Four Day conference:
"Holography and Quantum Information"
May 31 - June 3

Tue. May 31

9:20 - 9:30	**Opening**
9:30 - 10:15	**Sandip Trivedi (TIFR)** "Entanglement Entropy in Gauge Theories"
10:15 - 11:00	**Christopher Herzog (Stony Brook University)** "Tales from the Edge: Boundary Terms and Entanglement Entropy"
11:30 - 12:15	**Dmitri Fursaev (Dubna State University)** "Conformal Anomalies, Entanglement, Boundaries, and Distributional Geometry"
12:15 - 13:00	**Tatsuma Nishioka (University of Tokyo)** "Supersymmetric Rényi entropy"
14:30 - 15:15	**Sumit Das (University of Kentucky)** "Quantum Quench and Critical Behavior : Scaling at Any Rate"
15:15 - 16:00	**Sinya Aoki (YITP, Kyoto)** "Flow equation for the large N scalar model and induced geometries"
16:30 - 16:50	**Short talk: Elena Caceres (Universidad de Colima)** "Causal Holographic Information in Higher Derivative Theories"
16:50 - 17:10	**Short talk: Andrew Darmawan (Université de Sherbrooke)** "Numerical simulation of topological codes using tensor networks"
17:10 - 17:30	**Short talk: Max Riegler (TU Wien)** "Flat Space Holography and Entanglement Entropy in $2+1$ Dimensions"
17:30 - 17:50	**Short talk: Tokiro Numasawa (YITP, Kyoto)** "Interaction effect on Entanglement propagation in 2d RCFT"
17:50 - 18:10	**Short talk: Po-Yao Chang (Rutgers University)** "Entanglement negativity in free fermion systems"

Wed. June 1

9:00 - 9:45	**Jan de Boer (University of Amsterdam)** “Entanglement holography”
9:45 - 10:30	**Bartek Czech (Stanford University)** “A stereoscopic look into the bulk”
11:00 - 11:45	**Sung-Sik Lee (McMaster University/Perimeter Institute)** “Horizon as critical phenomenon”
11:45 - 12:30	**Beni Yoshida (Perimeter Institute)** “Complexity by design”
14:00 - 14:45	**Aninda Sinha (Indian Institute of Science)** “Conformal bootstrap in Mellin space”
14:45 - 15:30	**Yasuhiro Sekino (Takushoku University)** “Equilibration in matrix quantum mechanics”
16:00 - 16:20	**Short talk: Feng-Li Lin (National Taiwan Normal University)** “Toward Holographic Quantum Energy Teleportation”
16:20 - 16:40	**Short talk: William Kelly (UC Davis)** “ ’t Hooft suppression and holographic entropy”
16:40 - 17:00	**Short talk: Ahmed Almheiri (Stanford University)** “Linearity of Holographic Entanglement Entropy”
17:00 - 17:20	**Short talk: Yuki Yokokura (RIKEN)** “Thermodynamic entropy as a Noether invariant”
17:20 - 17:40	**Short talk: Cedric Beny (Leibniz University)** “Computing quantum Fisher information metrics in QFT”
17:40 - 18:00	**Short talk: Sho Sugiura (University of Tokyo)** “Thermodynamic geometry emerges from Fubini-Study metric of thermal pure quantum states”

Thu. June 2

9:00 - 9:45	**Jan Zaanen (Leiden University)** "Fermion signs, entanglement and the strange metals"
9:45 - 10:30	**Kouichi Okunishi (Niigata University)** "Sine-square deformation and Mobius quantization of CFT"
11:00 - 11:45	**Aitor Lewkowycz (Princeton University)** "Modular hamiltonians and relative entropies for holographic states"
11:45 - 12:30	**Shunsuke Furukawa (University of Tokyo)** "Mutual information of two disjoint intervals in Tomonaga-Luttinger liquids: bosons versus fermions"
14:00 - 14:45	**Erik Tonni (International School for Advanced Studies)** "Some geometrical aspects of entanglement in CFT and Holography"
14:45 - 15:30	**Sunil Mukhi (Indian Institute of Science Education and Research)** "Finite Temperature Renyi Entropy and Modular Invariance"
16:00 - 16:20	**Short talk: Hiroaki Matsueda (Sendai National College of Technology)** "Snapshot entropy: An alternative holographic entanglement entropy"
16:20 - 16:40	**Short talk: Noburo Shiba (YITP, Kyoto)** "Aharonov-Bohm effect and entanglement entropy in conformal field theory"
16:40 - 17:00	**Short talk: Shuo Yang (Perimeter Institute)** "Loop optimization for Tensor network renormalization"
17:00 - 17:20	**Short talk: Aurelio Romero (University of Cambridge)** "Mazur-Suzuki bounds in holography"
17:20 - 17:40	**Short talk: Alex Turzillo (California Institute of Technology)** "Classifying one-dimensional gapped quantum phases with tensor networks and TQFTs"

