Editorial

Advances in precision cosmology, neutrino physics, and atomic and condensed matter physics have grabbed the headlines over the past couple of decades. A less publicized advance over the same period, which is nonetheless astonishing, has been the reinvention of nuclear theory. When I was a graduate student in the early 1980s, nuclear physics seemed to be lacking in the theoretical tools required to go beyond a qualitative description of the complexities of strongly interacting many-body physics. Too much was being asked of the Nambu Jona-Lasinio model, the quark model, the bag model, and so on. Solving the Schrödinger equation for light nuclei, or the shell model for heavier nuclei was beyond the reach of existing computational resources. The previous decade had witnessed the precise formulation of Quantum Chromodynamics (QCD), and the disconnect between nuclear theory and the underlying theory of the strong interactions was striking. Furthermore, rather than borrowing freely from related fields of research, nuclear physics drifted in the doldrums of a tedious preoccupation with the sociological boundaries of the field: whether, for example, the properties of a single nucleon could be called nuclear physics or not, and worthy of support.

Being director of the Institute for Nuclear Theory (INT) has given me a front row seat to witness to what extent nuclear theory has changed since then. Last summer the INT hosted a summer school on lattice QCD, where students could calculate hadron masses on their laptops and heard about ongoing research into nucleon–hyperon interactions on the lattice; this summer nuclear and atomic physicists are meeting with chemists to discuss cluster algorithms in computational many-body theory; we recently organized a program on applications of string theory to QCD, such as models for jet quenching in heavy ion collisions. In a typical year at the INT one can hear seminars on such amazingly diverse topics as the implications of observed seismic modes in neutron stars, how spectroscopic regularity arises from underlying chaotic dynamics, or the results of a high precision effective field theory calculation for neutrino–matter interactions.

There has been a wholesale replacement of the old heuristic models by precision calculations, while on the advancing frontiers of the field completely new models have been developed to describe phenomena for which there is yet little theory. In place of the NJL and quark models there are sophisticated calculations in perturbative QCD, lattice QCD, and chiral perturbation theory. In areas of physics where previously theory had no traction, the new models include AdS/QCD, currently a cutting edge model for relativistic plasma physics; color superconductivity, which has changed the paradigm for dense quark matter; and the color glass condensate, which has redefined how one thinks about the initial state in relativistic heavy ion collisions.

While nuclear physics used to comprise of theory and experiment, a third sub-discipline has emerged: computational nuclear physics. Radical change in nuclear theory is being brought about by the inexorable improvements of computers under the thrill of Moore’s law. We have entered the age of the petaflops computer and it is suddenly possible to investigate numerically from first principles a host of complex phenomena. Lattice QCD is currently able to compute meson properties at the 1% accuracy level, while multinucleon calculations are beginning to be pursued. In nuclear structure, ab initio calculations up to carbon are possible, and shell model and density functional techniques are being calibrated and applied with growing accuracy across the entire periodic table. Computational nuclear physics is similar to experimental physics in that it involves collaborations using large expensive facilities, and entails rigorous data analysis; yet at the same time it requires intensive theoretical and algorithmic developments to be of use, such as effective field theory for lattice physics, or the no-core shell model and density functional theory developments for nuclear structure calculations.

Nuclear theorists are now happily disregarding artificial intellectual boundaries and are appropriating what they need to get the job done, finding inspiration and intersections with
research in fields as far flung as neutrino physics, quantum dots, solar physics, extra dimensions, graphene, cosmic rays, and trapped atoms.

In the United States the nuclear physics community recently devised a long-range plan to map out the future of the field; although such a plan is a useful budgeting tool, nuclear theorists are aiming to render that document obsolete at the earliest possible moment—as you would expect in a vibrant and dynamic field.

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