Adrian Wüthrich
The Genesis of Feynman Diagrams.
Dordrecht: Springer Verlag 2011.
200 pages
US$139.00 (cloth ISBN 978-90-481-9227-4)

Anyone interested in the development of theoretical physics in the last 60 years, be they a physicist, a philosopher or a historian, will have encountered Feynman diagrams, the schematic stick figure depictions of scattering processes and interactions used for calculations in a variety of physical sub-disciplines, from high energy particles to condensed matter. Indeed, it is almost de rigueur to begin any treatment of Feynman diagrams by marveling at their ubiquity, and Adrian Wüthrich's *The Genesis of Feynman Diagrams* makes no exception. That is, however, where the similarities with most other treatments end: Wüthrich takes objection to the second standard statement on Feynman diagrams, often echoed by cautioning physicists and cautious historians, that despite their evocative, pictorial nature, they are nothing but devices for structuring complicated calculations.

To demonstrate that this cannot be the whole story, Wüthrich takes a twofold approach. On the one hand, he shows how Feynman diagrams evolved in Richard Feynman's work from diagrams actually depicting physical processes occurring in space and time. And on the other hand, he shows how Feynman diagrams immediately brought with them conceptual changes in quantum electrodynamics going beyond the mere simplification of calculations.

Tracing the evolution of Feynman diagrams in Feynman's work forms, as already indicated by the title, the core of the book and takes up Chapters 3 through 5. To this end, Wüthrich delved into the Feynman archives at Caltech, where he unearthed some very interesting material, with which he manages convincingly to reproduce the different stages in Feynman's use of diagrams.

Chapter 3 provides an excellent introduction to Feynman's approach to quantum electrodynamics and to his reformulation of quantum mechanics using the path integral. Although subject matter and presentation are certainly not light on the mathematical formalism, Wüthrich does an admirable job of carefully guiding the reader step by step along the logic of the calculations. It is also very pleasant that he does not let himself be sucked in by Feynman's sometimes overly simplifying rhetoric. Wüthrich clearly states when an argument is sloppy or not understandable, sometimes even slightly overshooting the mark (like on p. 53, where he states that Feynman must have overlooked a passage in a paper by Paul Dirac, when in fact that passage is highly ambiguous and easily reconcilable with Feynman's statements).

Wüthrich continues to show, in Chapter 4, how diagrammatic elements entered Feynman's work in his attempts to 'understand' and 'visualize' (two terms, whose meaning for Feynman Wüthrich analyzes) Dirac's relativistic wave equation of the electron. In Feynman's notes, Wüthrich finds sketches that resemble Feynman diagrams, but describe the actual paths (in the sense of the path integral formulation, where all possible paths are integrated over) of the electron in space and time. Positrons, as anti-particle of the electron, are described as electrons moving backwards in time. In Chapter 5, Wüthrich goes on to show how the introduction of electromagnetic interactions necessitated a change in this diagrammatic representation and led to the inclusion first of more and more abstract interaction potentials and finally of virtual photons, giving what could be termed the first actual Feynman diagram.

This concludes the central part of the book, in which Wüthrich clearly demonstrates that diagrams were not primarily a calculational aid for Feynman, but rather provided him with an important heuristic tool in his reformulation of quantum electrodynamics and that for the most part his diagrams represented physical processes in space and time, rather than mathematical expressions.

Wüthrich's second line of argument, concerning the conceptual changes brought about through Feynman's introduction of diagrammatic techniques, is somewhat less straightforward. The three central chapters are framed by two further technical chapters, describing the state of quantum electrodynamics before Feynman's innovation (Chapter 2) and the immediate reception and systematization of Feynman diagrams in the work of Freeman Dyson (Chapter 6). These two chapters naturally fall a bit short compared to the three on Feynman, since they are not fleshed out and contextualized with the rich archival material that Wüthrich uses to analyze Feynman's work.

By providing a before-after comparison, they do however serve to demonstrate what Wüthrich identifies as the decisive conceptual advance brought along by Feynman diagrams: The effective isolation of the problematic parts of the theory (the appearance of infinite results had been plaguing calculations in quantum electrodynamics for two decades), made possible by reducing all physical processes to a few elementary building blocks in the diagrammatic representation. Wüthrich shows that this was also in fact Feynman's goal from the very start: To reformulate the theory in such a way that one could more easily identify the decisive points where it needs to be slightly modified.

To reinforce that this advance is not simply a matter of greater calculational ease, Wüthrich points out how certain processes, after being reformulated in terms of Feynman diagrams by Dyson, also obtained a new physical interpretation. Wüthrich presents some convincing examples, such as when he shows how the analogy between Moller and Compton scattering, which becomes apparent in the diagrammatic representation, led to an extension of the concept of vacuum polarization; but understandably he tends to overstate the role of Feynman diagrams (e.g., Compton scattering had already been understood as a process of emission and absorption, as opposed to a scattering process, for quite some time, when Feynman diagrams came along, as opposed to what is claimed on p. 164). The second line of argument may thus not be as clear-cut as the first, but Wüthrich definitely proves his general point that Feynman diagrams have a conceptual significance that goes even beyond their historical, heuristic role in Feynman's work.

With the five central chapters aimed at proving that there is more to Feynman diagrams than meets the eye (or rather that there is as much to them as meets the eye, despite claims to the contrary), the two framing chapters give a non-technical overview and summary, and are thus the most interesting to a general reader with no desire to engage with the mathematical formalism. In the introduction Wüthrich also discusses in more detail the philosophical point on which, in a way, his whole analysis rests: it is possible for a calculational tool to also provide a physical representation of the phenomenon under study so that a pure reformulation of a theory (even if it were aimed only at calculational simplification) can lead to a conceptual overhaul. These rather brief comments provide an enlightening framework for the reader mostly interested in the physics, but more importantly point the more philosophically minded reader towards how best to read this book—viz., as a case study on how, as Wüthrich himself writes in his closing paragraph, scientific problems are sometimes 'not solved in the usual sense of the word but are rather made to disappear by using a symbol system that appropriately represents an adequate model.' Anybody interested in such questions will benefit greatly from this thorough analysis not just of the genesis of but also of the conceptual transformation wrought by Feynman diagrams.

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