

Proof by OpenAI of the Existence of Quantum Yang-Mills theory

Statement by the shepherding committee

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AI agents are beginning to dramatically accelerate progress in mathematics, theoretical physics, and many other disciplines. This era of rapid change calls for new ideas on how to comprehend and disseminate scientific results. We are pleased to contribute to a new experimental approach where a group of scientists serves as an interface between AI generated breakthroughs and the broader scientific community. We are honored to work on shepherding this result to the community.

We were delighted to learn of the recent proof by OpenAI of the existence of quantum Yang-Mills theory, including coupling to fermions. This constitutes an important juncture for the entire subject of Quantum Field Theory (QFT), which applies quantum mechanics to systems with an infinite number of degrees of freedom and provides a universal language for a variety of observed physical phenomena. The new proof by OpenAI appears to be an important step towards putting QFT on a rigorous mathematical footing.

On Oct. 16, David Gross was asked by OpenAI to assume custody of the proof, decide on the best way to release it to the community, and shepherd the release process. David Gross then chose the rest of the committee. We will work on behalf of the academic community, to shepherd the release of the exciting new results discovered by OpenAI's LLM, while minimizing the risks (such as putting out wrong results or carelessly omitting attributions.) We have no responsibility to OpenAI.

The quantum Yang-Mills (YM) theory with group $SU(3)$ coupled to quarks is the part of the Standard Model of Particle Physics called Quantum Chromodynamics (QCD), which provides a theoretical explanation of the strong nuclear force. A salient feature of YM and QCD is asymptotic freedom: that forces weaken at short distances and grow stronger at long distances. This has enabled the many successful testable predictions at high energies over the last 50 years and is believed to lead to the confinement of quarks within hadrons and to a mass gap. Understanding all of these effects together is an outstanding challenge for theoretical and mathematical physics.

The OpenAI work builds on methods to tackle these problems developed over several decades. These include a lattice regularization of Yang-Mills theory introduced by Kenneth G. Wilson in 1974, soon after the discovery of QCD. This led to the formation of the global Lattice Gauge Theory community, which has dedicated monumental efforts to approximate numerical evaluation of properties of QCD and connecting them with real world data. More generally, their work has provided strong evidence for the existence of the continuum limit of the quantum Yang-Mills theory, for confinement and the mass gap, as well as accurate calculations of hadronic masses.

Another approach to this problem is the renormalization group, which involves repeated coarse graining of the lattice by integrating out a subset of the degrees of freedom. It was long hoped that this method would allow researchers to access the continuum limit of the theory where it “forgets” about the lattice regularization. Importantly, in the infinite volume limit, it must become translationally and rotationally invariant.

While many researchers have worked on the lattice regularized Yang-Mills theory, a rigorous treatment of the renormalization group was developed in constructive quantum field theory papers published by Tadeusz Balaban in the 1980s. Balaban’s ideas were among the important elements that recently enabled OpenAI to follow the theory all the way to infinite distances and prove the existence of its proper continuum limit. But confinement and the mass gap remain very important open challenges.

The length and complexity of the OpenAI manuscripts are formidable, and some time will be needed to digest its methodology and meaning in both physics and mathematics. Our working group will lead the efforts towards this goal. In due course, we plan to release the proof by OpenAI along with our assessment of it. Before we release it, we would like to be convinced that it is correct. OpenAI is providing a formalization in the Lean interactive theorem proving language, which will help make this feasible. Our first objective will be to check that the definitions and problem statement correspond with those which are standard in physics and mathematics, and that the formalization aligns with the informal treatment. Once this validation is done, we will release the Lean proof.

We will then turn to developing a deeper understanding and exploration of ways the proof can be used to advance the physics and mathematics of quantum field theory. We intend to draw upon the talent and expertise of other members of the community to help us with this difficult task. When we are satisfied with the quality and correctness of the proofs, we will provide our assessment together with the full 1147-page LLM proofs.

This is an experiment in how the academic community can deal with the rapid development of new knowledge by AI. We intend to proceed very carefully.

For a very recent review of this topic, we refer you to: Douglas, M.R. The Yang–Mills Millennium problem, Nat. Rev. Phys 8, 86–97 (2026).

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