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Always relevant

It has been around fifty years since Kenneth Wilson's work on the renormalization group. *Nature Physics* celebrates this anniversary with a collection of Comments on its development and applications.

For the most part, studying physics is a continuous process of specialization. As part of postgraduate study, or the late part of undergraduate education, we choose specific topics that lead us into different fields. This often results in physicists losing touch with other areas and, in some cases, in the lack of mutual understanding between specialists.

The renormalization group is a technique in theoretical physics that bucks this trend. Typically a graduate level topic, it provides tools to understand how physics changes at different length scales. Whether working to identify which microscopic laws are responsible for the world around us, or what can emerge from the laws we already know, the renormalization group is a language that is shared between seemingly disparate fields, such as particle physics and condensed-matter physics.

The modern formulation of the renormalization group relies heavily on work by Kenneth Wilson in the 1970s, for which he was awarded the Nobel Prize[1]. In this Focus issue, we celebrate the 50th anniversary of his work on the topic with a group of Comments.

The collection begins with a piece from Philip Phillips reviewing the evolution of the renormalization group from its origins in the 1930s to potential progress beyond the Wilsonian framework. Much of the work – including that of Wilson – took place during the Cold War, a time of fundamental developments in many-body theory but also of significant struggles in international collaborations. Nevertheless, Soviet physicists had an important influence on Wilson's work, as described by Premala Chandra.

The next four pieces describe different applications of this theoretical technique. For example, a challenge in finding a quantum theory of gravity is that perturbation theory cannot be applied in the same way as the other fundamental forces. Astrid Eichhorn surveys the role of nonperturbative renormalization group techniques in potentially identifying a microscopic theory of quantum gravity.

More abstractly, Jaewon Song discusses the use of renormalization group tools to explore the space of quantum field theories. When these tools are combined with supersymmetry, it becomes possible to identify and study strongly coupled theories for which more common perturbative methods no longer work.

The renormalization group also makes close contact with current experiments. As Diogo Boito explains in the context of quantum chromodynamics, renormalization group methods enhance the precision of perturbative calculations used to test the standard model of particle physics.

Moving to larger length scales, Yuhai Tu discusses the application of the renormalization group to non-equilibrium models and especially biological systems. He recounts the discovery that a two-dimensional model of flocking features long-range order at finite temperatures – a behaviour that is impossible in equilibrium low-dimensional systems.

Many tools of modern theoretical physics were developed using a degree of physical intuition often disregarding mathematical rigour. This includes the techniques involved in many renormalization group studies. In our final Comment, Antti Kupiainen summarizes efforts by mathematical physicists to put renormalization group schemes on a formal footing.

It would be impractical to cover all the progress and applications of the renormalization group since the 1970s, and we did not attempt to do so. For example, the collection does not cover complex networks, where the formulation of renormalization methods is still an open problem[2]; or the density matrix renormalization group, which has provided many important advances in the understanding of quantum chemistry and many-body systems[3].

One of the striking implications of the renormalization group is that phase transitions in many different models and physical systems can be classified in a relatively small group of universality classes. Interactions can be classed as relevant, irrelevant and marginal, depending on their significance at large length scales.

This categorization can give the impression of a research programme that provides a definitive answer and comes to an end. The broad – and growing – influence of the renormalization group instead suggests that it will always be relevant.

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References

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