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Book review

The Birth of String Theory, Andrea Capelli, Elena Castellani, Filippo Colomo, Paolo Di Vecchia (Eds.), Cambridge University Press (2012). xxv + 636pp., Hardback, £60.00, ISBN: 978-0-521-19790-8

1. The Missing History of String Theory

Here is a book that was sorely needed. Though there have been multiple accounts of the histories of particle physics (including specialisations to QED and QCD), cosmology, and relativity, there has yet to be published a (scholarly) book dealing with string theory.[1] This has been a rather curious neglect since string theory's earliest days are full of novel and interesting features that, to the best of my knowledge, are simply absent from other episodes in the history of physics. As I will discuss briefly below, some of these features make this book essential reading for philosophers of science too, not just historians, since, as a case study in the development of scientific theories, string theory has the potential to provide new challenges. However, the present book is certainly a gift to the small handful of present historians interested in string theory and quantum gravity, and also to future historians who will inevitably have to deal with string theory's developmental stages at some point.

The method employed by the editors involves the assemblage of a vast cast of many of the major physicists involved in the earliest phases of string theory (pre-1984; post 1968), including Gell-Mann, Green, Lovelace, Mandelstam, Montonen, Nambu, Neveu, Nielsen, Olive, Polyakov, Ramond, Schwarz, Susskind, Veneziano, and Yoneya. Some of the contents were drawn from a workshop held in May 2007—a workshop the editors claim was the first time most of them were together since a Durham workshop on dual models in 1975.[2] This results in a rather substantial book, with a very long list of contributors, some of whom provide only very brief remarks (for example, Murray Gell-Mann's contribution amounts to but two pages). This provides ample ingredients and guideposts for any future history of string theory—despite the fact that the contributions are often anecdotal and inescapably clouded by the biases of first-person perspectives and many decades of intervening time for memories to warp. Indeed, my only substantial gripe is that the history that emerges does not delve as far as it might have, peering behind the various anecdotes and so on, and what results is a compendium of tales that could serve to guide a future (more scholarly) history of the subject. It is not so much a historical study as data for a historical study—it is especially useful for charting out the various research collaboration networks within which dual model and string theory was studied. In this sense it is broadly similar to Hoddeson et al.'s series of books charting the various phases of particle physics:

- *The Birth of Particle Physics* (CUP, 1986).
- *Pions to Quarks: Particle Physics in the 1950s* (CUP, 2009).
- *The Rise of the Standard Model: A History of Particle Physics from 1964 to 1979* (CUP, 1997).

There is some small amount of overlap with the latter two books, as might be expected given string theory's origins lying squarely in the physics of hadrons. But it is surprising that there isn't *more* overlap with these books, since the dual models occupied a central role in their day, and share much genetic material with quark theory and the eventual standard model.[3] In this way, the present book is of enormous value in filling in such gaps in the historical record as given in those books.[4]

[1] The author reviewed another book for this journal that included some history of string theory, though it was really a festschrift for Gabriele Veneziano: Gasperini, M., & Maharana, J. (eds.), *String theory and fundamental interactions* (Springer, 2008). James Cushing's *Theory construction and selection in modern physics* (Cambridge University Press, 1990) also explores several overlapping themes (with chapter 8 specifically focusing on dual resonance models and the emergence of superstring theories). Cushing argues that analogies and models played a crucial role in the development of the S-matrix theory (including the later dual models), a point reinforced by Elena Castellani in her chapter of the book under review. Both also make the point that, even at this early stage, there is a strong tendency for mathematics to push the physical aspects of the programme forwards ("formalism leading physical intuition," in Cushing words, p. 190). However, there are also plenty of examples of physical principles leading to the search for 'off the shelf' mathematics.

[2] They also point out in the Preface that this initial workshop allowed for 'compatibility checks' to take place amongst the various reminiscences. However, Jöel Scherk, one of the most important figures in the early days (responsible for the study of zero-slope limits leading to the transfiguration of string theory into a theory of gravity and gauge particles), is no longer around to tell his tale—though John Schwarz contributes a second chapter covering Scherk's contributions. Several of the contributors to the book have died since the book was released.

[3] The early history overlaps directly with the history of QCD and quantum field theory, and the attempt to formulate alternatives to the latter. The most hotly pursued approach was Chew's 'bootstrap', which focused on the S-matrix (mathematically, an amplitude) representing the observable content of the physics of hadrons. It seemed difficult to get a model of hadrons as either elementary or composite in quantum field theory, and the bootstrap was a principle that attempted to sidestep this by selecting a closed set of hadrons no one of which was more fundamental than any other and out of which they were all created. Bootstrapping the hadronic world involved trying to find a self-consistent model for which this 'nuclear democracy' could happen. The step that led to this (imposing duality in the s- and t-channels) was the origin of dual resonance models, which were the direct ancestors of string theory.

