Interpreting QM_∞: The Art of the Possible

I am trying to write a book about the interpretation of QFT. The project, which continues work represented in (1999a,b), (2002b,c,d), (2003a,b), (2004a), (2005), (2006), and (forthcoming a,b,c,d), has several aims, and several intended audiences. The most modest, and focused, aim is to close the gap between a growing body of formal results and the capacity most philosophers of physics have to appreciate those results. This means not only motivating the project of interpreting QFT and explicating formal notions relevant to that project, but also getting clear on the possible pertinence of particular formal results to interpretative questions. So even modestly construed, the project is not merely expository. The book's more ambitious, and most general, aim is to establish the interpretation of QFT as fertile ground for philosophical investigation.

QFT challenges an assumption—which has framed much, but by no means all, of the philosophical literature about quantum theories in the last quarter of the twentieth century—about how a quantum theory characterizes its possible worlds. This assumption is that the characterization proceeds by way of a *Hilbert space representation*, that is, a structure, called a *Hilbert space*, on which act mathematical objects obeying certain relations. (For present purposes, the details don't matter.) Two quantum theories, so understood, are physically equivalent, in the sense that the sets of possibilities they recognize coincide, if and only if their Hilbert space representations are stand in the mathematical relation of *unitary equivalence*. A formal result known as the *Stone-von Neumann uniqueness theorem* states that all Hilbert space representations quantizing a system of finitely many particles *are* unitarily equivalent. If unitary equivalence guarantees physical equivalence, such representations are simply different ways of expressing the same physical theory. For systems of finitely many particles, the directive "quantize!" has a unique outcome.

This heartening uniqueness does not extend to quantum field theories, which one obtains not by quantizing a system of finitely many particles, but by quantizing a field, an entity defined everywhere in space. (The crux of the field/particle contrast is that to specify the classical state of a system of particles, one needs only finitely many numbers [the values of their positions and momenta], whereas to specify the state of a field, one needs infinitely many [its value at every point of spacetime].) According to very same criterion of physical equivalence by whose lights ordinary quantum theories are reassuringly unique, a field theory admits infinitely many *physically inequivalent* Hilbert space representations. This dramatic non-uniqueness raises foundational questions on which the book will focus. What is a quantum theory? How, if not by Hilbert space structures, does it characterize its contents? What criteria of equivalence are appropriate to quantum theories?

My strategy for evaluating accounts of the content of quantum theories is to examine theoretical settings (e.g. spontaneous symmetry breaking, cosmological particle creation, and the thermodynamic limit of quantum statistical mechanics) in which unitarily inequivalent representations occur, with a view toward determining what accounts of the content of quantum theories sustain the uses to which these inequivalent representations are put. This approach not only brings work on the foundations of quantum theories in contact with the foundational investigation of other sorts of physical theories (e.g., thermodynamics, statistical mechanics, solid state physics, general relativity, and cosmology), it also brings the philosophy of physics in contact with other sorts of philosophy of science (e.g., accounts of explanation, reduction, and 'explanationist' defenses of scientific realism). A conclusion I tentatively think the evaluation will support—that received notions of physical content and physical modality must be revised if they are to apply usefully to particular physical theories—should interest philosophers of many stripes.