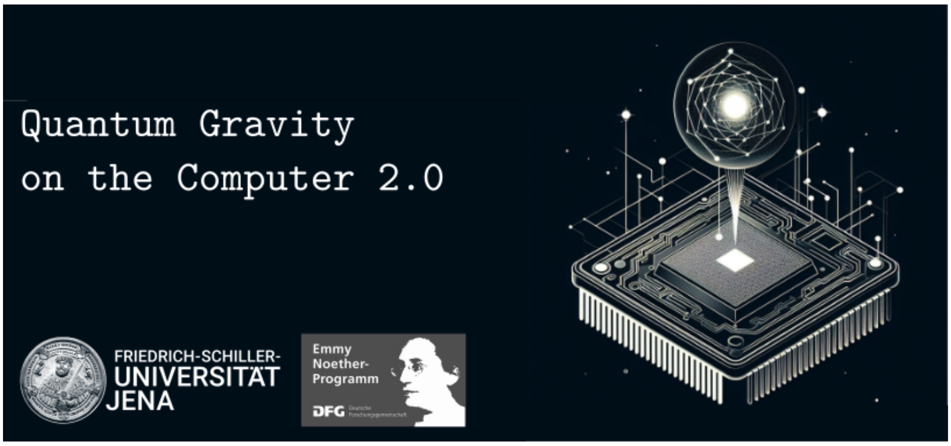
Quantum Gravity on the Computer 2.0

Monday 9 September 2024 - Friday 13 September 2024

TPI, FSU Jena



Book of Abstracts

Contents

1

Welcome

2

Computing Lorentzian scattering amplitudes in Asymptotic Safety

Scattering amplitudes in flat-space QFT are useful objects, as they connect first-principle computations to high-energy observables like cross sections, and thus do not suffer from gauge or regularisation ambiguities. For Asymptotic Safety, they can play a key role to investigate open questions about unitarity and causality.

In this talk, I will outline the computational challenges (and partial solutions) that one encounters on the path starting from the formulation of the Wetterich equation in Euclidean signature and ending at Lorentzian gravitational scattering amplitudes in Asymptotic Safety.

3

Relational Lorentzian Asymptotically Safe Quantum Gravity

The asymptotic safety (ASQG) and canonical (CQG) approach to quantum gravity have been developed to a large extent independent of each other. In this work we take first steps to bringing them into closer contact by working with the Lorentzian version of the functional renormalisation group of ASQG which we relate to the reduced phase space formulation of CQG.
Particular care is needed due to the necessary switch to Lorentzian signature which has strong impact on the convergence of "heat"kernel time integrals in the heat kernel expansion of the trace involved in the Wetterich equation and which requires different cutoff functions than in the Euclidean version.

4

Discussion

5

Towards the phase structure of the Barrett-Crane GFT model for 4d Lorentzian quantum gravity

The Barrett-Crane (BC) spin foam and GFT model is a state-sum model which provides a tentative quantization of first order Lorentzian Palatini gravity written as a constrained BF-theory. It is conjectured that this model gives rise to continuum spacetime with General Relativity as an effective description for the dynamics at criticality via phase transition. In this talk, we discuss how phase transitions in this model can be studied using Landau-Ginzburg mean-field theory. We demonstrate this by restricting the building blocks of the model such that the Feynman diagrams are dual to spacelike triangulations and then show how this is generalized when arbitrary Lorentzian building blocks are incorporated. As a main result, we demonstrate that the mean-field approximation of a phase transition towards a non-trivial condensate state can always be realized. In particular, we show that the critical behavior is entirely driven by spacelike faces which are characterized by the boost part of the Lorentz group. In contrast, timelike faces do not play a role in this as they are characterized by the rotational and thus compact part of the Lorentz group. Since such a state is typically populated by a large number of GFT quanta, our work lends further considerable support to the existence of a sensible continuum gravitational regime for causally complete GFT models. Finally, we note that this setting paves also the way for the analysis of the phase structure of this model via functional renormalization group techniques in future research. This work is based on arXiv:2112.00091, arXiv:2206.15442, arXiv:2209.04297 and arXiv:2211.12768, arXiv:2305.06136, arXiv:2404.04524 and arXiv:2407.02325.

