Discussion led by Alok

We list the questions and some salient points of the discussion that followed.

1. What is canonical gravity good for?

   - There's no spacetime to begin with, so need to build it
   - Role of spacetime diffeomorphisms in string field theory
   - Build string theory target space from solutions to Wheeler-deWitt (WdW) equation
   - What does LQG achieve, say in 2d?
   - Most older work ignored boundaries

   (a) Does it account for topology change and signature change?

   - Using Ashtekar variables, LQG corrections to canonical answers can sometime be solved numerically. This provides a natural change from Lorentzian to Euclidean signature

     References: Bojowald et. al
     (i) Deformed GR and Effective Actions from LQG
     (ii)Some implications of signature-change in cosmological models of LQG

2. Anomaly in the constraint algebra

   - In the constraint algebra (specifically in the commutator of Hamiltonian constraint with itself), there arises a field dependent structure constant. So it's not a Lie algebra
   - Role of anomaly free constraint algebra in the quantum theory (even semi-classically)
   - LQG manages to find operators that represent the algebra. However, these are complicated and the physical meaning of the resulting states is unclear.
   - Is taking the constraint algebra seriously at the non-perturbative level a bad idea?

   (a) Non-renormalization of gravity and the problem of time

   - Non-renormalizable even perturbatively
   - Subtleties in non-perturbative gravity
     - Choice of internal time
     - If the same wavefunction has different branches, can you make a consistent choice of time in each branch?

(b) Reduction and quantization: ordering

- This is the standard string theory approach. For example, while quantizing the Bosonic string on $S_1 \times R$ ala Polyakov
- However, there are other approaches to quantization which give different results. Some of these are listed below:

i. Dirac quantization of 2-d gravity with "D" scalar fields
References, by Kuchar and Torre:
(i) Worldsheet diffeomorphisms and the canonical string
(ii) Strings as poor relatives of relativity

ii. Dirac quantization of Nambu-Goto string
References:
(i) Pohlmeyer, A group-theoretical approach to the quantization of the free relativistic closed string
(ii) Dorothea Bahns, The invariant charges of the Nambu-Goto String and Canonical Quantization
(iii) Urs Scheiber, DDF and Pohlmeyer invariants of (super)string

- Can we take these quantizations seriously and ask what are the spacetime interpretations?

(c) Problem of time

i. Can we deparametrize a gravitational system?
- Kuchar decomposition
- Find a canonical transformation in phase space that naturally finds an emergent time
- References for examples of Kuchar decompositions:
(i) Hajicek and Ambrus, Embedding variables in finite dimensional models
(ii) Hajicek and Kouletski, Pair of null gravitating solutions, Parts 1 , 2 and 3

ii. Relational time
- Scalar field coupled to GR as the clock
- GR + incoherent dust
Reference:
(i) Brown and Kuchar, Dust as a standard of space and time in canonical quantum gravity

Discussion led by Onkar

Focus on lower dimensional models

1. Canonical quantization in JT gravity
   - Phase space variables in the "length" basis: (ℓ, P)
   - From AdS/CFT, expect an isometric map between bulk and boundary Hilbert spaces $V : \mathcal{H}_{bulk} \to \mathcal{H}_{CFT}$

   (a) What is V?
   - What are boundary duals of length basis states $V|\ell\rangle$?

   i. One answer: $|\ell\rangle = \int dE f(E,\ell)|E\rangle \xrightarrow[finite\ N]{discrete} \sum_i f(\ell, E_i)|E_i\rangle$

   ii. Another answer: Krylov basis $B = \{|\Omega\rangle, H|\Omega\rangle, ...\}$

   (b) What does internal time evolution look like in the dual?
   i.e. reparametrize boundary dynamics to get bulk evolution.

   (c) What is special about the boundary dual of the length basis?
   - Is there a way to discover AdS/CFT?
   - Does it minimize a basis dependent quantity?
     i. Minimize "spread"
     ii. Minimize "non-classicality"

   (d) How does entanglement get geometrized in this basis?

Discussion led by Sandip

1. Path integral is ill-defined so canonical
   - Sidnely Coleman: Universe probably has $\Lambda = 0$
2. Cosmology
   - Problem of time
   - What is $|\psi\rangle_{universe}$?
   - What are observables/observers?
3. Lower-dimensional models
   - Path integral and canonical
4. Blackhole Physics
   - Information loss using canonical quantization

General discussion

- Can we do QFT with relational time?
  - Parametrized field theories
- How to deal with clocks disintegrating?
- In a closed universe, deparametrize GR and find $E \neq 0$ states?
  - Look at the York Hamiltonian in JT-dS: Find eigenstates, normalize with well-defined inner product.
- Canonical quantization of JT gravity in I order formalism?
  - Blommaert, Mertens, Verschelde, Fine Structure of JT Quantum Gravity
  - Kolchmeyer, Jafferis Entanglement Entropy in JT Gravity
  - Iliesiu, Pufu, Verlinde, Wang An exact quantization of JT gravity
- Explicit violation (via some process) of global symmetry in any solvable model of quantum gravity?
- Can we do constraint analysis in $f(R)$ theories of gravity?
  - Ezawa, Iwasaki et. al A canonical formalism of $f(R)$ type of gravity
- What do we give up in canonical quantization of gravity if we were to include topology change?