Scientific Report on the Workshop

Holographic Renormalization Group and Entanglement

Paris, January 26-28 2015

Workshop website : https ://indico.in2p3.fr/event/10745

1 Summary

The gauge/gravity holographic duality has established itself as a novel way to think about local quantum field theories, by mapping them to appropriate gravitational models described by General Relativity or more generally String Theory. The workshop focused on the recent developements connecting, through holography, the physics of gravity, quantum fields, and information theory. Central to these developements is the concept of entanglement entropy, which gives a way of counting degrees of freedom in quantum field theories, and has a geometric realization on the dual gravity side.

2 Scientific content of the meeting

The meeting has brought together several of the leading world experts in the field of holography as well as experts in quantum field theory working on topics such as information, entanglement and the renormalization group. Many of the most recent trends in research were presented, and many aspects of the relation between these aspects of QFT and holographic correspondence were explored.

Some of the talks focused on the relation between geometry in the bulk and the renormalization group on the field theory side. Focusing on the gravity side, K. Skenderis described how one can reconstruct the bulk space-time given the field theory data plus some assumptions about regularity of the geometry ; J. Papadimitriou described how holographic RG flows take the form of a Hamiltonian flow. With the attention more shifted towards the field theory side, Y. Nakayama presented the concept of local RG and how this is realised in holographic duality ; S.S. Lee showed how a holographic dimension and dynamics of sources can naturally arise by projecting the RG flow onto a subsector of the theory governed by single-trace operators, suggesting a constructive procedure to potentially derive the bulk space-time from field theory.

Several other talks revolved around the concept of information and entanglement in holography and its relation to the RG group. In particular, R. Myers

explored the relation between holography and c-theorems for entanglement entropy ; N. Obers described the algebraic structure of gravity duals to theories with non-relativistic scaling symmetries (Lifshitz) and the properties of entanglement entropy in these contexts ; J. de Boer discussed the possibility of deriving an analogue of the Cardy's formula for CFTs with enlarged symmetry algebras, dual to higher-spin theories in AdS ; M. Rangamani discussed some subtle issues that arise when matching the Ryu-Takayanagi prescription with the properties expected from field theory for the entanglement (such as causality, strong subadditivity) and the role of non-trivial topologies in the bulk geometry.

A recent developement of holography that was discussed is the relation between AdS/CFT and the tensor network approach to quantum systems. In this context, F. Verstraete gave an overview of tensor networks and how they can be effectively used to find the ground state of complicated quantum many-body systems ; B. Czech proposed a new interpretation of the geometric dual description of the MERA tensor network, which is related to the Wilsonian RG.

Finally some of the talks focused on how information-theoretical data can be encoded in the bulk geometry. M. Guica presented the results about the information-related features of the AdS-Geon geometry ; J. Simon discussed the time-dependence of entanglement entropy in out-of-equilibrium situations.

P. Calabrese provided a field-theoretic perspective on the properties of entanglement and introduced a different measure called the entanglement negativity, for which it is not yet known whether there is a corresponding holographic concept.

3 Results and impact

The workshop presented a representative cross-section of various ideas that are currently being explored around the themes of information-theoretic concepts and methods applied to QFT and their implementation in the context of holographic dualities. In particular, it has been understood that studying the entanglement structure encoded in the ground state and the excited states can give important insight into the properties of a theory. It has been found that this structure can be expressed very efficiently in terms of "tensor network" states and much work has already been devoted to make the connection between the space of such states and the dual geometry. Different points of view have been advocated and further research is needed to clarify these issues.

More generally, there is a feeling that in one form or another, the entanglement might be the best language in which to express the connection between the renormalisation group flow and the geometric properties of the dual background, and even to realise a long-sought for *constructive* derivation of the holographic

correspondence. In this context many speakers have emphasised the relations and differences between the conventional and the holographic view of the RG flow, the latter taking into account in crucial ways the possibility of "localising" the renormalisation procedure by introducing a space-time dependent moving cutoff.

Throughout the workshop, the level of discussion and interaction between scientists was consistently high. The format privileged a relatively small number of talks, all of which were of outstanding quality, and ample time for discussion. The workshop brought together a good portion of the experts on the subject – virtually all the European ones, and some of the most important American major experts – and allowed them to exchange ideas in a concentrated and effective way. The workshop has also been well-attended by the local community, with the participation of many researchers based in the Parisian region, including a large number of postdoctoral researchers and graduate students for whom this has been a great chance to learn about the most recent developments in the field from the world-leading experts and to interact with them.