Fri. June 3

9:00 - 9:45 **Yasuaki Hikida (Ritsumeikan University)**
"Higher spin holography and Higgs phenomenon"

9:45 - 10:30 **Jonathan Oppenheim (University College London)**
"Do black holes create polyamory?"

11:00 - 11:45 **Yasusada Nambu (Nagoya University)**
"Probability of boundary conditions in quantum cosmology"

11:45 - 12:30 **Roberto Emparan (Universitat de Barcelona/ICREA)**
"Black holes at large D: Things we've learned so far"

Talk abstract

Tue. May 31

Sandip Trivedi (TIFR)
"Entanglement Entropy in Gauge Theories"

Christopher Herzog (Stony Brook University)
"Tales from the Edge: Boundary Terms and Entanglement Entropy"

Conformal transformations to hyperbolic space should be a useful tool for calculating entanglement entropies in conformal field theories (CFTs). There are subtle issues associated with the boundary of hyperbolic space, however. I will discuss these subtleties in the context of computing the universal log contribution to the entanglement entropy across a sphere in even dimensional CFTs. Time permitting, I will also discuss thermal corrections to this entanglement entropy.

Dmitri Fursaev (Dubna State University)
"Conformal Anomalies, Entanglement, Boundaries, and Distributional Geometry"

A relation between conformal anomalies and logarithmic terms in the entanglement entropy (EE) is known to exist for CFT's (in even dimensions). It is also reproduced by holographic computations. In my talk, I discuss boundary effects in the conformal anomaly and EE, when the entangling surface crosses the physical boundary of the system. The talk covers the following recent results: classification and calculation of 'boundary' charges in the integrated conformal anomaly of a CFT effective action in 3 and 4 dimensions; relation between 'boundary' and 'bulk' charges; derivation of boundary logarithmic terms in EE. I also report on our new studies of distributional properties of intrinsic and extrinsic geometries of a boundary in the presence of conical singularities in the bulk. These properties allow one to make a connection of EE to the boundary terms in the anomaly.

Tatsuma Nishioka (University of Tokyo)
"Supersymmetric Rényi entropy"

The Rényi entropy is a one-parameter generalization of entanglement entropy that can be a useful order parameter for various phase transitions. In QFTs, it is calculated using the so-called replica trick that reduces the computation to the partition function on a singular space. This method, however, is not compatible with supersymmetry in general. In this talk, we define the supersymmetric extension of the Rényi entropy by introducing a chemical potential for the R-symmetry in $\mathcal{N} = 2$ supersymmetric gauge theories in three dimensions. Using the localization method, we write down the matrix model representation that allows us to examine its properties such as the duality invariance, the large-N behavior and the expansion with respect to the parameter. We also discuss the gravity dual and the higher-dimensional counterparts as well.

Sumit Das (University of Kentucky)
"Quantum Quench and Critical Behavior : Scaling at Any Rate"

Sinya Aoki (YITP, Kyoto)
"Flow equation for the large N scalar model and induced geometries"

We study the proposal that a $d+1$ dimensional induced metric is constructed from a d dimensional field theory using gradient flow. Applying the idea to the O(N) φ^4 model and normalizing the flow field, we have shown in the large N limit that the induced metric is finite and universal in the sense that it does not depend on the details of the flow equation and the original field theory except for the renormalized mass, which is the only relevant quantity in this limit. We have found that the induced metric describes Euclidean Anti-de-Sitter (AdS) space in both ultra-violet (UV) and infra-red (IR) limits of the flow direction, where the radius of the AdS is bigger in the IR than in the UV.

