contexts producing interference of probabilities can appear in the macro-world. Such combinations are described by quantum formalism. Therefore we might find quantum effects in classical statistical mechanics, economics, cognitive sciences, or even sociology.

### 4 Is there any connection between mental and quantum?

**Luigi Accardi:** To say that there is connection is a truism once we accept quantum mechanics as our fundamental physical theory. The hard problem is to deduce something nontrivial from this statement. At the moment we can only say that it is a beautiful dream and, in any case it seems to fascinate several people! Also dreams play a role in the development of science ...

**Oliver Benson:** Biophysics developed enough to look for smaller systems where there would be hints of such effects (and don’t start with such a complex system as a brain).

**Gregg Jaeger:** The desired quantum effects in microtubules have never been witnessed in the brain’s environment, nevertheless.
Helmut Rauch: There is a connection, yes. All our existence is based on quantum world. Quantum is not specifically needed to understand this (mean field description is enough). However, I do not see any field where quantum mechanics does not play a role. Quantum mechanics is everywhere, stability of atoms, molecules, biological cells, evolution of the universe, etc.

Andrei Khrennikov: Many years ago, Quantum Theory was supposed to provide a new understanding of Mental. Now people in cognitive sciences, neurophysiology, psychology are however very upset. They spent ten years learning Quantum Theory for nothing, and they are now very angry. I think that the root of the problem is that attempts to connect Quantum and Mental are done in a very direct way, by trying to reduce mental behavior to the properties of quantum systems composing the brain (Penrose, Homeroff,...).

Olga Nanasiova: Mathematical structures as orthomodular lattices = Quantum (and quantum logic is important for this).

Luigi Accardi: We should sadly acknowledge that, at the moment, even classical physics and mathematics, applied to concrete biological problems has been of a very limited importance: I don’t know of any mayor breakthrough in biology, not to speak of medicine or of neurophysiology, where either fundamental physics or sophisticated mathematics has played a role comparable to the role now played in physics. For this reason i believe that we should be very prudent in doing grandiose statements on the possible role of quantum mechanics in the explanation of the brain mechanisms. There is a concrete risk that science will loose credibility if one promises much more than one can effectively deliver. Let us not forget that the path from first principles to final comprehension of individual complex phenomena is very slow: it has historical times. For example a first principle explanation of the mechanism of formation of crystals is still lacking notwithstanding the efforts of several first class physicists and mathematicians!

Marcos Peres-Suarez: On the one hand, the question as proposed seemed to me to be reductionistic and, on the other hand, that it was surprising that no one had mentioned Pauli’s collaboration with Jung and his fascinating involvement with the notion of archetype, with the latter’s role in physics, and with the consideration of psychophysical parallelism. In particular, there are some features in quantum theory which are significantly reminiscent of the interplay between physics and the psyche in the terms proposed by Pauli.

Andrei Grib: Brain functions as a whole. There is some coherence in the work of its different parts typical for a wave. The psychophysical problem
as the problem of interaction of consciousness and the physical substance of
the brain have much similarities with the role of measurement and collapse
of the wave function in quantum mechanics. One can speak about property
like complementarity in different states of consciousness especially in hyp-
nnosis, dreams etc. However, it does not necessarily means that this quantum
mechanics of brain similarly to superconductivity occurs due to quantum
physics of neurons or some molecules of brain. It can arise because for such
complex system as brain chance is not described by the standard probability
theory but one must use the formalism of the probability amplitude being
more general description of chance.

Andrei Khrennikov: In collaboration with the group of psychologists
from the University of Bary we have performed experiments on students
(“incompatible tests”) and collected data which showed the presence of in-
terference of probabilities. I interpret the results of these experiments as a
preliminary evidence of the possibility to use quantum formalism in mental
sciences. I do not think that it would be possible to derive Mental from
Quantum with a reductionist approach, but I am convinced that Mental
could and should be described by quantum mathematics.
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