Effective quantum gravity from the point of view of perturbative algebraic QFT

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Outline of the talk

1. Algebraic approach to QFT
   - AQFT
   - LCQFT

2. Quantum gravity
   - Effective quantum gravity
   - Symmetries
   - Background independence
A convenient framework to investigate conceptual problems in QFT is the **Algebraic Quantum Field Theory** (recently also perturbative AQFT).
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The physical notion of subsystems is realized by the condition of **isotony**, i.e.: $\mathcal{O}_2 \supset \mathcal{O}_1 \Rightarrow \mathcal{A}(\mathcal{O}_2) \supset \mathcal{A}(\mathcal{O}_1)$. We obtain a **net of algebras**.
Difficulties in QFT on curved spacetimes

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- Problems with the Fourier transform: calculations relying on momentum space cannot be performed.
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- Algebras $\mathcal{A}(\emptyset)$ are constructed using only the local data.
- Local features of the theory (observables) are separated from the global features (states).
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- Require that $\psi$ preserves orientations and the causal structure (no new causal links are created by the embedding).
- Assign to each spacetime $\mathcal{M}$ an algebra $\mathcal{A}(\mathcal{M})$ and to each admissible embedding $\psi$ a homomorphism of algebras $\mathcal{A}\psi$ (notion of subsystems). This has to be done covariantly.
Locally covariant fields

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- Let $\mathcal{D}(\mathcal{O})$ denote the space of test functions supported in $\mathcal{O}$. An **LC field** is a family of maps $\Phi_M : \mathcal{D}(\mathcal{M}) \to \mathcal{A}(\mathcal{M})$, labeled by spacetimes $\mathcal{M}$ such that:

  $$\mathcal{A}\psi(\Phi_\mathcal{O}(f)) = \Phi_\mathcal{M}(\psi*f)[h].$$

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$\psi$ $\psi^{-1}$

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Let $\mathcal{D}(\Theta)$ denote the space of test functions supported in $\Theta$. An **LC field** is a family of maps $\Phi_M : \mathcal{D}(M) \rightarrow \mathcal{A}(M)$, labeled by spacetimes $M$ such that:

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- Locally covariant fields are candidates for observables in GR.
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- "Points" lose their meaning. The theory is invariant under diffeomorphism transformations.
- As a QFT, quantum gravity is power counting non-renormalizable.
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- **Dynamical nature of spacetime**: make a split of the metric into background and perturbation, quantize the perturbation as a quantum field on a curved background, show background independence at the end.

- **Diffeomorphism invariance**: use the BV formalism to do the gauge fixing. Possible difficulties: base manifold is Lorentzian and non-compact, symmetry group is infinite dimensional, so is the space of metrics.
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Think of the measured observable as a function of a perturbation of the fixed background metric:

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\tilde{g}_{\mu\nu} = g_{\mu\nu} + h_{\mu\nu}.
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Building models in LCQFT

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We work all the time on the same set of functionals, but we equip it with different algebraic structures (i.e. Poisson bracket, non-commutative $\star$ product).
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$$\Phi_M : \mathcal{D}(\mathcal{M}) \to \mathcal{F}(\mathcal{M}), \text{ where } \mathcal{M} \equiv (M, g).$$

Let $\xi \in \Gamma(TM)$ be an infinitesimal diffeomorphism. It acts on $\Phi_{(M,g)}(f)$ as

$$(\rho(\xi)\Phi)_{(M,g)}(f)[h] =$$

$$\left\langle (\Phi_{(M,g)}(f))^{(1)}[h], \mathcal{L}_\xi(g + h) \right\rangle + \Phi_{(M,g)}(\mathcal{L}_\xi f)[h]$$
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Example: $\int R[g + h] f \, d\mu_{g+h}$ is diffeomorphism invariant, but $\int R[g + h] f \, d\mu_g$ is not.
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- Denote such metric dependent coordinates by $X_g^\mu + h$.
- Each $\Phi_f$ induces a relational observable $g \mapsto \Phi_f(h, X_{g+h})$.  

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Let $\mathcal{N}_+$ and $\mathcal{N}_-$ be two spacetimes that embed into two other spacetimes $\mathcal{M}_1$ and $\mathcal{M}_2$ around Cauchy surfaces, via admissible embeddings $\chi_{k,\pm}, k = 1, 2$. 

$\begin{align*}
\beta &= A\chi_1 + \circ (A\chi_2 + \circ (A\chi_1 - \circ (A\chi_2 - \circ (A\chi_1 - \circ (A\chi_2))))) \\
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Then
\[
\beta = \mathcal{A}\chi_{1+} \circ (\mathcal{A}\chi_{2+})^{-1} \circ \mathcal{A}\chi_{2-} \circ (\mathcal{A}\chi_{1-})^{-1}
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is an automorphism of $\mathcal{A}(\mathcal{M}_1)$. This is the consequence of the Time-slice axiom of LCQFT.
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We have shown that our theory is \textbf{background independent}, i.e. independent of the split into free and interacting part.
Thank you for your attention!