Elena Caceres (Universidad de Colima)
"Causal Holographic Information in Higher Derivative Theories"

In higher derivative theories gravity can travel faster than the speed of light. Thus, the causal structure is not necessarily determined by null curves but by the mode that travels fastest. We revisit the construction of the bulk causal wedge and causal holographic information in a Gauss-Bonnet theory which is known to possess superluminal modes. We point out some distinctive features occurring when boundary causality is violated.

Andrew Darmawan (Université de Sherbrooke)
"Numerical simulation of topological codes using tensor networks"

The surface code is a promising candidate for quantum error correction in many architectures, requiring only nearest-neighbour interactions on a two-dimensional square lattice. Our understanding of the performance of the surface code is mostly based on numerical simulations which have found a high threshold relative to other error correction schemes. These simulations usually assume Pauli noise which has the advantage that it allows efficient simulation within the stabilizer formalism. However most realistic noise processes (e.g. amplitude damping and systematic over rotation), are non-Pauli. In this work we present an improved simulation scheme for the surface code under local non-Pauli noise. Our schemes are based on the tensor network description of the surface code as a projected entangled pair state (PEPS). Syndrome sampling, computation of the process matrix and logical error rates can all be performed by contracting an appropriate tensor network.

Max Riegler (TU Wien)
"Flat Space Holography and Entanglement Entropy in 2 + 1 Dimensions"

I will present a method which allows one to determine the entanglement entropy of a quantum field theory, located at null infinity of asymptotically flat 2+1 dimensional spacetimes, holographically. This method is based on using a Wilson line, similar to the AdS case which generalizes the Ryu-Takayanagi proposal to include higher-spin symmetries. I will also show how to extend this formalism in flat space to include higher-spin symmetries and use it to furthermore determine thermal entropy of flat space cosmology solutions.

Tokiro Numasawa (YITP, Kyoto)
"Interaction effect on Entanglement propagation in 2d RCFT"

Recently the chaotic nature of holographic CFT is the focus of attention related to the black hole information problem. Because of the chaotic behavior of the system, entanglement structure can be changed drastically by a small perturbation. Also we expect the entanglement production by a small perturbation. On the other hand, in the case of integrable system such as RCFT, we does not expect such chaotic behavior. In this talk, we talk about the non-production of entanglement by the scattering of quasi-particle in RCFT.

Po-Yao Chang (Rutgers University)
"Entanglement negativity in free fermion systems"

Wed. June 1

Jan de Boer (University of Amsterdam)
"Entanglement holography"

I will describe an attempt to reorganize the degrees of freedom of a CFT in a novel way inspired by entanglement entropy.

Bartek Czech (Stanford University)
"A stereoscopic look into the bulk"

I introduce a new "stereoscopic" entry in the holographic dictionary, which allows the CFT to register depth in AdS. On the CFT side, stereoscopic operators are OPE blocks–contributions to the OPE from a single conformal family. In holographic theories, OPE blocks are dual at leading order in $1/N$ to integrals of effective bulk fields along geodesics or homogeneous minimal surfaces in AdS. To illustrate the usefulness of stereoscopic variables, I will sketch new, conceptually clean derivations of the following known results: (1) the form of the vacuum modular Hamiltonian, (2) the first law of entanglement in holography, (3) linearized

Einstein's equations, (4) the HKLL form of local bulk operators, (5) geodesic Witten diagrams.

Sung-Sik Lee (McMaster University/Perimeter Institute)
"Horizon as critical phenomenon"

We show that renormalization group flow can be viewed as a gradual wave function collapse, where an initial state associated with the action of field theory evolves toward a final state that describes an IR fixed point. The process of collapse is described by the radial evolution in the dual holographic theory. If the theory is in the same phase as the assumed IR fixed point, the initial state is smoothly projected to the final state. On the other hand, the initial state can not be smoothly projected to the final state, if the system is in a different phase. Obstructions to smooth projection appear as dynamical phase transitions, which in turn give rise to horizons in the bulk geometry. We demonstrate the connection between critical behavior and horizon in an example, by deriving the bulk metrics that emerge in various phases of the $\mathrm{U}(N)$ vector model in the large N limit based on the holographic dual constructed from quantum renormalization group.

