Overview of Loop Quantum Gravity

and open gauge field systems

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Presentation plan

- Motivation and problems of quantizing gravity
- General relativity as $SU(2)$ gauge theory
- Construction of states - Quantum Mechanics "over" GR
- Quantum geometry
- Predictions and issues of LQG
- Our contribution - open systems in LQG
- Loop quantization in other gauge theories

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  - Black hole evaporation and information loss

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- $\Rightarrow$ A new framework is needed to describe spacetime geometry in the quantum regime.

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Einstein-Hilbert action (metric formulation)

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Key point: GR is a fully constrained system

- No true Hamiltonian evolution
- Dynamics generated by constraints (gauge symmetries)

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These exhaust the configuration variables from GR, but we still have the momenta - extrinsic curvature K_{ab}.

A conjugate variable has to be introduced for quantization

In similar spirit we can introduce

$$K_a^i := K_{ab} e^{bi},$$

but it turns out that more suitable variable is:

$$A_a^i := \Gamma_a^i + \gamma K_a^i,$$

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This gives us the canonical pair:

$$\{A_a^i(x), E_j^b(y)\} = \gamma \delta_a^b \delta_j^i \delta(x-y),$$

$$\{A_a^i(x), A_b^j(y)\} = \{E_i^a(x), E_j^b(y)\} = 0.$$

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Our variables are distributions so we introduce smearing.

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which give us symplectic structure we are able to effectively quantize

$$[h_e, F^i_S] = iC h_{e_1} \tau^i h_{e_2}, \quad e_1 \circ e_2 = e$$

We build quantum mechanics from operators over a phase space

So we have operators formulated on an underlying $SU(2)$ space. This is the same as constructing $[x, p] = i\hbar$ from the classical phase space $\{x, p\}$ on $\mathbb{R}^{2n}$ phase space.

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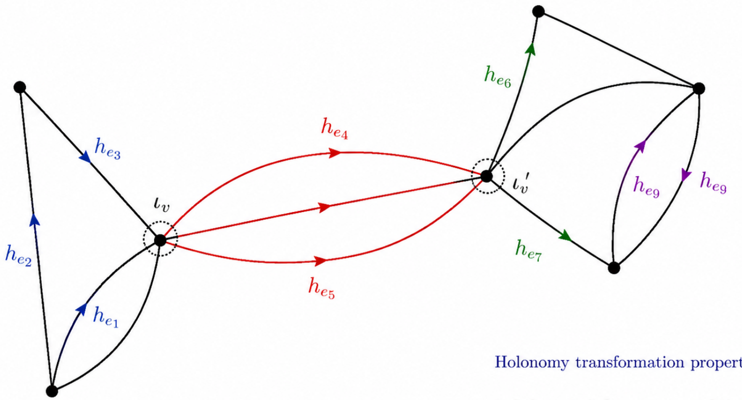
Since holonomies amount to parallel transporting from a point to another, and transform as

$$h_e[A]' = U_s h_e[A] U_t^\dagger,$$

the gauge invariant Cyl functions are going to form networks.

Gauge covariance condition leads to networks



Holonomy transformation property:

$$h_e[A] \to h_e[A]' = U_{s(e)} \;\; h_e[A] \; U^{-1}_{t(e)} \,,$$

$U(x) \in \mathrm{SU}(2)$

$s(e),\, t(e)$: source and target of edge e

◌ = invariant tensor (intertwiner) $\iota_v \in Inv\left(\bigotimes_{e \supset v} V_{j_e}\right)$

V_{j_e} : SU(2) representation space on edge e (spin j_e)

We define a Hilbert space over networks

- Cylindrical states on a graph Γ with L edges:

$$\Psi_{\Gamma,f}[A] = f(h_{e_1}[A], \ldots, h_{e_L}[A]), \quad f : SU(2)^L \to \mathbb{C}.$$

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- Using the Haar measure on $SU(2)$, define the Ashtekar–Lewandowski measure and scalar product:

$$\langle \Psi_{\Gamma,f}, \Psi_{\Gamma,g} \rangle = \int_{SU(2)^L} \prod_{e=1}^{L} dh_e \, \overline{f(h_1, \ldots, h_L)} \, g(h_1, \ldots, h_L).$$

