THE GROUP FIELD THEORY APPROACH TO QUANTUM GRAVITY: 
A QFT FOR THE MICROSTRUCTURE OF SPACETIME

Daniele Oriti

Max Planck Institute for Gravitational Physics (Albert Einstein Institute)
Golm, Germany, EU

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Quantum Gravity as a QFT for the “Atoms of Space”?

- Main lesson from GR: "Gravity is spacetime geometry", thus spacetime is itself a physical system
- Quantum Gravity not so much a quantization of GR, but a microscopic quantum theory of the spacetime structure (“atomic theory of space”)
- QFT is best formalism we have for microscopic physics (particle and atomic physics, condensed matter,…) → a QFT for quantum gravity?
- A QFT on which space?
  - QG should explain origin and properties of spacetime itself (geometry and topology?) → background independence!
  - it can be only be a QFT on some auxiliary, internal or “meta-space”
- a QFT of what? what are the fundamental quanta?
  - quanta of space itself! fundamental excitations of space around the vacuum (nothing = not even space)
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- complex field $\phi$ over $D$ copies of a group manifold $G$ (e.g. Lorentz group, for QG): $\phi(g_1, \ldots, g_D) : G \times \ldots \times G \rightarrow \mathbb{C}$
- field can be expanded in modes $j$ (irreducible representations of $G$)
- $\phi \simeq$ building block of quantum geometry - $(D-1)$-simplex or spin network vertex

Field action:

$$S_D(\phi, \lambda) = \int dg_i d\tilde{g}_i \phi(g_i)K(g_i, \tilde{g}_i^{-1})\phi(\tilde{g}_i) + \lambda \int dg_{ij} \phi(g_{1j}) \ldots \phi(g_{D+1j}) \mathcal{V}(g_{ij})$$

- combinatorics of arguments in $\mathcal{V}$ reflects gluing of $(D-2)$-faces in a $D$-simplex,
  $K \rightarrow$ gluing of $D$-simplices along $(D-1)$-simplices
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\[ Z = \int \mathcal{D}\phi \, e^{iS[\phi]} = \sum_{\Gamma} \frac{\lambda^{N\Gamma}}{\text{sym}[\Gamma]} Z(\Gamma) \]

- Feynman diagrams $\Gamma$ are simplicial complexes of arbitrary topology
- $Z(\Gamma) \sim$ discrete and algebraic (only group and representation theory) QG path integral $\rightarrow Z(\Gamma) \sim'' \int \mathcal{D}g_{\Gamma} \, e^{iS_{\Gamma}(g)}''$
- Quantum Gravity formulated as a sum over simplicial complexes (discrete spacetimes) of all topologies, as interaction processes, weighted by a simplicial gravity path integral formulated in algebraic terms
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- **Loop Quantum Gravity and spin foam models:**
  - GFT states are Spin Networks, the quantum states of geometry as identified by LQG
  - GFT Feynman amplitudes are Spin Foam models (sum over histories of spin networks)

- **Quantum Regge Calculus**: a single GFT Feynman amplitude defines discrete QG path integral (related to Regge theory in various ways)

- **Dynamical Triangulations**: GFT describes QG (perturbatively) as sum over triangulations, weighted by discrete action

- ......plus ideas and tools from non-commutative geometry

At the same time, GFTs offer new tools, and a new perspective on continuum/classical approximation......
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Problem of the continuum in discrete QG: continuum geometry from atoms of space?
**WHENCE THE CONTINUUM?**

- **GFT** as fundamental (atomic) theory for the micro-structure of quantum space
- study the corresponding “many particle” regime
- ideas and tools from condensed matter theory and analog gravity models:
  - spacetime as a quantum condensate/liquid phase of fundamental discrete constituents + geometry as an emergent concept
- so:
  - study GFT phases ad phase transitions → geometrogenesis as GFT condensation?
  - continuum spacetime ≡ fluid phase, i.e. intertwiners/(D-1)-simplices condense to form a fluid-continuum
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  - (modified) General Relativity from GFT hydrodynamics?
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Microscopic GFT
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Statistical GFT $\rightarrow$ GFT fluid, GFT hydrodynamics

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Effective continuum spacetime and geometry

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astrophysics, particle physics, cosmology
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**MESSAGES:**

- Quantum Space could be understood as a “background independent condensed matter system”
- Group Field Theories are a candidate microscopic description of the properties and dynamics of the atoms of space, in simplicial, algebraic language
- GFTs are **unifying** framework for discrete approaches to quantum gravity
- **continuum spacetime is a fluid of GFT quanta**, and geometry emerges as a collective, effective variable in the fluid phase
- **(modified) GR emerges from GFT hydrodynamics**
- in progress........................so.........stay tuned!