Beni Yoshida (Perimeter Institute)
"Complexity by design"

Recent studies on chaotic dynamics in black holes have firmly established that 4-point out-of-time ordered (OTO) correlation functions are diagnostics of delocalization of quantum information, a phenomena known as scrambling. However, the growth of complexity, which is believed to continue after scrambling time, remains elusive since any entanglement measures are saturated once the wormhole of a two-sided black hole becomes long. Here, we examine OTO correlation functions from the viewpoint of quantum circuit complexity. Namely, we will prove a simple theorem in theory of quantum channels which implies that ensemble averages of OTO correlators can detect complexity of randomness, a notion known as design of unitary operators in quantum information community. We also find that higher-point OTO correlation functions, corresponding to geometries with multiple shockwaves, are sensitive to the growth of randomness in unitary operators. This talk is based on an ongoing work with Daniel Roberts.

Aninda Sinha (Indian Institute of Science)
"Conformal bootstrap in Mellin space"

I will discuss a reformulation of the modern conformal bootstrap program in Mellin space. This reformulation is closely related to the position space approach advocated by Polyakov in 1974 but which has never been used in the literature. The advantage of this way of doing bootstrap is that it reproduces the Wilson-Kogut epsilon expansion results analytically in a Feynman-diagram-free approach. Preliminary analysis in 4 dimensions suggests that the numerical constraints in this version of bootsrap is more stringent than what has been found so far. I will also discuss results in the large spin limit which can be exactly reproduced using AdS/CFT thus hinting at a universal sector in CFTs that is captured by gravity.

Yasuhiro Sekino (Takushoku University)
"Equilibration in matrix quantum mechanics"

We study matrix quantum mechanics whose degrees of freedom are two 2×2 bosonic matrices interacting via commutator-squared term. This model is simple but not known to be integrable, and can be regarded as a toy model for BFSS Matrix theory. We find its spectrum by numerically diagonalizing the Hamiltonian, and show that there is a relation between energy and angular momentum which closely resembles the Regge trajectory. We make some exact statements about equilibration in this model.

Feng-Li Lin (National Taiwan Normal University)
"Toward Holographic Quantum Energy Teleportation"

William Kelly (UC Davis)
" 't Hooft suppression and holographic entropy"

Recent works have related the bulk first law of black hole mechanics to the first law of entanglement in a dual CFT. These are first order relations, and receive corrections for finite changes. In particular, the latter is naively expected to be accurate only for small changes in the quantum state. But when Newton's constant is small relative to the AdS scale, the former holds to good approximation even for classical perturbations that contain many quanta. This suggests that – for appropriate states – corrections to the first law of entanglement are suppressed by powers of N in CFTs whose correlators satisfy 't Hooft large-N power counting. We take first steps toward verifying that this is so by studying the large-N structure of the entropy of spatial regions for a class of CFT states motivated by those created from the vacuum by acting with real-time single-trace sources. We show that $1/N$ counting matches bulk predictions, though we require the effect of the source on the modular hamiltonian to be non-singular. The magnitude of our sources is ϵN with ϵ fixed-but-small as $N \to \infty$. Our results also provide a perturbative derivation – without relying on the replica trick – of the subleading Faulkner-Lewkowycz-Maldacena correction to the Ryu-Takayagi and Hubeny-Rangamani-Takayanagi conjectures at all orders in $1/N$.

Ahmed Almheiri (Stanford University)
"Linearity of Holographic Entanglement Entropy"

We consider the question of whether the leading contribution to the entanglement entropy in holographic CFTs is truly given by the expectation value of a linear operator as is suggested by the Ryu-Takayanagi formula. We investigate this property by computing the entanglement entropy, via the replica trick, in states dual to superpositions of macroscopically distinct geometries and find it consistent with evaluating the expectation value of the area operator within such states. However, we find that this fails once the number of semi-classical states in the superposition grows exponentially in the central charge of the CFT. Moreover, in certain such scenarios we find that the choice of surface on which to evaluate the area operator depends on the density matrix of the entire CFT. This nonlinearity is enforced in the bulk via the homology prescription of Ryu-Takayanagi. We thus conclude that the homology constraint is not a linear property in the CFT. We also comment on the existence of entropy operators more generally in systems with large number of degrees of freedom.