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- By Peter–Weyl on Γ:

$$\Psi_{\Gamma,f}[A] = \sum_{\{j_e, m_e, n_e\}} f^{\{j_e\}}_{\{m_e\},\{n_e\}} \prod_{e=1}^{L} D^{j_e}_{m_e n_e}(h_e[A]).$$

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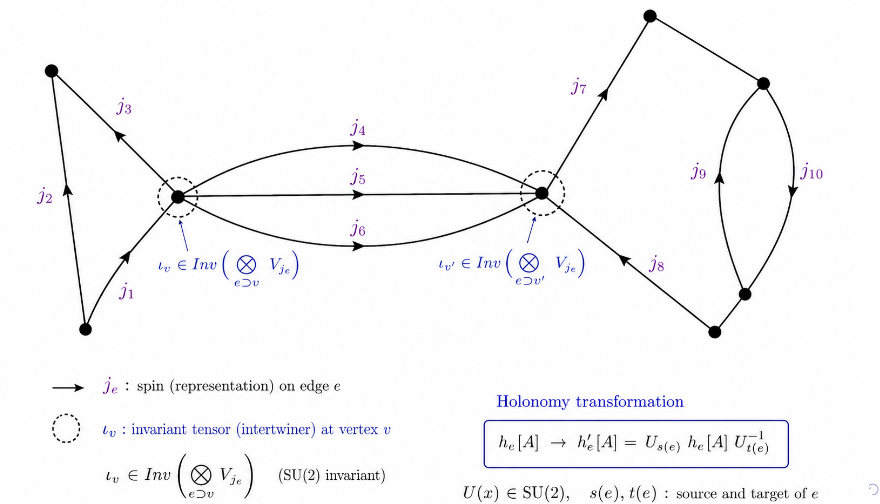
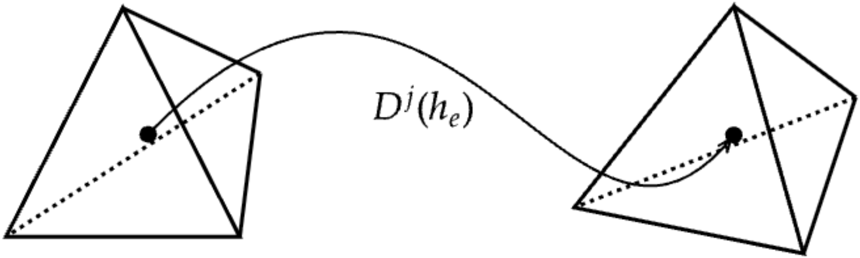
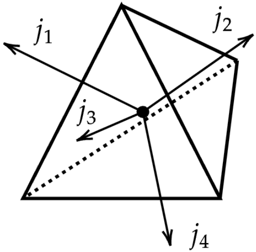


Representations of holonomies are related to quantum geometry



Quantum geometry of spin networks is consistent with Gauss law



$$Area = \int_S d\sigma^2 \sqrt{E^i_a E^j_b \delta_{ij} n^a n^b}$$

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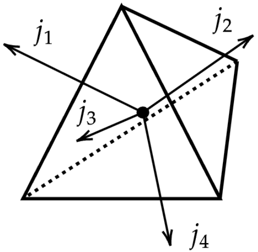

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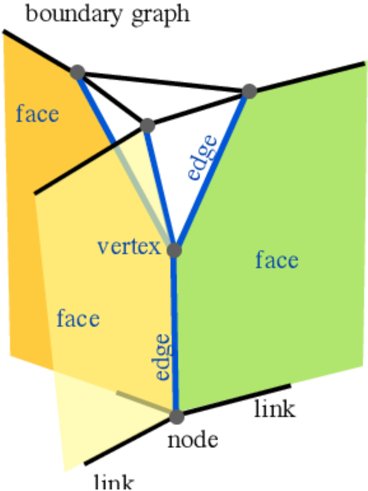
Gauss constrint is consistent with geometric requirement of closed polyhedra

$$\sum_e \vec{j}_e = 0.$$

Dynamics of spin networks form spinfoams



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Main predictions:

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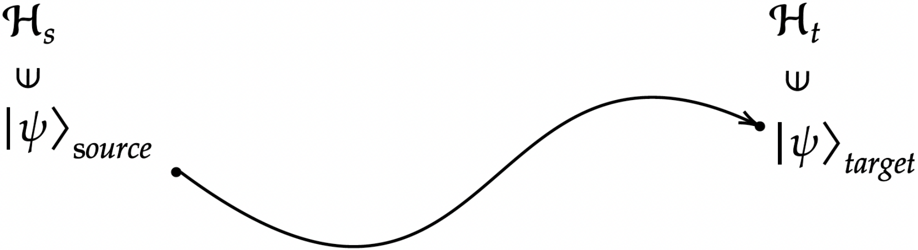
- Lack of experimentally testable predictions at accessible energy scales.

In our work we introduce external influence on the connections



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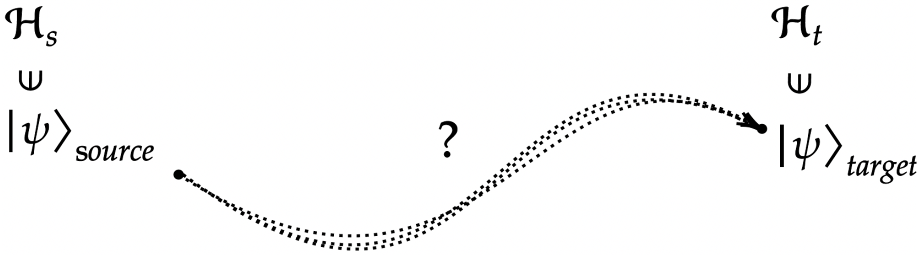

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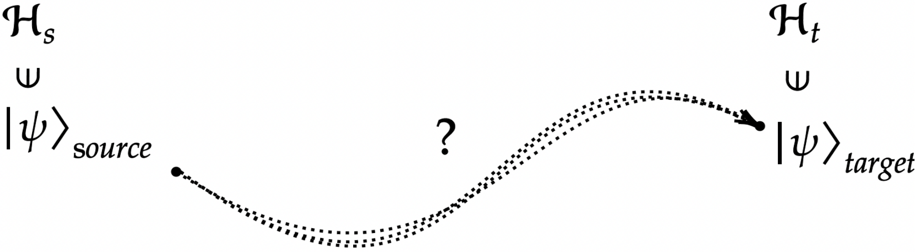

Introducing noise has more benefits than it first seems

Noise also lets us model decoherence, and thus possibly the classical limit.

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- Leads to quantum channels (CPTP maps):

$$\rho_S \mapsto \Lambda(\rho_S) = \sum_i K_i \rho_S K_i^\dagger$$

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- Spin network $\Rightarrow$ network of quantum channels

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- Kinematical Hilbert space:

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- Gauge invariance imposed via intertwiners as in standard LQG

We are utilizing a pushforward map from unitary holonomies

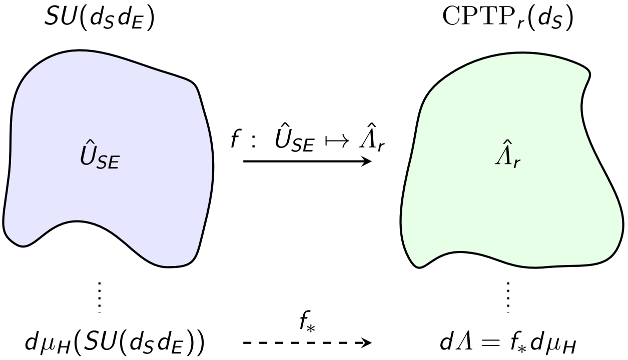

Figure: A diagram of mappings used in our formulation.

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- Possible interpretation:
  - effective matter sector
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Thank you for your attention!