THIS WEEK

Be here now

New views of quantum theory that can be tested and have practical applications bring welcome echoes of physics past.

The phrase "Shut up and calculate" is popularly associated with the Cornell University physicist David Mermin, who coined it to describe how many physicists use the mathematics of quantum theory without thinking too hard about its deeper implications.

Mermin himself is clearly not content to shut up and calculate. He has mused on the meanings of quantum theory and of physical theory more generally for many decades, notably in his Reference Frame column for the magazine *Physics Today*. Now, on page 421 of this issue, he considers a new view of quantum theory, called quantum Bayesianism or QBism, and what it implies for a long-standing question. Namely, how can we reconcile our perception that the present moment is special with the relativistic view that space-time is a continuum that reaches from past to future, with nothing to privilege 'the Now'?

Some will see this as a metaphysical question. Certainly, while the gulf remains between the formal machinery of quantum mechanics, with its wavefunctions and probabilities, and our conscious experience of the world, it is hard to see how the question can be framed with the rigour that science usually demands.

Yet QBism offers a way to put us in the picture, even in the absence of a theoretical link between the abstract microworld and the subjective macroworld. It suggests that quantum theory is telling us what an individual can know about a system in the light of what he or she already knows and expects, just as in standard Bayesian probability.

The idea has been given something of a rough ride by physicists, who seem uncomfortable with QBism because they see it as a solipsistic view of the world. Perhaps Mermin's advocacy will secure it a more sympathetic hearing. At any rate, it has the virtue of refusing to ignore quantum theory's long-standing tussle with the role of the observer.

Aside from the merits of the idea, it is striking that Mermin should discuss it at all. Any view of quantum (or indeed classical) physics that borders on the metaphysical has long been out of fashion. Yet the early architects of quantum theory, such as Niels Bohr, Werner Heisenberg and Max Born, had no reservations about examining the philosophical issues it raised, and the problem of 'the Now' troubled Einstein.

Most famously, Bohr and Einstein argued about whether quantum mechanics allowed any room for the idea of realism — of an objective world that exists independently from our efforts to observe and measure it. Bohr insisted that physics was concerned with what we can know, and was silent on the matter of 'how things really are'. He, Born and Heisenberg made claims about quantum theory's challenge to causality and determinism that today look like a bit of an intellectual stretch.

Mermin is not alone in admitting such debates back into science. In a Perspective article on page 443, physicists Artur Ekert and Renato Renner place current work on quantum cryptography in a broader context that encompasses the thorny concept of free will.

Quantum methods of encoding information, they argue, combined with "an arbitrarily small amount of free will are sufficient to conceal whatever we like". To enable foolproof secrecy, "free will is our most valuable asset". This, too, is the kind of claim that a few decades ago would have risked being dismissed, if not ridiculed, as idle coffee-room chat. It reveals researchers' new boldness for engaging with the meanings and corollaries of quantum physics. In doing so, they enrich the discussion as Bohr, Einstein and their colleagues did.

"Researchers have a new boldness for engaging with the meanings and corollaries of quantum physics."

But why now? Interest in the foundations of quantum theory — what it really tells us about the character of the world that we experience in reassuringly classical terms — has flourished since the late 1980s. That has been driven partly by the development of experimental techniques, especially in quantum optics, that can test ideas about phenomena such as entanglement (the codependence of remote quantum states), measurement and wavefunction collapse, and which were previously accessible only to theoretical speculation. As a result, physicists can more clearly see the most fundamental features of quantum theory — in particular the nonlocality and contextuality (contingency on how results are obtained) of quantum systems.

The other driver is an emphasis on quantum theory as a theory of information: of what we can know, transmit and share. This view has already thrown up practical applications such as quantum cryptography and rudimentary quantum computers. But it has also reawakened long-deferred foundational questions in new guises. It shows us that Bohr and Einstein could already see the ramifications for the philosophy and epistemology of science. Lacking the experimental tools to make progress, they doubted that these issues could ever be much more than metaphysical. Now they can be, and it is right that scientists should have the confidence to raise them afresh. ■

Wheat lag

Growth in yields of the cereal must double if the Green Revolution is to be put back on track.

Wheat is widely considered to be the world's most important crop, and Norman Borlaug knew a thing or two about how to grow it. The US agronomist developed varieties that could better resist disease and gave higher yields. In doing so, he saved an estimated one billion people from starvation.

This week marks a century since Borlaug's birth, so what better time to consider why millions still go hungry, and to ponder how the next Green Revolution can be kick-started? At a meeting in Mexico this week, organized by the International Maize and Wheat Improvement Center

(CIMMYT) in collaboration with the Association for Agricultural Research and Experimentation of the State of Sonora, researchers will look again at the prospects for wheat. Although wheat consumption is growing, the investment needed to build on Borlaug's legacy is scarce.

Wheat provides 20% of the dietary energy for the world's population. Yet growth in yields has stagnated at around 0.9% per year over the past decade — by contrast, maize (corn) yields grow by almost double that at approximately 1.6% per year. To meet future demand for food, researchers say that wheat yields must grow by 1.7% each year. That will require investment. The total global spend on wheat breeding and research, around US$500 million per year, is currently one-quarter of that spent to improve maize.

The discrepancy arises because seed companies can make higher profits from maize than from wheat. Maize is a hybrid crop that produces seeds with poor yields, so there is little incentive for farmers to keep and replant them. To get the best results, they must buy new maize seeds each year. Seed producers get no such annual income from wheat because farmers can reap and replant seeds from several successive harvests without losing much yield.