[4] I might also mention Tian Cao's recent book *From current algebra to quantum chromodynamics: A case for structural realism* (Cambridge University Press, 2010) which also curiously omits aspects of the early history of string theory that are clearly of the utmost relevance to the early stages of QCD. Cao only devotes 2 pages to string models, and does not give due credit to the extent of the phenomenological success of early string models of hadrons, pointing only to the problems stemming from the point like nature of hadronic interactions revealed by the deep inelastic collision experiments at SLAC.

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2. Synopsis of the book

The book is divided into two halves, the first focusing on “Early String Theory” with the second devoted to “Towards Modern String Theory”. Each of these then consists of three parts as follows:

1. Early String Theory
   (a) The Prehistory: The Analytic S-Matrix
   (b) The Dual Resonance Model
   (c) The String
2. Towards Modern String Theory
   (a) Beyond the Bosonic String
   (b) The Superstring
   (c) Preparing the String Renaissance

The book begins with an “Overview” part, consisting of four general chapters, including a useful opening synopsis (presenting the periodisation into the six phases above), two survey chapters by two of the chief early architects of the theory (Gabriele Veneziano and John Schwarz), and a philosophical discussion of string theory, by Elena Castellani—rather regrettably, there are no chapters by professional historians. That the book focuses primarily on the earliest phase of string theory research (including portions of the ‘prenatal phase’) is utterly understandable (it is *manageable*, for example) and certainly the most interesting and valuable approach.[5] One can get a better feel for why present day string theory looks the way it does, and how many of the central concepts were originally formulated—often this is not as one would expect, and involves various heuristic moves and thought experimentation. For this reason, both philosophers and historians wishing to study string theory would be well advised to begin with this book.

Each of the parts in the main body of the text, following the overview, begins with an introduction to the necessary technical tools and concepts (e.g. S-matrix theory, Regge theory, and conformal symmetry). These are absolutely first rate, very detailed and clear—there are many concepts that I've met many times before but feel I only just really understand now after absorbing these introductory chapters. As are the appendices (five of them), which I would urge readers to turn to first if they do not have a background in strong interaction physics from the 1950s to 1970s.

The main chapters themselves are, for the most part, clearly written for their professional colleagues, and since many originated from a conference they would have been written with that audience in mind. As such, they often make for rather taxing reading. On the other hand, there are some chapters that are entirely ‘equation free’, that could easily be understood by readers with no prior experience of strings and elementary particle physics.

I might also note that the editors have uploaded additional materials onto a website that accompanies the book: http://theory.fi.infn.it/colomo/string-book/. This features a pdf of the previously hard to find article by Holger Nielsen, in which he develops his approach to the Veneziano model in terms of two-dimensional ‘ribbons’ (and at that stage, does so only ‘heuristically’).

3. Case study potential

In his *Theory construction and selection in modern physics*, James Cushing pointed to the methodologically salient fact that S-matrix theory constitutes “an example of an abandoned research program giving rise to a possibly ‘correct’ theory [superstring theory] that might otherwise never have been formulated” (p. 189). It is certainly bizarre the way string theory qua unified quantum gravity theory was produced from this hadronic background. In a forthcoming book on the history of string theory[6] I refer to the curious way that the formalism was assigned a different function as ‘theoretical exaptation’ (by analogy with exaptation in evolutionary biology). By rescaling the theory, and redefining the ‘target systems’ described by the theory, string theory was able to soldier on beyond its ‘defeat’ at the hands of QCD. Such moves should certainly be of interest to philosophers of science with an interest in the methodology and development of science. A potential research project might be to find similar cases, to assess how rare this kind of exaptation is (and therefore how bizarre string theory's history is).[7] Philosophers of science with a more sociological bent might also find something worth pursuing in this example. When QCD emerged as a leading framework for understanding hadrons, string theory lost its ‘market’ (no longer able to compete),[8] and so if it was to survive it became necessary to switch to find another market. A weakness (the appearance of excitations invisible in the observable spectrum, including massless spin-2) in one environment (hadron phenomenology) became a strength in another (quantum gravity).