Yuki Yokokura (RIKEN)
"Thermodynamic entropy as a Noether invariant"

We study a classical many-particle system with an external control represented by a time-dependent extensive parameter in a Lagrangian. We show that thermodynamic entropy of the system is uniquely characterized as the Noether invariant associated with a symmetry for an infinitesimal non-uniform time translation $t \to t + \eta\hbar\beta$, where η is a small parameter, $\hbar$ is the Planck constant, β is the inverse temperature that depends on the energy and control parameter, and trajectories in the phase space are restricted to those consistent with quasi-static processes in thermodynamics. [arXiv:1509.08943]

Cedric Beny (Leibniz University)
"Computing quantum Fisher information metrics in QFT"

Information-theoretical quantities such as statistical distinguishability typically result from optimisations over all conceivable observables. Physical theories, however, are not generally valid for all mathematically allowed measurements. For instance, many quantum field theories are not meant to be correct or even consistent at arbitrarily small length scales. A general way of limiting such an optimisation to certain observables is to first coarse-grain the states by a quantum channel. We show how to calculate such regularised contractive quantum information metrics in perturbative QFT, and apply our approach to scalar field theory with a quartic interaction. We observe that, if the phase-space resolution is coarse compared to $\hbar$, the various quantum generalisations of the Fisher information metric converge and the calculations simplify. [arXiv:1509.03249]

Sho Sugiura (University of Tokyo)
"Thermodynamic geometry emerges from Fubini-Study metric of thermal pure quantum states"

Thermodynamic geometry is gathering much attention in the high energy physics. In condensed matter physics, on the other hand, Fubini-Study metric of ground states with varying parameters is known to be able to capture the quantum phase transitions and their topological aspects. In this talk, I will extend this metric to finite temperature using recently proposed thermal pure quantum (TPQ) state, which is a typical realization of an equilibrium state. I will show this metric reproduces the thermodynamic geometry in commuting cases. Furthermore, when the parameters do not commute with Hamiltonian, I will show an additional quantum correlation emerges in the geometry.

Thu. June 2

Jan Zaanen (Leiden University)
"Fermion signs, entanglement and the strange metals"

The central result of holography as applied to condensed matter physics is the prediction of non-Fermi liquid metallic states of matter [1]. These strange metals are quantum critical phases that do not require fine tuning to quantum phase transitions, while they are in turn characterized by scaling properties of a novel kind, reminiscent of what seems to be observed in high T_c superconductors. I will present the case that this is rooted in the fermion signs stabilizing a densely, infinite party entangled vacuum state that should be characterized by a fractal geometry of the zero's of the vacuum wave function. Departing from an Ansatz where this is explicitly realized we have computed the bipartite entanglement entropy finding that this quantity is not at all sensitive to the precise nature of the nature of the many body entanglement [2].

References:
[1]. J. Zaanen, Y.-W. Sun, Y. Liu and K. Schalm, "Holographic duality in condensed matter physics" (Cambridge Univ. Press, 2015).
[2]. N. Kaplis, F. Kruger and J. Zaanen, arXiv:1605.02477

Kouichi Okunishi (Niigata University)
"Sine-square deformation and Mobius quantization of CFT"

Aitor Lewkowycz (Princeton University)
"Modular hamiltonians and relative entropies for holographic states"

Shunsuke Furukawa (University of Tokyo)
"Mutual information of two disjoint intervals in Tomonaga-Luttinger liquids: bosons versus fermions"

In one-dimensional (1D) quantum critical systems, the entanglement entropy of a single interval exhibits a universal logarithmic scaling with a coefficient determined by the central charge of the underlying conformal field theory (CFT). It has been recognized in the past several years that the entanglement entropy or the mutual information of two disjoint intervals can determine more refined information of the CFT than the central charge. Specifically, in systems described by the Tomonaga-Luttinger liquid (TLL) theory, the mutual information is related to the TLL parameter (or equivalently, the compactification radius of a bosonic field). This result was demonstrated numerically in a spin chain model [1], and shown by sophisticated calculations in compactified bosons [2]. Because of a correspondence between bosons (spins) and fermions in one dimension, one might expect that a similar result holds in fermionic systems. However, it has recently been pointed out that the behavior of mutual information can depend on the statistics of the constituent particles because of the non-local nature of the statistical transformation [3]. Here we calculate the dependence of the (Renyi) mutual information on the TLL parameter numerically and analytically in interacting fermionic systems, and discuss that the difference from the bosonic case arises from a twisted structure in the zero modes of the bosonized fields.

