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Book Review: Gauge/Gravity Duality: Foundations and Applications

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A Book Review on

Gauge/Gravity Duality: Foundations and Applications

Martin Ammon and Johanna Erdmenger, (Cambridge, UK: Cambridge University Press), 2015, 533 pages. ISBN: hardback 978-1-107-01034-5, ebook 978-0-511-84637-3.

The first edition of *Gauge/Gravity Duality* by Ammon and Erdmenger [1] was published in April 2015 by the Cambridge University Press. This textbook is aimed at providing graduate students and researchers in string theory and quantum gravity (but also in strongly coupled gauge theories and condensed matter physics) with fundamental concepts and applications of gauge/gravity duality. It is one of three textbooks published in 2015 [1–3] which provide an introduction to all the necessary concepts of the Anti-de Sitter/Conformal Field Theory (AdS/CFT) correspondence, proposed by Maldacena [4, 5] (see [6–9] for reviews), relating gravity theories on $d+1$-dimensional Anti-de Sitter spacetime to conformal field theories in d dimensions, e.g., type IIB superstring on 5-dimensional AdS space and a compact 5-sphere ($AdS_5 \times S^5$) to $\mathcal{N} = 4$ Super Yang–Mills theory in 3+1 dimensions. The book is divided into three parts: the prerequisites for gauge/gravity duality, the main elements of gauge/gravity duality, and its applications. The prerequisites for establishing gauge/gravity duality in the first part include some elements of quantum field theory (e.g., Lorentz and Poincaré symmetry, conformal symmetry, supersymmetry) and general relativity, as well as a brief review of superstring theory including bosonic string, D-branes, T-Duality and S-duality. The second part of the book focuses on the main concepts of the AdS_{d+1}/CFT_d correspondence, mostly $\mathcal{N} = 4$ Super Yang–Mills theory and type IIB superstring, and other examples of the AdS/CFT correspondence such as those involving D3-branes, M2-branes, and M5-branes, followed by dual supergravity with D-branes, and gravity dual of finite temperature quantum field theory, i.e., relating the Hawking temperature to the field theory temperature. The final part of the book provides important applications of gauge/gravity duality, including the fluid/gravity correspondence in relativistic hydrodynamics, strongly coupled gauge theories applicable to quantum chromodynamics, and strongly coupled systems in condensed matter physics.

Both this book [1] and the textbook by Năstase [2] are well organized and provide the necessary background and basic elements of the AdS/CFT correspondence for $\mathcal{N} = 4$ Super Yang–Mills theory vs. the background solution of $AdS_5 \times S^5$, and gauge-gravity dualities. The first three chapters of both the books cover basics of quantum field theory, general relativity, and supersymmetry. While Năstase [2] introduced supergravity, D-branes, and superstring theory in three separate chapters, Ammon and Erdmenger [1] briefly covered them in one chapter on superstring theory (Ch. 4). Moreover, Năstase [2] introduced Kaluza–Klein (KK) dimensional reduction in one chapter before discussing the KK reduction in the following chapters. Black holes extended to p spatial dimensions, called "black p-branes," were also introduced and discussed in another chapter by Năstase [2]. Although Ammon and Erdmenger's textbook [1] did not cover all the prerequisites included in Năstase's book [2], a further reading section including relevant references at the end of

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each chapter of Ammon and Erdmenger's book [1] will be useful for graduate students (and also researchers) who look for extensive and supplementary material in the literature. In particular, supplementary boxes (in gray color) included in each chapter of Ammon and Erdmenger [1] provide a brief introduction to the concepts being discussed in text.

The second part of this textbook [1] introduces the AdS/CFT correspondence in $\mathcal{N} = 4$ Super Yang–Mills theory vs. type IIB string theory on $AdS_5 \times S^5$ referred to as the "AdS side," where AdS_5 is the 5-dimensional Anti-de Sitter space and S^5 is a 5-dimensional compact spherical space. The same content was also discussed in the second part of Năstase's textbook [2]. Although Năstase extensively explained Heisenberg Spin chains in one chapter (Ch.18 in [2]), Ammon and Erdmenger discussed it among integrable structures (section 7.1.1 in [1]). Gravitational shockwave scattering and parallel plane ("pp") wave correspondence are supplementary material which can be found in the book by Năstase [2]. Witten prescription for correlation functions [10, 11] was suggested for further reading at the end of Chapter 5 by Ammon and Erdmenger [1], whereas a chapter was devoted to it in Năstase's book [2]. However, some additional examples of the AdS/CFT correspondence are presented in Chapter 8 of Ammon and Erdmenger's book [1]: D3-branes at singularities, AdS_4/CFT_3 correspondence based on M2-branes, AdS_7/CFT_6 on M5-branes, and Dp-brane duality with $p = 3$. The holographic approach to quantum chromodynamics (AdS/QCD) and condensed matter systems (AdS/CMT) have been discussed in both the books [1, 2], but Ryu–Takayanagi holographic entanglement entropy [12, 13] was briefly discussed in section 15.6 by Ammon and Erdmenger [1] and suggested for further reading at the end of Chapter 15, whereas Năstase [2] described it in detail in the last chapter (Ch. 27) of his book. The Springer lecture notes by Natsuume [3] is another textbook published in 2015, and the AdS/CFT application of the GKP-Witten relation [10, 11] to non-equilibrium physics is one of topics covered by it [3], but not by the other two textbooks [1, 2]. In summary, either of the two books [1, 2] can be used by lecturers as a textbook for teaching graduate students many aspects of gauge/gravity duality.

The future edition of this textbook [1] could be enhanced by incorporating the recent developments on holographic entanglement entropy (see e.g., [14] for review; partially presented in section 15.6 of [1]). In particular, a book by Rangamani and Takayanagii [15] recently published in the Springer series Lecture Notes in Physics in 2017 covers many aspects of holographic entanglement entropy and quantum gravity. Higher-spin gravity has also recently made significant progress in the AdS/CFT correspondence (see e.g., [16–18]; see also [19] for a review on early works), which could be included. There is a recent book published in 2017 based on a workshop on higher-spin gauges theories [20] that contains some AdS/CFT advancements in higher spin gauge theory and holography.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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