Tian Yu Cao
From Current Algebra to Quantum Chromodynamics: A Case for Structural Realism.
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Quantum chromodynamics (QCD) is a physical theory that is a central part of our current most fundamental theoretical framework about matter. It provides our best understanding of the strong interaction, describing the hadrons (such as the particles that compose the atomic nucleus, the protons and neutrons) in terms of the elementary quarks and gluons and their interactions. The development of QCD is a major scientific achievement of the second part of the 20th century, mobilizing some of the greatest physicists of the time; huge technical and conceptual difficulties were overcome along the way. Cao's book aims to provide a historical and conceptual account of a crucial period in this development, namely from the current algebra hypothesis suggested by the physicist Murray Gell-Mann in the early 60s to the formulation and first experimental successes of QCD in the early 70s. Cao's historical and conceptual study further aims at describing the key technical and conceptual steps in the development of QCD in the light of the philosophical conception of structural realism. Cao intends to articulate and advocate a version of structural realism he calls constructive structural realism, which is argued to provide a relevant methodological and metaphysical framework for understanding QCD and its development. This philosophical perspective is explicitly meant to constitute a distinguishing feature of this book, which is part of a broader project of Cao on the historical study of the physics of the strong interaction. This review mainly focuses on this philosophical aspect of Cao's book.

Seven out the ten chapters of the book (Chapters 2 trough 7) mainly deal with the detailed historical account of the major technical steps in the development of QCD. After the Introduction, which contains important claims about Cao's constructive structural realism and the outline of the main structural steps in the development of QCD, Chapter 2 sets the experimental and theoretical context in which Gell-Mann (a central figure in the history of QCD, around which important parts of Cao's book revolve) proposed the current algebra framework for hadron physics, with the notion of (SU(3)) symmetry at its heart. Chapters 3 to 6 discuss key steps following the current algebra proposal—notably its important experimental implications as well as the deep conceptual challenges it had to face—and the resulting difficult emergence of the fundamental notion of constituents of hadrons (namely quarks and gluons) against the dominant view of the time, according to which all hadrons were equally fundamental ('nuclear democracy'). Chapter 7 examines the final stage of this intricate development that led to the first formulation of QCD in the early 70s; it highlights in particular the crucial bridging role played by the gauge-theoretic understanding of gluons between the 'color' SU(3) symmetry and the inter-quark strong interactions (hence 'chromodynamics', although the term 'color' in this context has no link with its usual meaning). The first theoretical and experimental successes of QCD are discussed in Chapter 8. The last two chapters of the book develop Cao's structural realist analysis of the conceptual 'construction' of QCD as well as broader considerations in history and philosophy of science in general.

The account of the crucial steps in the development of QCD (which constitutes the major part of the book) heavily relies on an abundance of technical descriptions that renders the reading rather difficult for anyone without some strong background in quantum field theory. Even the readers with the required background may feel that many of the interesting technical steps are not accounted for in a conceptually clear way. On the other hand, the book also provides an interesting perspective on the key steps in the development of QCD through several detailed accounts of important talks (such as some of the talks at the 14th Solvey Conference in Brussels in October 1967 (§4.3)) and of crucial experiments (such as the deep inelastic electron-proton scattering experiments at Stanford's National Accelerator Laboratory (Chapter 5)) as well as through the material Cao obtained by direct exchanges with many of the prominent figures in QCD. All the chapters end with a section entitled 'Remarks', which is often helpful and insightful, touching core conceptual issues (the philosophy inclined reader may wish that theses sections would be more elaborate and more central to the book).

Cao's constructive structural realism (CSR) and the corresponding structuralist interpretation of the 'construction' of QCD constitute the central philosophical thesis of the book. CSR is claimed to be an alternative between the two main contemporary versions of structural realism, namely epistemic structural realism (ESR) and ontic structural realism (OSR). Besides providing a convincing account of the development of QCD, CSR aims to genuinely address the standard anti-realist challenges, such as the meta-pessimistic induction and the Kuhnian scientific revolutions, which, Cao argues, both ESR and OSR fail to properly address. This last claim seems a bit strange, since CSR adopts a similar strategy through the use of the notion of 'ontological synthesis' in order to face the anti-realist challenges, namely arguing for some sort of continuity in the history of science (arguably, ESR defends some continuity at a different 'level').

The 'standard' structuralist conceptions in the contemporary philosophy of science ESR and OSR possess a fairly clear content: very roughly, according to ESR, structure is all we can know (hence 'epistemic'), whereas according to OSR, structure is all there is (hence 'ontic'). Of course, a detailed account would require one to define precisely the notion of 'structure' involved in the two contexts (it should be noted that several such detailed discussions of ESR and OSR have flourished in the recent years—not without controversies of course—but unfortunately they are not discussed in Cao's book). By contrast, it is quite difficult to get a grip on the central thesis of CSR, beyond the few claims that are made about it (this is almost exclusively in Chapters 1 and 9). Contrary to ESR, CSR does not claim that there are unknowable entities underlying the structures described by fundamental physics. In contrast to the (controversial) 'objectless' understanding of OSR, CSR does accept objects (which Cao often a bit imprecisely refers to as 'entities') in its ontology. Of course, the elucidation of the relationship between structures and objects is crucial. The exact commitment of CSR on this central issue is unclear. On the one hand, it is claimed that the constructive version is 'based on the metaphysical understanding that concrete structures of primary scientific interest … and their elements are ontologically inseparable and enjoy the same ontological status' and that 'the constructive structural realist conceives the identity (or nature) of physical entities in a structural way' (224)—such claims seem completely in line with certain variants of OSR that retain the notions of objects and relata. But on the other hand, Cao argues that the 'relational structure' has to be 'interpreted' so that 'no structural statement of fundamental entities could be purely relational'. Indeed, 'the structural statements of stable physical relations among the underlying entities have to invoke or at least assume something more than relational, namely some qualitatively distinct properties

that are causally effective.' (225) Oddly enough, the conception according to which relational structures themselves are considered as causally effective is not mentioned. The further claim that 'concrete structures as specific relations of relata are determined by causally effective properties as their relata' (226) does not seem reconcilable with the above claim that structures and their elements have the 'same ontological status' within CSR. Moreover, it seems to weaken considerably the very structuralist nature of the conception: it can be argued that since the structures are determined by their underlying objects (relata) and their causally effective, non-relational properties, Cao's conception has effectively left the realm of structural realism altogether.

Cao emphasizes an important methodological aspect of his conception, for which his account of the development of QCD aims to provide a compelling illustration. Within the framework of CSR, we have access to the underlying fundamental 'entities' (objects) through the 'structural knowledge' we gain in fundamental physics. In the QCD case, roughly, the current algebra model provides some structural knowledge of the underlying level—the 'deeper' level of the hadronic constituents, the quarks and gluons. Within the framework of the development of QCD, Cao highlights in particular the role of symmetries in the acquisition of structural knowledge. QCD then emerged on the basis of this structural knowledge through the 'mechanism of ontological synthesis': QCD as the combination of structural statements and structural constraints. From this perspective, the structural component of Cao's view reduces to the way in which we gain knowledge of the fundamental non-structural elements of reality.

Despite the difficulties mentioned above, Cao's book provides many historical and conceptual insights into the fascinating development of QCD—even if very few arguments for structural realism emerge in the end.

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