Book Review:
Tian Yu Cao, *From Current Algebra to Quantum Chromodynamics: A Case for Structural Realism*, Cambridge: Cambridge University Press, 2010, ISBN 978-0-521-88933-3, Hardback $85, x + 308 pages.

Christian Wüthrich*
University of California, San Diego

28 May 2014

Written for *HOPOS: The Journal of the International Society for the History of Philosophy of Science*

In this book, Tian Yu Cao chronicles the decade-long trials and tribulations of the particle physicists that led to Quantum Chromodynamics (QCD), to this day the best theory of the strong nuclear force and the hadrons it governs, such as the protons and neutrons of the atomic nucleus. He retraces the conceptual developments from Murray Gell-Mann's proposal of current algebra in 1962 to the first articulation of QCD involving asymptotic freedom and early signs of confinement by the end of 1972. As Cao informs the reader in the preface, *From Current Algebra to Quantum Chromodynamics* is one of two planned monographs on the development of QCD; in fact, it constitutes, according to the preface, the more philosophical companion piece to the historical book which will cover the longer period from the late 1940s to the late 1970s. *Caveat emptor*, the two 'philosophical' chapters of the book (Chapters 9 and 10) are still pitted against six mostly historical chapters (Chapter 2 through 7)!

After the introductory Chapter 1, where Cao articulates the version of structural realism he takes to be supported by the narrative that follows in the next seven chapters, Chapter 2 recounts the theoretical and experimental backdrop against which Gell-Mann formulated his earliest attempt to capture the emerging phenomenology of hadrons and their strong interaction, as well as that approach ('current algebra'). The next four chapters, Chapters 3 through 6, cover the development from the first attempts to probe the internal structure of hadrons in the wake of Gell-Mann's current algebra approach of 1962 to the advent of QCD in early 1972. Ontologically, at the end of this development, we arrive at the first model of the strong interaction that accepts quarks as the real, physical, and basic constituents of hadrons, exchanging gluons as the carriers of the strong force. Methodologically, the circle closes back to perturbation theory as the primary way of calculating interactions between elementary particles. Chapter 7 finishes the historical arch by offering a conceptual introduction to early QCD and by thereby displaying the triumph of non-Abelian gauge theory in the emerging locally gauge-invariant quark-gluon model for strong interactions. This chapter thus prepares the ground for the last two chapters—Chapters 9 and 10—, where the philosophical 'pay off' is analyzed. Chapter 8 reviews the most important theoretical justifications and ramifications of QCD circa 1973.

*I thank Tomasz Bigaj, Jonathan Cohen, and John Dougherty for comments.

Cao's in-depth analysis of QCD is technically rather dense to the point of indigestibility but for the readers conversant with advanced concepts in contemporary particle physics. The book thus presupposes a serious level of familiarity with particle physics: a reader who brings to the text no prior understanding of what a sum rule, a diffractive production process, incoherent scattering, a deep inelastic scattering process, the gauge principle, a ghost loop, bilinear forms, or non-Abelian gauge symmetries are, is unlikely to get much out of it. Even an old hand at quantum field theory will occasionally be challenged. Unfortunately, equations often contain unexplained terms and sporadically misleading typos (e.g. in the indices), and the text is sometimes ungrammatical and often hard to penetrate. That this book cannot serve as a standalone introduction to the conceptual and philosophical foundations of QCD and related physics is a missed opportunity to bring a woefully understudied area of physics closer to the HOPOS community.

To its credit, the book also contains many interesting and valuable tidbids, and even substantive historical and conceptual analyses. Unfortunately, it is often difficult to recognize how they are supposed to align into a cohesive argument in support of Cao's self-termed 'constructive structural realism' (CSR). According to Cao, the two basic theses of CSR are "(i) the physical world consists of entities that are all structured and/or involved in larger structures; and (ii) entities of any kind can be approached through their internal and external structural properties and relations that are epistemically accessible to us." (6) The purported advantage of CSR over its competitors in the structural realist department is that it alone can infer to the reality of unobservable "entities"—presumably objects—from the reality of structure. While advocates of other structural realisms will deny that they cannot infer to the reality of electrons, or indeed of quarks, they not only maintain, against the anti-realists, that the entities posited by our best science exist, but they also insist, against standard forms of realism, on the fundamentality of structures over objects. In contrast, Cao seems concerned only with establishing the *existence* of quarks, e.g. against Murray Gell-Mann's original insistence that they are mere calculational devices, and in fact rejects their ontological dependence on structure. Thus, his CSR appears to fall outside of the usual purview of structural realisms in the contemporary literature. Judge for yourself:

> The switch of attention from R[, i.e., the ratio of the total cross sections for hadron and muon production in electron-positron annihilation,] as an expression of structural relations among various entities (electron, [etc...]) to the underlying entities themselves was very methodical because the former as a necessary window, through which one could have access to deeper layers of physical reality, enjoys much less explanatory power than the underlying entities themselves; or more precisely, structural relationships themselves have to be understood in terms of underlying entities. (199)

Apparently, CSR thus involves a *rejection* of structural realism in favor of a more standard form of scientific realism. However, according to Cao, "this componential conception of structure remains within the structuralist discourse since the constituents of a structure are embedded in various structural relations and they have their own internal structures." (213) But most philosophers of science with a stake in that debate would not consider as structuralist a position that maintains that the fundamental objects are ontologically prior to the relational structures they help constitute (cf. 220f). So while CSR has *metaphysically* little in common with its structuralist brethren, it may earn the moniker for its *methodological* thesis that knowledge of causally efficacious but unobservable objects (such as quarks) and their intrinsic qualities (such as their 'color') must be arrived at via knowledge of structural relations that obtain among such objects (such as their algebra of observables).

Labels aside, Cao makes it clear that he takes his CSR to be sharply distinct from both epistemic and ontic versions of structural realism. He takes CSR's commitment to fundamental *objects*, as

opposed to structures, to be what allows it to give a coherent account of the synthesis of modern particle physics and to interpret the mathematical structures of the emerging theories as physical and thus to enable a deeper understanding of the physical world. He simply denies that other versions of structural realism can succeed in any of these tasks. Unfortunately, the engagement with the original structuralist motivation to move away from commitments to objects precisely in order to attain these goals remains superficial and references to the pertinent literature are sparse. The only difference between CSR and traditional scientific realism, it seems, would be that an object an advocate of CSR is committed to "is not a member or an instance of a fixed natural kind, but rather a manifestation of a historically constructed, revisable natural kind, which is subject to reconstitution time and again." (229) One wonders, however, whether turning such ontological transience into the hallmark of a realist position does not put the fox in charge of the henhouse, an impression that is solidified by much of what is said in Chapter 10.

As can also be gleaned from the brief description of the content of the ten chapters, the book is very historical, particularly given that it is the more 'philosophical' of the two planned sister tomes. In fact, even in the final two chapters, Chapters 9 and 10, the author often argues in a historical mode. For instance, the reader is urged to accept ontological commitments of quantum electrodynamics and QCD on the basis of a careful analysis showing that the practitioners themselves did in fact enter into such commitments and were justified at the time in doing so. But of course this will not sway philosophers. And it shouldn't. There is every reason to take seriously the scientists' own interpretations and understanding of the theories they are formulating, but these considerations cannot establish a conclusive argument deciding the debate between realists and antirealists. Just imagine someone were to write a book on the history of the development of the caloric theory of heat before Count Rumsford started boring cannons but after Lavoisier's complete articulation of the theory, including his forceful arguments that it was superior to phlogiston theory. An argument completely analogous to Cao's could then have been made in this book to the effect that philosophers should accept an ontological commitment to caloric. So Cao's argument does little more to advance the realism debate than offering a case study of how practitioners of quantum field theories did in fact accept the prima facie ontological commitments of the theories they developed and were rational in doing so *in their context*, i.e., given the assumptions they accepted and the evidence available to them.

Cao's historical methodology is unapologetically and refreshingly internalist, considering only the field's scientific advances and the actors' intellectual exchanges in papers, talks, and interviews. Despite being philosophically somewhat light, it is here that we find the main strength of the study: in its old-style pursuit of intellectual history, enriched with conceptual and philosophical awareness. The result is a piece of integrated HPS scholarship that offers a valuable resource for further, and deeper, philosophical consideration of the foundations of modern particle physics.