Overall, all these points show that the event has been successful in advancing the field of holographic renormalisation and entanglement, by allowing a fruitful exchange of ideas among the major experts, by contributing to the training of younger scientists, and by giving a complete overview of the state of the art of the subject and defining its major goals and prospects for the future.

4 Scientific Programme

Monday 26th January : Amphi Turing, Univ. Paris Diderot

09 :15 - 09 :45	Registration	
09 :45 - 10 :45	J. De Boer	Entanglement in higher spin theories
11 :00 - 11 :30	Coffee	
11 :30 - 12 :30	F. Verstreate	Holography from the point of view of tensor networks
12 :45 - 14 :30	Lunch	Restaurant Buffon
14 :30 - 15 :30	K. Skenderis	Holographic renormalization and reconstruction of space-time
15 :45 - 16 :30	Coffee	
16 :30 - 17 :30	J. Simon	"Quantum entanglement of locally perturbed thermal states"

Tuesday 27th January : Amphi Turing, Univ. Paris Diderot

09 :00 - 10 :00	M. Rangamani	A holographic entanglement triptych
10 :15 - 10 :45	Coffee	
10 :45 - 11 :30	M. Guica	Behind the geon horizon
11 :30 - 12 :30	P. Calabrese	Entanglement negativity and quantum field theory
12 :45 - 14 :30	Lunch	Restaurant Buffon
14 :30 - 15 :30	R. Myers	Entanglement and C-theorems
15 :45 - 16 :30	Coffee	
16 :30 - 17 :30	B. Czech	From integral geometry to tensor networks
20 :00 - 22 :00	Workshop Dinner	Restaurant "Le Moulin Vert"

Wednesday 28th January : Biopark Auditorium

09 :30 - 10 :30	N. Obers	Torsional Newton-Cartan geometry in Lifshitz holography and non-relativistic field theories"
10 :45 - 11 :30	Coffee	
11 :30 - 12 :30	S-S. Lee	Ab initio holography
12 :45 - 14 :30	Lunch	Restaurant Buffon
14 :30 - 15 :30	Y. Nakayama	Local RG, quantum RG and holographic RG
15 :45 - 16 :30	Coffee	
16 :30 - 17 :30	I. Papadimitriou	Renormalization Group as a Hamiltonian flow and the symplectic structure of quantum field theory

Holographic Renormalization Group and Entanglement

26-28 janvier 2015
Univ. Paris Diderot
Europe/Paris timezone

Overview
Timetable
Venue
Accommodation
Speakers
Participants
Workshop Dinner

Contact
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Aprile, Francesco (University of Crete)
Bena, Iosif (IPhT, Saclay)
Bhattacharya, Jyotirmoy(Durham University)
Binetruy, Pierre (APC Paris)
Calabrese, Pasquale (Pisa University)
Cassani, Davide (LPTHE Jussieu, Paris)
Czech, Bartlomiej (Stanford University)
de Boer, Jan (University of Amsterdam)
El-Showk, Sheer (CERN)
Gath, Jacob (CPHT, Ecole Polytechnique)
Green, Andrew (University College London)
Guica, Monica (Nordita)
Gursoy, Umut (Utrecht University)
Halmagyi, Nick (LPTHE Jussieu, Paris)
Hartong, Jelle (Niels Bohr Institute)
Kiritsis, Elias (University of Crete)
Kulaxizi, Manuela (Brussels University)
Jarvinen, Matti (LPTENS, Paris)
Lee, Sung-Sik (Perimeter Institute)
Li, Wenliang (APC Paris)
Lopez, Esperanza (Universidad Autonoma Madrid)
Mukhopadyhay, Ayan (University of Crete)
Myers, Robert (Perimeter Institute)
Nakayama, Yu (Tokyo IPMU)
Niarchos, Vasilis (University of Crete)
Nitti, Francesco (APC, Paris)
Noui, Karim (Univ. Tours)
Obers, Niels (Niels Bohr Institute)
Orus, Roman (University of Mainz)
Papadimitriou, Ioannis (SISSA, Trieste)
Parnachev, Andrei (University of Dublin)
Pieroni, Mauro (APC, Paris)
Policastro, Giuseppe (LPTENS, Paris)
Rangamani, Mukund (Durham University)

Redigolo, Diego (LPTHE Jussieu, Paris)
Simon, Joan (University of Edimburgh)
Skenderis, Kostas (University of Southampton)
Solodukhin, Sergey (LMPT, Tours)
Steer, Daniele (APC, Paris)
Svanes, Eirik (LPTHE Jussieu, Paris)
Tonni, Erik (SISSA, Trieste)
Turton, David (IPhT, Saclay)
Verstraete, Frank (University of Vienna)