Leo P. Kadanoff (1937–2015): An appreciation

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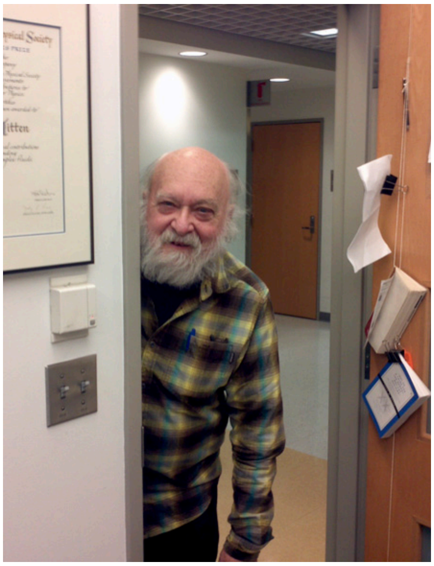
Leo P. Kadanoff, who died on October 26, 2015, devoted his scientific life to trying to elucidate how much of the world can be understood using mathematical models. Historically, physics has addressed this problem by searching for fundamental laws that completely specify the right ingredients to put into a theoretical model. For example, the standard model of particle physics provides a specification of the properties of elementary particles and their interactions. In principle, the standard model could be used to describe macroscopic physical systems. However, because of the enormous number of elementary particles in any macroscopic amount of matter, implementing such a calculation is not feasible. Leo was the first to understand clearly that the behavior of systems on different length scales can be understood using different effective theories, and that the effective theories that describe macroscopic phenomena should be derivable by a suitable mathematical procedure from the microscopics (1, 2). K. G. Wilson succeeded in constructing a complete mathematical formulation of this procedure, known as the renormalization group (3, 4). Renormalization group theory shows that there is universality, in that many different microscopic models can give rise to the same effective theory on long length scales. Universality is a remarkable and powerful concept, because it says that sometimes it is possible to make quantitative statements in situations where the microscopic model is not completely known (2, 5). Leo's remarkable 1966 paper (1) showed how universality arises in certain situations at transitions between different phases of matter, such as between liquid and gas.

Universality implies that in some situations theoretical models need not faithfully describe every microscopic detail, but rather that the most useful models are the simplest ones in the appropriate "universality class." This remarkable result motivated Leo to see if other types of complex systems that have many different interacting constituents, including biological and social systems, could be understood using relatively simple theoretical models.

In the late 1960s Leo started to work on problems in urban studies. His careful numerical investigations demonstrated that the results obtained from computer models depended greatly on small changes in the ingredients put into the models. Leo recognized that this sensitivity of the results on the details of the models that he constructed made it difficult to make robust predictions, and after several years he returned to physics research (6). Over the succeeding decades, Leo investigated a broad variety of complex systems, with a particular focus on identifying phenomena with universal features. He excelled at bringing people together to perform interdisciplinary investigations incorporating theory, experiment, and computation, and thought deeply about the role of computation in scientific discovery (7). Although he never achieved a breakthrough of the magnitude of his work in the 1960s, Leo's work did a great deal to deepen our understanding of many systems, including granular materials, fluid flows, and supernovae, and inspired a great deal of exceptional interdisciplinary research around the world.



Leo P. Kadanoff. Image courtesy of Thomas A. Witten (University of Chicago, Chicago).

Born on January 14, 1937, Leo Kadanoff received bachelor's, master's, and doctorate degrees from Harvard University in 1957, 1958, and 1960, respectively. After doing postdoctoral work in Copenhagen at the Niels Bohr Institute (1960–1962), Leo became a faculty member at the University of Illinois at Urbana–Champaign (1962–1969) and Brown University (1969–1978). Leo then joined the faculty at The University of Chicago in 1978, where he remained for the rest of his career. His many honors include the Wolf Foundation Prize in Physics, the Grande Medaille d'Or of the Académie des Sciences de l'Institut de France, the American Physical Society's Buckley and Onsager prizes, the Franklin Institute's Elliott Cresson Medal, the Boltzmann Medal of the International Union of Pure and Applied Physics, the Lorentz Medal of the Royal Dutch Academy of Sciences,

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The author declares no conflict of interest.
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the Newton Medal of the Institute of Physics, and the National Medal of Science. Leo served the scientific community as President of the American Physical Society and twice as Director of the Materials Research Science and Engineering Center at The University of Chicago.

Among Leo's many remarkable qualities, his intellectual honesty was particularly notable. He saw the limitations of his work and of his knowledge clearly, and was always on the lookout for work by others that made progress toward his vision of achieving true understanding of complex systems. We are inspired by Leo to strive to achieve breakthroughs over the coming decades that will move us closer to realizing this vision.

1 Kadanoff LP (1966) Scaling laws for Ising models near Tc. *Physics* 2(6):263–272.

2 Goldenfeld N, Kadanoff LP (1999) Simple lessons from complexity. *Science* 284(5411):87–89.

3 Wilson KG (1971) Renormalization group and critical phenomena. I. Renormalization group and the Kadanoff scaling picture. *Phys Rev B* 4(9):I3174–I3183.

4 Wilczek FA (2013) Ken Wilson: A scientific appreciation. *Proc Natl Acad Sci USA* 110(32):12855–12856.

5 Anderson PW (1972) More is different. *Science* 177(4047):393–396.

6 Ashrafi B, Hall K, Schweber S (2002) *Interview with Leo P. Kadanoff, Part III*. Available at authors.library.caltech.edu/5456/1/hrst.mit.edu/hrs/renormalization/Kadanoff/Kadanoff3.htm. Accessed December 24, 2015.

7 Kadanoff LP (2004) Excellence in computer simulation. *Comput Sci Eng* 6(2):57–67.