6

Discussion

7

Poster session

8

Tensor network approach to 2D Lorentzian quantum Regge calculus

We demonstrate a tensor renormalization group (TRG) calculation for a two-dimensional Lorentzian model of quantum Regge calculus (QRC). This model is expressed in terms of a tensor network by discretizing the continuous edge lengths of simplicial manifolds and identifying them as tensor indices. The expectation value of space-time area, which is obtained through the higher-order TRG method, nicely reproduces the exact value. The Lorentzian model does not have the spike configuration that was an obstacle in the Euclidean QRC, but it still has a length-divergent configuration called a pinched geometry. We find a possibility that the pinched geometry is suppressed by checking the average length squared in the limit where the number of simplices is large. This implies that the Lorentzian model may describe smooth geometries. Our results also indicate that TRG is a promising approach to numerical study of simplicial quantum gravity.

9

Towards canonical LQG with neural networks: principles, toy models, next steps.

The problem of obtaining and interpreting solutions to the quantum Hamilton constraint of LQG is a long-standing and difficult one. We approach this problem with novel numerical methods from the context of neural networks, thereby taking the first step in applying deep learning methods in LQG.

We present the basic idea of parameterizing quantum states with a neural network, and of obtaining solutions to the constraints in this way. Then we consider U(1) BF theory and Smolin's weak coupling limit of 3d gravity as toy models to demonstrate the applicability of neural network quantum states (NNQS). The quantum theory is truncated by introducing a fixed graph and a cutoff on representations, to make it accessible for numerics. We show that NNQS can approximate solutions to the constraints, and that they can be used to go beyond the regime in which exact diagonalization methods are applicable. We also discuss limitations and the dependence on the truncation. In an application that points beyond the toy model, we compare approximate solutions of Thiemann's regularization of the Hamilton constraint with a more naive one and show quantitatively that they have more in common than one might expect.

We finish by giving an outlook on the next steps and the challenges for applying the methods to more physically relevant models.

10

Discussion

11

Calculating volume and full Hamiltonian operator in LQG: from semiclassical to quantum

In loop quantum gravity (LQG), the volume operator plays a crucial role in the study of quantum geometry and quantum dynamics. However, the effect of the volume operator is studied only for some simple cases. In this talk, we introduce a numerical algorithm that can give the matrix elements of the volume operator on arbitrary valent gauge-variant and gauge-invariant spin network states and their corresponding coherent states. Moreover, we propose an improved version of the semiclassical perturbation theory of the volume operator, which gives the correct semiclassical approximation to the matrix elements and the gauge invariant expectation values. Our numerical algorithm verifies the result and links the full quantum evaluation to the semiclassical regime. Based on this analysis, we implement an algorithm for the computation of the matrix elements of the full Hamiltonian operator with the Lorentzian term on arbitrary spin network states and for the computation of its semiclassical expectation value on the corresponding coherent states. This opens the possibility to study the genuine full quantum dynamics in LQG. Examples of cosmological perturbations based on the semiclassical perturbation theory of full LQG can be discussed.

12

Lessons from lattice QCD

In this talk, I will provide a short introduction to lattice gauge theory, its history, and current challenges. I will try to draw connections to the developments of quantum gravity and possible lessons to be learned.

13

Discussion

14

Quantum dynamics in Causal Set Theory

Causal Set Theory is a Lorentzian approach to quantum gravity in which spacetime is fundamentally discrete. Lorentzian discreteness poses an obstruction for a Hamiltonian formulation of dynamics, but it is well-suited for exploring dynamics in the spirit of the path integral. This talk will focus on the Decoherence Functional, a generalisation of the probability measure that encodes quantum interference. We will illustrate how one can obtain a Decoherence Functional that describes the quantum dynamics of a causal set spacetime (via the Complex Growth models prescription) and introduce the Decoherence Functional for scalar quantum field theory on a fixed causal set background.