[1] S. Furukawa, V. Pasquier, and J. Shiraishi, Phys. Rev. Lett. 102, 170602 (2009).
[2] P. Calabrese, J. Cardy, and E. Tonni, J. Stat. Mech (2009), P11001; J. Stat. Mech. (2011). P01021.
[3] M. Headrick, A. Lawrence, and M. Roberts, J. Stat. Mech. (2013), P02022.

Erik Tonni (International School for Advanced Studies)
"Some geometrical aspects of entanglement in CFT and Holography"

In the first part we discuss the holographic entanglement entropy in AdS_4/CFT_3 for finite domains with generic shapes. For smooth shapes the constant term can be evaluated by employing a generalisation of the Willmore functional for two dimensional surfaces. Asymptotically AdS_4 black holes, domain wall geometries and time dependent backgrounds are considered.

The second part is focused on the entanglement negativity in CFT. In 1+1 and for two disjoint intervals in the Ising and the Dirac fermion models, the contribution of a given spin structure is the scaling limit of a specific lattice term. This analysis provides also the moments of the partial transpose for the free fermion. Also some numerical results in 2+1 will be discussed.

Sunil Mukhi (Indian Institute of Science Education and Research)
"Finite Temperature Renyi Entropy and Modular Invariance"

Hiroaki Matsueda (Sendai National College of Technology)
"Snapshot entropy: An alternative holographic entanglement entropy"

We examine the scaling relation of the information entropy (snapshot entropy) defined from the singular value spectrum of a snapshot. This is an alternative way of examining the holographic entanglement entropy. We analyze the Monte Carlo snapshots of the 2D Ising and Potts models at various temperatures. We find that the entropy behaves like an order parameter and at Tc shows the scaling relation similar to the Calabrese-Cardy formula for 1D critical systems. We can exactly derive the entanglement spectrum and the entropy in ideal fractal cases, and find that they are essentially equal to the spectrum and the entropy for 1D free fermions.

Noburo Shiba (YITP, Kyoto)

"Aharonov-Bohm effect and entanglement entropy in conformal field theory"

We consider entanglement entropy in 1+1 dimensional conformal field theory with a constant vector potential. The Aharonov-Bohm effect affects the entanglement entropy. We obtain some exact results for a charged massless free scalar field.

Shuo Yang (Perimeter Institute)
"Loop optimization for Tensor network renormalization"

We introduce a tensor renormalization group scheme for coarse-graining a two-dimensional tensor network, which can be successfully applied to both classical and quantum systems on and off criticality. The key idea of our scheme is to deform a 2D tensor network into small loops and then optimize tensors on each loop. In this way we remove short-range entanglement at each iteration step, and significantly improve the accuracy and stability of the renormalization flow. We demonstrate our algorithm in the classical Ising model and a frustrated 2D quantum model. [arXiv:1512.04938]

Aurelio Romero (University of Cambridge)
"Mazur-Suzuki bounds in holography"

We investigate the Drude weight and the related Mazur-Suzuki (MS) bound in a broad variety of strongly coupled field theories with a gravity dual at finite temperature and chemical potential. We show that the MS bound, which in the context of condensed matter provides information on the integrability of the theory, is saturated in Einstein-Maxwell-dilaton (EMd) and R-charged backgrounds. We also explore EMd theories with U(1) spontaneous symmetry breaking and gravity duals of non-relativistic field theories including an asymptotically Lifshitz EMd model with two massless gauge fields and the Einstein-Proca model. In all these cases, the Drude weight, computed analytically, shows that the MS bound is not saturated. Finally, we study the effect of a weak breaking of translational symmetry by coupling the EMd action to axion fields. We show the coherent part of the conductivity in this limit is simply the product of the MS bound and the scattering time obtained from the leading quasinormal mode. For asymptotically AdS theories it seems that the MS bound sets a lower bound on the DC conductivity for a given scattering time. Full paper available at: arXiv:1512.04401.