Existing solutions to this are as much economic as agronomic. One strategy is for plant breeders to collect royalties from farmers who save seeds — as is done in countries such as Australia and the United Kingdom. Although this approach is reasonable for farmers who harvest substantial profits, it is less applicable to subsistence farmers in the developing world; for them, science might provide better solutions.

An international research effort to boost wheat yields by 50% by 2035 will be officially launched at this week's meeting. The International Wheat Yield Partnership — a consortium of research institutions including CIMMYT and the United Kingdom's Biotechnology and Biological Sciences Research Council — is a long-term project that aims to raise US$100 million in the next five years.

Researchers plan to use the cash to explore, for example, how to improve the way wheat photosynthesizes. Wheat, frankly, does it badly; it converts just 1% of incoming light to grain. Maize is three times more efficient; sugar cane eight times.

The map of the wheat genome remains a job half-finished. An estimated US$50 million is needed to map the remaining 20 of wheat's 42 chromosomes. Obtaining the complete genome should accelerate the effort to make wheat more tolerant to heat and drought through both conventional breeding and genetic-modification techniques.

Crucial work to monitor the spread of wheat pathogens must continue. Borlaug championed this research through the Durable Rust Resistance in Wheat project led by Cornell University in Ithaca, New York, and the Borlaug Global Rust Initiative, a consortium of more than 20 institutions, which has its secretariat at Cornell. Famously, he said that "rust never sleeps", and the continued spread of the devastating Ug99 stem-rust fungus in Africa and other new strains in Ethiopia (see page 404) demonstrate the truth of his words.

"The total global spend on wheat breeding and research is currently one-quarter of that spent to improve maize."

Today, yield is not the only impact by which agriculture is judged. The Intergovernmental Panel on Climate Change will next week report on farming's direct and indirect consequences for the planet. The focus on the carbon footprint of food production is necessary, but the message cannot be boiled down to the misleading idea that all agricultural techniques bar organic farming are a plague on the environment.

Borlaug believed that increasing yields through the use of new and improved varieties, along with the responsible application of fertilizer and pesticides, could benefit natural ecosystems. Less land would need to be converted into agricultural production to grow food. Recent studies suggest that he was right (J. R. Stevenson *et al. Proc. Natl Acad. Sci. USA* **110,** 8363–8368; 2013).

Misguided opposition to some aspects of big agriculture, such as chemical-fertilizer use in the developing world, could stop many nations from growing the food they need. Objections should be saved for the irresponsible overuse of fertilizer in the West and Asia, which has led to widespread water and air pollution.

One of Borlaug's guiding principles was that food is the moral right of all who are born into this world. He won an important battle against hunger, but the war continues. ■

A parlous state

The decay at ancient Pompeii is symbolic of a deeper malaise in Italy's heritage.

Chuck Palahniuk, the US author of *Fight Club*, noted that "we'll be remembered more for what we destroy than what we create". For anyone who has been following the saga of ancient Pompeii over the past few years, that observation has the bite of reality. Report after report has appeared in the press detailing the collapse of this wall, the closure of that house or, in one extreme case in 2010, the destruction of a whole building.

Pompeii, which attracts some 2.3 million visitors a year, may be adept at grabbing the headlines, but the insidious creep of heritage erosion is far from limited to the Bay of Naples — in fact, it is a problem that encompasses the archaeological wealth of the globe.

Heritage is ensnared in a particularly vicious catch-22. On the one hand, ruins are a key source of inspiration and income, as tourists flock to connect with the past. On the other, that throng so in thrall to history does untold damage merely by turning up to have a look. But even without hordes of tourists inflicting wear and tear on fragile remains, ruins face a determined and dangerous enemy in the shape of the elements.

As soon as an artefact is unearthed, decay sets in. Objects and buildings that have lain preserved for centuries beneath the earth immediately begin to suffer when exposed to the atmosphere. A few kilometres down the road from Pompeii, the site of Herculaneum, which was buried by the same volcanic eruption in AD 79, is faring better than its more famous sibling. True, the exposed site is much smaller, but with a high number of multi-storey buildings and a lot of preserved organic matter, Herculaneum presents unique challenges. The site's enhanced ability to hold decay at bay is largely down to a public–private venture launched in 2001 and the multidisciplinary approach that the ensuing project has taken.

That success is an object lesson not only for Pompeii, which hopes to set up a similar project to help preserve the ruins (see page 411), but also for the malaise that grips Italy's heritage as a whole. Hampered by debt, the country lacks the finances to reverse the decay afflicting its monuments. Instead, it must rely on external funds and philanthropists. The crumbling Colosseum in Rome, for example, is being repaired thanks to some €25 million (US$35 million) from billionaire Diego Della Valle. Yet this is still not enough. Just west of Rome, ancient Ostia is beset by weeds, and was even flooded earlier this year.

Although structural repairs and conservation at any site require money and coordinated expertise, fending off many of the agents of erosion — by controlling vegetation, for example, or employing more guards to keep tourists in check — is relatively easy to achieve. Such steps would be important gains in this war of attrition. Finding ways to maximize the revenues coming into the sites and relaxing the austerity law stopping the employment of public-works personnel would be a start. For if preventable problems are not tackled urgently, then no amount of money from external sources will be able to reverse the tide of decay. ■

➲ NATURE.COM
To comment online, click on Editorials at:
go.nature.com/xhunqv