Gauge-invariant observables in perturbative quantum gravity

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It is well known that the diffeomorphism invariance of gravitational theories makes it impossible to define local and gauge-invariant observables in perturbative (quantum) gravity, except at linear order. While in flat space on can study the S-Matrix, which is a gauge-invariant global observable, no analogue exists in a general curved space. Relational observables (i.e., the value of one field at the point where a second field has a prescribed value) are natural candidates for observables in (quantum) gravity, but they are not local when constructed around flat space or around a cosmological (FLRW) background spacetime due to the high symmetry of the latter.
We present two different approaches to this problem: a) correlation functions at fixed geodesic distance, and b) a construction of invariant coordinates, for which explicit and fully renormalized results for one-graviton-loop corrections to two- point functions and coupling constants have been obtained. While the former does not seem viable, the latter approach has a number of advantages:

- it can be computed algorithmically up to arbitrary orders in perturbation theory,
- it is renormalizable, and gives finite results without uncontrolled approximations and/or smearings,
- it is independent of the dynamics of the gravitational theory, and thus can be used to compare different models of gravity and inflation including corrections from graviton loops,
- it reduces at linear order to the well-known gauge-invariant cosmological perturbations.