15

Discreteness and Causality : Causal Sets on the Computer

The causal set approach to quantum gravity is a theory of locally finite posets with a very specific continuum approximation. It is motivated by a unique feature of Lorentzian geometry, namely the causal structure poset which captures the full conformal geometry. Being a discrete theory of spacetime, it lends itself rather naturally to computer simulations and numerics, albeit with a characteristic nonlocality. Because of this, the standard tools of lattice and simplicial geometry need to be replaced with those that are purely order theoretic. I will discuss the progress made over the years in both the kinematics and dynamics of causal set theory using computational methods and end with the very many open avenues left to be explored.

16

Discussion

17

sl2cfoam-next: how to calculate exact Lorentzian spinfoam amplitudes

Spinfoams provide a rigorous definition of transition amplitudes in quantum gravity. I will present the code sl2cfoam-next that I developed to calculate Lorentzian spinfoam amplitudes on the computer, showcasing its basic usage, its strengths and limitations and a few important applications so far.

18

Cosmological Dynamics from Covariant Loop Quantum Gravity with Scalar Matter

We numerically study homogenous and isotropic quantum cosmology using the spinfoam formalism of Loop Quantum Gravity (LQG). We define a coupling of a scalar field to the 4-dimensional Lorentzian Engle-Pereira-Rovelli-Livine (EPRL) spinfoam model. We employ the numerical method of complex critical points to investigate the model on two different simplicial complexes: the triangulations of a single hypercube and two connected hypercubes. We find nontrivial implications for the effective cosmological dynamics. In the single-hypercube model, the numerical results suggest an effective Friedmann equation with a scalar density that contains higher-order derivatives and a scalar potential. The scalar potential plays a role similar to a positive cosmological constant and drives an accelerated expansion of the universe. The double-hypercubes model resembles a symmetric cosmic bounce, and a similar effective Friedmann equation emerges with higher-order derivative terms in the effective scalar density, whereas the scalar potential becomes negligible.

19

Discussion

20

Voice of the young

TBA

21

The notion of topology and dimension in lattice quantum gravity

The developments of the past decades in computational power allowed us to implement numerical simulations to test the impact of the fluctuations of gravity furthermore to see if there are any interesting effects when one couples matter systems to it. In my talk I will present results regarding coupling matter fields to CDT including scalar and gauge fields. Only the scalar fields were minimally coupled, the gauge fields are only tested in the quenched approximation. Using matter fields one can strengthen the results of the four-dimensional nature of the observed deSitter spacetimes furthermore discuss the meaning of topology and dimensions in lattice theories of geometries. When there is an interaction between matter and geometry those two observables are not trivial.

22

Improved algorithm for dynamical triangulations and simulations of finer lattices

I will first briefly introduce Euclidean dynamical triangulations with a non-trivial measure term and motivate the need for an algorithm that is more efficient than a standard Metropolis algorithm. I will then introduce the concept of rejection-free algorithms, and discuss generalizations that are necessary to employ those algorithms for EDT. I will test the generalized algorithm on the 2d Ising model, and against results for EDT obtained with standard Metropolis. If time permits, I will comment on results obtained with the new algorithm, where we find that geometries approximate semiclassical Euclidean de Sitter space better for finer lattice spacings.

23

Discussion

24

Closing remarks

25

Quantum Gravity on the computer - Challenges

26

Discussion

27

Conference Dinner

The workshop dinner will take place on Thursday, September 12th, 19:30, at the restaurant "Cafeteria zur Rosen", Johannisstraße 13, 07743 Jena.

For more information, see https://indico.tpi.uni-jena.de/event/386/page/42-conference-dinner.