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The Emergence of Spacetime in String Theory

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Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2019
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
52 Vanderbilt Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

Library of Congress Cataloging-in-Publication Data
A catalog record for this title has been requested

ISBN: 978-1-8489-3593-8 (hbk)
ISBN: 978-1-315-54415-1 (ebk)

Typeset in Sabon
by codeMantra

To Massimo, Isotta and Tristel

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Introduction

It is widely held inside the quantum gravity circles that string theory is a background-dependent theory (namely a theory whose physical content is spacetime dependent) and that for this reason any attempt of tracing in the theory any notion of space and time emergence is simply a non-starter. In this book, I will develop a train of thoughts supporting a different, perhaps less popular view, namely, that string theory actually shows background independence in different ways and degrees. In order to rescue the theory from the charge of being background dependent, I will present a philosophical analysis of its physical content and formal articulation. I will argue that the theory delivers a quite composite notion of spacetime emergence and that this notion produces new metaphysical insights adding an important dimension on the traditional debate about emergence. A main metaphysical payoff is the natural consequence of the fact that in order to understand spacetime emergence in string theory, one is somehow forced to formulate some criterion of metaphysical explanation applicable to fundamental physics. This introduction contains a broad presentation of the book's structure. Each chapter analyzes the emergence of space and time in string theory from a different angle, but they all contribute to the same philosophical enterprise of producing a metaphysics sensitive to the physics occurring at the Planck scale.

Chapter 1 contains an introduction to the philosophical debate on emergence in general. It also describes the argumentative line intersecting any chapter along which my analysis of spacetime emergence in string theory develops. Finally, it illustrates how this analysis of spacetime emergence is complementary to the search for some non-causal metaphysical scheme of explanation in fundamental physics.

Chapter 2 is a self-contained presentation of some basic formal features of string theory. It only refers to the bosonic case. The bosonic string is a toy theory, but it presents the main physical insights of advanced versions of the theory in a relatively simple fashion. The goal is that of delivering a basic description of quantum strings physics that can be grasped without having a technical background and be useful to have a sense of the technical aspects of the debate on spacetime emergence in the theory.

Chapter 3 analyzes a crucial formal derivation (originally found in the early 1990s) of general relativistic spacetime structure from the quantum string dynamical structure. String theorists, along with many philosophers of the quantum gravity circles, tend to remain unimpressed by this derivation. It is widely held that the derivation is purely formal and background dependent. In this chapter, I argue against this view (see also Huggett and Vistarini, 2015). More precisely, I reconstruct the derivation, and I argue that it accounts for general relativistic spacetime emergence. The physical meaning of this derivation defines the status of general relativistic spacetime from the perspective of quantum string laws: general relativistic spacetime is an emergent byproduct of underlying quantum string dynamics that do not posit any fundamental geometry. This type of emergence produces a way of reading background independence through the perturbative formulation of string theory. Interestingly, this type of emergence also turns out to be interpretable via some non-causal metaphysical scheme of explanation.

Chapter 4 develops the idea of non-fundamentality of spacetime following a slightly different argumentative line. The methodology used to show the emergent nature of spacetime only involves the spatial extra dimensions introduced by the theory, and it develops around the notion of string dualities. The duality chosen in this chapter is T-duality.

Chapter 5 analyzes a physical scenario of spacetime non-fundamentality more radical than T-duality. Indeed, it analyzes the anti-de Sitter (AdS)/conformal field theory (CFT) duality. Also called holographic duality, this correspondence ties together two quite different physical worlds. It amounts to be a physical equivalence between a string theory describing a world with gravity (an AdS spacetime) and a conformal field theory living on its lower dimensional boundary, which does not contain gravity (namely, a Minkowski spacetime).[1] This correspondence is the most concrete scenario in which some spatial dimensions of some bulk spacetime arise from dynamics occurring on its distant boundary. Those spatial dimensions are encoded in the boundary as internal degrees of freedom of quantum fields. Differently from T-duality, the non-fundamentality of spacetime here also points to the non-fundamentality of quantum string theory itself in virtue of its physical equivalence to a quantum field theory not containing strings. So, the holographic duality produces reflections on the emergent nature of spacetime that add some new philosophical dimension and physical meaning to the scenario produced by T-duality. In this chapter, I revise the analysis developed by me elsewhere about emergence in the AdS/CFT duality and in the de Sitter (dS)/CFT conjecture (Vistarini, 2016).

Chapter 6 formulates string theory background independence through the theory's moduli space. The local structure I posit on this abstract space unveils the different degrees of background independence characterizing the physical content of the theory. For this reason, this chapter presents a sort of unifying framework in which separate argumentative lines connected to different dualities can eventually join. As we will see, the structure I posit on this abstract space and the use I make of it do not completely overlap with the mainstream uses made within string theory's circles.

Chapter 7 concludes the analyzes of spacetime emergence in string theory by using a third methodology, namely, non-commutative geometry. Indeed, the chapter explores a possible way for getting some set of fundamental equations for some topological, non-geometrical structure in string theory. Non-commutative "spacetimes" are not really spacetimes; rather, they exemplify cases of topological backgrounds which are not geometrical since on them ordinary notions of duration and distance break down. However, ordinary spacetime (cosmological solutions of general relativity) is derivable from these exotic structures via low energy limits taken on their physical parameters. This fact, along with some theoretical findings about the endurance of quantum string theory when time exhibits a non-commutative behavior, is indicative of the theory's potential to account for deeper dynamics possibly happening in fundamental topological backgrounds like these ones.

Note

1 Note that both AdS and Minkowski spacetimes are physical solutions of general relativity equations.