Fit for purpose

The biologist Ernst Mayr once suggested that nothing in biology makes sense, except in the light of evolution. The evolutionary process provides a framework for all of theoretical biology, and often the only means to explain the origins of biological order. The idea of evolution, however, is also deeper than biology. Chance variation coupled with selection and differential replication represents, abstractly and generally, an extraordinarily powerful algorithm for solving complex problems. It has found myriad applications in areas ranging from computer science to engineering. What about physics?

Some theorists have suggested that an evolutionary process might play a role in cosmology. When stars die they can create black holes, and Lee Smolin proposed some years ago that the process might, under certain conditions, give rise to an isolated region of space-time tantamount to a new universe, with its laws of physics inherited as a small variation on those of the previous universe. Such evolution would in the long run favour universes with physics much as we know it, enabling stars to form, evolve and die, producing high numbers of black holes — and new universes as offspring. In this view, the Big Bang would be only the most recent in a cosmic evolutionary process of creation events.

Such efforts to bring the logic of evolution into physical law remain unusual, although they will surely proliferate in future; almost any rich mathematical process invented one day becomes part of some possible physics. But evolutionary dynamics may have a more immediate role in transforming the face of experimental physics. In an ingenious demonstration, physicists have now shown how evolution can be put to work in experiments in quantum physics.

Over the past few years, technology for creating and manipulating ultracold atomic gases on semiconductor chips has revolutionized experimentation in low-dimensional quantum gases or matter-wave interferometry. With carefully designed patterns of wires, physicists can create magnetic traps capable of holding millions of atoms, which can be readily cooled into the quantum regime. Achievements that were landmarks only a few years ago — the controlled production and probing of atomic Bose–Einstein condensates, for example — have now become quite straightforward.

Any measurement of the quantum gas produced — to determine the atomic density distribution, for example — invariably destroys the gas itself, and so can be made only once on any sample. Hence, probing the physics of such a system requires the repeated generation of a new gas under the same conditions. Doing so efficiently also means choosing the experimental parameters to produce optimal or near-optimal values of quantities such as the atomic density. This is not so easy, however, as the final Bose–Einstein condensate produced by this technology may depend on as many as 2,000 variable parameters.

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Even if one were to fix all but a few of these parameters, stepping through the space of possibilities can take many days, even though individual experimental runs can be done in less than a minute. But this, Wolfgang Rohringer and colleagues suggest, is where an evolutionary approach to experimental design can pay handsome dividends (arXiv:0810.4474; 2008).

They have explored the parameter space using a genetic algorithm, starting with an initial population of about 10–15 different parameter choices, selected at random. The idea is to set up a competition between these choices, with those doing better having more offspring. Running an experiment for each of the choices, the physicists found a range of results for some measure of outcome 'quality', such as the atomic density. Ranking these from first to last, they then assigned a 'fitness' to each set of parameters in proportion to its rank, and let the population of parameter choices reproduce in pairs, fitter parents having more offspring. They chose the offspring parameters by interpolation from the two parents, with further random variation.

Making this technique work well, the authors admit, is something of an art form. Choosing too large a population makes for a time-consuming evolution towards excellence, whereas making it too small leads instead to a rapid collapse of genetic diversity and a failure to explore adequately the space of possibilities. But for an intermediate choice of population size and spread in parameter space, the evolutionary approach works admirably. For example, it discovered impressive locally optimal sets of parameters in less than an hour, whereas optimization achieved by search through the entire parameter space would have taken 36 hours. In problems with higher numbers of parameters, the authors suggest, the genetic algorithm may help even more.

This is a fascinating demonstration of automation in the very design of the experiment. It intrudes into the traditional territory of the experimental physicist, who would normally determine which experiment is most likely to be useful. In this particular case, the search only targets improvement in relatively mundane features such as atomic densities, but in principle, the same method might do much more. One might, for example, measure the 'fitness' of an experiment as the deviation of some measured quantity from its theoretically expected value, in which case the evolutionary algorithm would be doing the experimenter's work in manipulating the system to give the strangest and most unexpected, and therefore most interesting, result possible.

Science itself, of course, has an evolutionary character and thrives on variation in ideas culled by judicious comparison with reality. So it is perhaps not surprising that evolutionary processes seem so powerful as tools for building knowledge almost automatically. This "closing of the loop" in experimental control, as Rohringer and colleagues put it, could point the way towards a very different scientific future. The algorithm might do the job of selecting which experiment to do more effectively than any human could, even if it will not in many cases be able to explain why. But then, human experimenters also make important discoveries by following hunches, or even taking guesses.

Mark Buchanan