A rather simple, but not uninteresting, story can be told about the development of the dual resonance model through its initial stages (as extracted from several of the chapters). After the discovery of an appropriate function capable of modeling a 4-point amplitude self-consistently, and respecting the various constraints for a nice amplitude, it was a natural subsequent step to generalise this function to N variables ($N=n+m$). In so doing, the operator formalism (with its introduction of vertex operators) was discovered. This was the really crucial step since it linked the dual models to standard notions in quantum field theory. In particular, the correspondence between the operators of the theory and harmonic oscillators. In trying to patch the patterns of oscillation to a physical explanation, several people (Nambu, Susskind, and Nielsen) were led to the idea that the underlying system was that of a one-dimensional vibrating string. Of course, initially these strings were models of hadrons. I find the way in which the theory was transformed (the exaptation from above) one of the most puzzling (in terms of theoretical development) episodes in the history of physics. The question of whether this was rational (and well motivated) remains an open topic for philosophers of science.

Another especially important aspect of the book is the prevalence and important role played by Regge theory, both in the pre-history of string theory and in its earliest days (it still plays a role today, in fact). Regge theory was developed as a tool for systematizing the understanding of strong interaction data, by classifying the various apparent elementary particles and resonances. What is interesting about it is that, although it provided a good fit with many aspects of the data (mostly a qualitative fit), it was not a *predictive* scheme. Again, one can easily see how this might be of interest to philosophers of science interested in theoretical virtues beyond prediction. This also indicates how even in string theory's earliest phases it was not focused so much

[5] I should, however, point out that though the book professes to be about early string theory (and sticks to this for the most part), many authors cannot resist the temptation to discuss contemporary issues, such as the AdS/CFT correspondence.

[6] *A biography of string theory: From dual models to M-theory* (Springer, forthcoming).

[7] One might consider the morphing of Weyl's original gauge theory from a unified theory of electromagnetism and gravity to the phase of the quantum mechanical wave function as a similar example.

[8] As Goddard notes (pp. 256–257), the loss of market share was particularly quick and extreme with a shift at CERN from a hotbed of dual theory activity to an institute were very few people had any interest in a period of one year.

on predicting the results of new experiments, but rather was concerned with fitting otherwise perplexing patterns in known experimental data.

Historians will, I expect, take issue with the rather loose way in which matters of historical meaning are presented. For example, in the introduction to Part III of the book, the editors write, with reference to the Virasoro model, that "[a]s understood later, the Shapiro-Virasoro model described the scattering of closed strings" (p. 141). This masks the fact that at the time, there was no notion that the model involved strings, and that it could, in principle, have been given an interpretation in terms of a somewhat different underlying dynamical system. But it is easy enough to adjust for such anachronisms.

The only notable absence from the book in my view was an investigation of the way in which string theory hooked up to areas of pure mathematics[9]—a feature of string theory from its earliest days. In particular, the discovery of Kac-Moody algebras, for which, say, a paper by Victor Kac and/or Igor Frenkel would have been welcomed. These links were understood early on and can't failed to have increased the confidence of string theorists in the face of the general sentiment against the theory. This omission is all the more noticeable since one has clear statements pointing to the mathematical factors leading theoretical physicists into the dual models very early on. As Peter Goddard describes his own path into string theory, after attending David Olive's lectures on dual models (impressed by "the sense he conveyed of an emerging mathematical structure") he remarks that it was the "theoretical potential, rather than any phenomenological relevance, that engaged my interest" (p. 240). Goddard briefly refers to some of the interesting intersections on p. 249, in connection with the link between the no ghost theorem and Borcherds' proof of the 'moonshine conjecture'—Goddard's chapter was certainly one of the more historically sensitive and enlightening in the book.

A natural worry for academics will be that since this early model of string theory was abandoned, and given that it contained tools specific to it that died when the early models did, it is a lot of effort to learn material that is not transferable. There is some truth to this, but if historians desire a fully accurate account of even the emergence of quantum gauge theories of the standard model—let alone the more esoteric areas of theoretical physics such as supergravity and so on—then they must get to grips with this once core formalism and framework that also shaped the research landscape at the time. The present book provides an ideal way of exploring this landscape and picking up many of those once essential tools.

Ultimately, the book must be viewed, I think, as a stepping stone to a still more 'serious' history, providing data for future studies, rather than a definitive treatment (I should point out that it doesn't claim to be in any way definitive). This is not to undermine the immense achievement of the editors in producing it. I believe it is an *exceptionally* important piece of work. In this role, as providing data for future studies, it has material enough to guide such research for very many years, and could (and should) also prompt and guide many future philosophical and methodological studies.

Dean Rickles
Unit for HPS, University of Sydney, Australia

[9] Part V straddles this theme, but doesn't pursue it as far as I would have liked.