Alex Turzillo (California Institute of Technology)
"Classifying one-dimensional gapped quantum phases with tensor networks and TQFTs"

Matrix product states are known to efficiently approximate the ground states of one-dimensional gapped quantum systems. This fact allows one to classify gapped phases by counting the MPS tensors that are RG fixed points. Another approach to classification is to work with topological field theories, which also describe gapped systems at fixed points. I will establish a dictionary between these two frameworks that allows us to explicitly construct tensor networks for states of TQFTs. The categorical nature of the dictionary makes it possible to generalize. Equivariant TQFTs give rise to symmetric MPS models of symmetry enriched topological phases, while spin TQFT defines a fermionic MPS ansatz for gapped fermionic phases, related to symmetric MPS by bosonization. Upon restricting to invertible phases, the group cohomology and spin cobordism classifications are recovered.

Fri. June 3

Yasuaki Hikida (Ritsumeikan University)
"Higher spin holography and Higgs phenomenon"

Higher spin gauge theory is a generalization of low spin examples such as electromagnetism and general relativity, and it is expected to describe superstring theory by breaking its symmetry. We first analyze the symmetry breaking of higher spin AdS_4 gravity dual to the 3d critical $\mathrm{O}(N)$ vector model as a basic example. The symmetry breaking generates masses of higher spin fields, and the masses can be read off from the anomalous dimensions of dual currents, which were already obtained from dual CFT. Here we reproduce them utilizing the bulk Witten diagrams for the purpose to understand the mechanism of symmetry breaking from the bulk viewpoint. We then give our results on the masses for higher spin AdS_3 gravity obtained with essentially the same method. Applying our proposal on the relation to superstring theory, we discuss their interpretation in terms of superstring theory.

Jonathan Oppenheim (University College London)
"Do black holes create polyamory?"

Of course not, but if one believes that information cannot be destroyed in a theory of quantum gravity, then we run into apparent contradictions with quantum theory when we consider evaporating black holes. Namely that the no-cloning theorem or the principle of entanglement monogamy is violated. Here, we show that neither violation need hold, since, in arguing that black holes lead to cloning or non-monogamy, one needs to assume a tensor product structure between two points in space-time that could instead be viewed as causally connected. In the latter case, one is violating the semi-classical causal structure of space, which is a strictly weaker implication than cloning or non-monogamy. We show that the lack of monogamy that can emerge in evaporating space times is one that is allowed in quantum mechanics, and is very naturally related to a lack of monogamy of correlations of outputs of measurements performed at subsequent instances of time of a single system. A particular example of this is the Horowitz-Maldacena proposal, and we argue that it needn't lead to cloning or violations of entanglement monogamy. For measurements on systems which appear to be leaving a black hole, we introduce the notion of the temporal product, and argue that it is just as natural a choice for measurements as the tensor product. For black holes, the tensor and temporal products have the same measurement statistics, but result in different type of non-monogamy of correlations, with the former being forbidden in quantum theory while the latter is allowed. In the case of the AMPS firewall experiment we find that the entanglement structure is modified, and one must have entanglement between the infalling Hawking partners and early time outgoing Hawking radiation which surprisingly tame violation of entanglement monogamy.

Yasusada Nambu (Nagoya University)
"Probability of boundary conditions in quantum cosmology"

One of the main interest in quantum cosmology is to determine which type of boundary conditions for the wave function of the universe can predict observational data of our universe. For this purpose, we solve the Wheeler-DeWitt equation numerically and evaluate probabilities for an observable representing evolution of the classical universe, especially, the number of e-foldings of the inflation. To express boundary conditions of the wave function, we use exact solutions of the Wheeler-DeWitt equation with constant scalar field potential. These exact solutions include wave functions with well known boundary condition proposals, the no-boundary proposal and the tunneling proposal. We specify them introducing two real parameters which discriminate boundary conditions and estimate values of these parameters resulting in observationally preferable predictions. We obtain the probability for these parameters under the requirement of the sufficient e-foldings of the inflation.

Roberto Emparan (Universitat de Barcelona/ICREA)
"Black holes at large D: Things we've learned so far"

The dynamics of black holes and black branes greatly simplifies in the limit in which the number of spacetime dimensions D grows very large. I will give an overview of some of the main things we have learned and of results we have achieved so far in the development of this program.