The Good, the Bad and the Awful - Scientific Simulation and Prediction

Worthwhile computer simulations are done to explore uncharted territory, resolve a well-posed scientific or technical question, or to make a design choice. Some excellent work is reviewed. Some less happy stories are recounted. I then concentrate my attention upon astrophysical simulations, showing how they can explore possible scenarios for stellar explosions.

Making a Splash; Breaking a Neck: The Development of Complexity in Physical Systems

The fundamental laws of physics are very simple. They can be written on the top half of an ordinary piece of paper. The world about us is very complex. Whole libraries hardly serve to describe it. Indeed, any living organism exhibits a degree of complexity quite beyond the capacity of our libraries. This complexity has led some thinkers to suggest that living things are not the outcome of physical law but instead the creation of a (super)-intelligent designer.

In this talk, we examine the development of complexity in fluid flow. Examples include splashing water, necking of fluids, swirls in heated gases, and jets thrown up from beds of sand. We watch complexity develop in front of our eyes. Mostly, we are able to understand and explain what we are seeing. We do our work by following a succession of very specific situations. In following these specific problems, we soon get to broader issues: predictability and chaos, mechanisms for the generation of complexity and of simple laws, and finally the question of whether there is a natural tendency toward the formation of complex ‘machines’.
Leo Kadanoff is best known for his invention of a new way of looking at critical phenomena, in which, for example, a substance changes from a gas to a liquid or a piece of metal changes from nonmagnetic to magnetic. Critical phenomena arise when a material vacillates between different phases and depends on the cooperative behavior of many different atoms and molecules. For such phase transitions, he introduced two key concepts. The first, called scale invariance, relates quantities at very different length scales. The second concept, called universality, says that the behavior near a critical point is subject to laws that are universal, regardless of what kind of transition is being studied. It doesn’t matter whether you are studying the magnetic field in a metal or the density of a gas; close to the critical point the behavior will obey the same equations.

Kadanoff developed the ideas of scale invariance and universality when he was 28 years old. His original idea has turned out to be remarkably powerful. He went on to develop a systematic approach to the understanding of what are known as complex systems. These are systems that develop the same intricate structures (called self-similar) for a range of length scales or time scales.

Scale invariance has also been applied by Kadanoff and his collaborators and by other theorists to study chaotic phenomena, such as fluctuations in the stock market, irregularities in heart rhythms, and the random appearance of traffic jams. Kadanoff, working with various collaborators, has constructed computer models that are simplified models of various physical situations. These models dealt with turbulence, fluid flow in a channel, urban growth and decay, the morphology of bacterial colonies, the flow of granular materials [such as sand], and the separation of a drop from a larger mass of fluid. Kadanoff has had a major influence on applied mathematics, physics, mechanics, cosmology, chemistry, and polymer science.

Kadanoff received an AB in 1957, an MA in 1958, and a PhD in 1960, all from Harvard University. After a postdoc at the Bohr Institute in Copenhagen he joined the University of Illinois in 1962, where he became a full professor at the age of 28. In 1969 he became University Professor at Brown University, where he remained until 1978. At that time he became a professor of physics at the University of Chicago, and in 1982 he became the John D. and Catherine T. MacArthur Distinguished Service Professor of Physics and Mathematics. He is now emeritus at Chicago.

Kadanoff is currently the president of the American Physical Society. His honors include the Buckley Prize from APS, Wolf Prize, Elliott Cresson Medal, Boltzmann Medal, from IUPAP, Quaintrell Award for excellence in teaching, Centennial Medal from Harvard, Onsager Prize from APS, Grande Medaille d’Or from the French Academy of Sciences, US National Medal of Science, and the Lorentz Medal from the Royal Dutch Academy of Sciences.

In 1986 Bill Fine assembled a small group of physicists to help him realize his dream of establishing a theoretical physics institute at the University of Minnesota. Leo Kadanoff, who has been a frequent contributor and adviser to Physics Today, agreed to help establish the institute. He developed the concept of the institute and its role within the university. And for four years he was a valuable member of the institute’s advisory committee. We are delighted to welcome him back to the Fine Theoretical Physics Institute, now celebrating its 20th anniversary.

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