Title: HPC in Quantum Gravity

Date: May 07, 2014 12:10 PM

URL: http://pirsa.org/14050037

Abstract: Application of numerical simulations to quantum gravity are so far largely neglected yet they possess remarkable potential to learn more about the theory. For approaches that attempt to construct quantum spacetime from fundamental microscopical building blocks e.g. spin foam models the collective behaviour involving many building blocks is unexplored.Therefore we numerically simulate the collective dynamics of many of these building blocks using coarse graining techniques i.e. tensor network renormalization and uncover a rich structure of fixed points with extended phases and phase transitions. Ref.: arXiv:1312.0905 [gr-qc]

HPC in Quantum Gravity

based on: arXiv:1312.0905

by Bianca Dittrich, Mercedes Martin-Benito and S. St.

Sebastian Steinhaus

Perimeter Institute f. Theoretical Physics

May 07 2014

Compute Ontario Research Day

Quantum Gravity

- Gravity is the last fundamental interaction resisting quantization
  - Perturbatively non-renormalizable
- Challenge: Give meaning to the gravitational path integral

$$\int_{\partial M} Dg \, \exp\{i S_{E-H}[g]\}$$

- Many approaches tackling this issue (to name a few):
  - Loop quantum gravity / Spin foam models
  - Asymptotic safety
  - Causal dynamical triangulations
  - Causal sets
  - String theory
- Some of them introduce a discretization $\rightarrow$ numerical studies?

Spin foam models: 'lattice gauge gravity'

What is a spin foam?

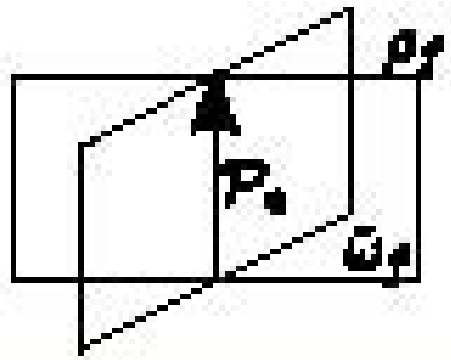
Spin foams: path integral approach related to Loop Quantum Gravity

[Barrett, Crane, Rovelli, Reisenberger, Engle, Livine, Perez, Freidel, Krasnov, ...]

- Generalized lattice gauge theories ($SO(4)$ or $SL(2,\mathbb{C})$) [Bahr, Dittrich, Hellmann, Kaminski '13]:

$$Z = \sum_{\rho_f} \left(\prod_f \tilde{\omega}_f(\rho_f) \right) \prod_\sigma \mathcal{P}_\sigma(\{\rho_f\}_{f \supset \sigma})$$

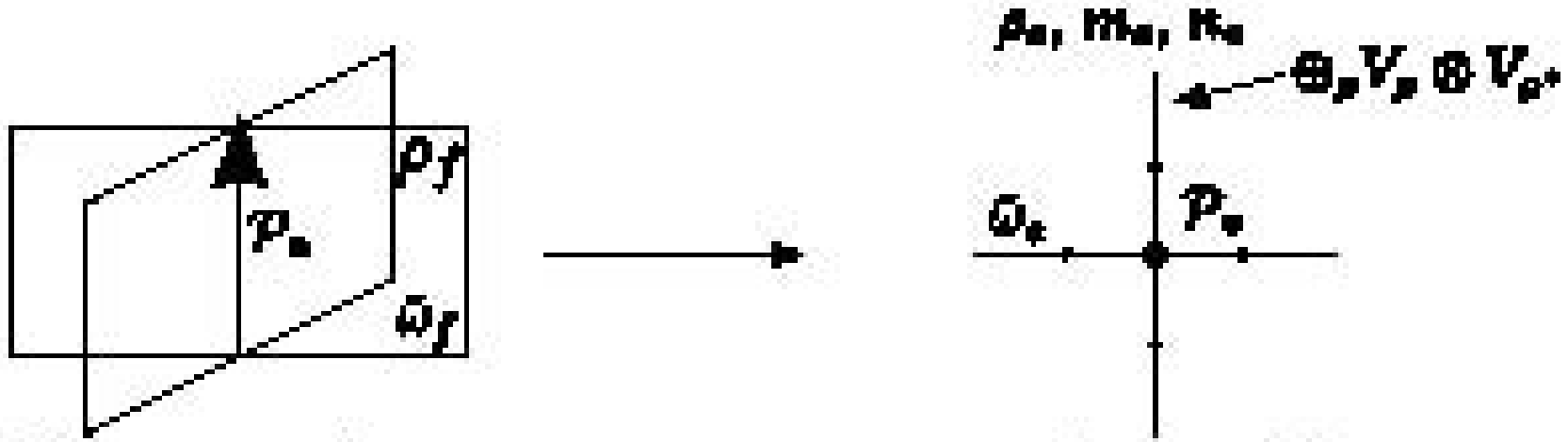
  - Irreducible representations ρ_f on the faces f.
  - Face weights $\tilde{\omega}_f$ on faces f.
  - Projectors $\mathcal{P}_\sigma$ onto (a subspace of) $\mathrm{Inv}(\otimes_{f \supset \sigma} V_{\rho_f})$.



How to compute Z?

Is there more structure / phases than in LGT?

Analogue spin foam models – spin nets[1]



lattice gauge theory in dual variables

vertex model in dual variables

- Dimensional reduction:
  - Gauge symmetry (Spin foam model) → global symmetry (spin net model)
- Replace SU(2) by quantum group $SU(2)_k$:
  - Irreps. $0, \frac{1}{2}, 1, \ldots, \frac{k}{2}$.

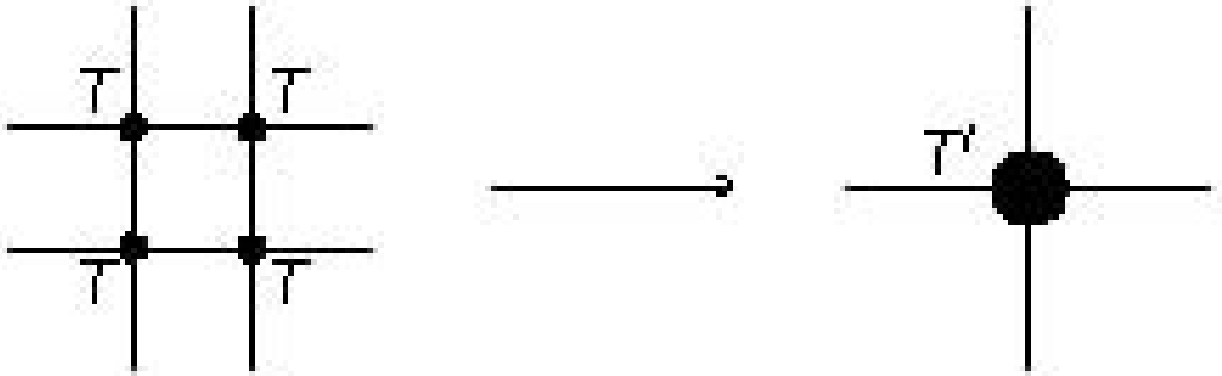
Quantum group spin nets.

[1] [Dittrich, Eckert, Martin-Benito '11], [Dittrich, Martin-Benito, Schnetter '13]

Constructing quantum spacetime

Conceptual difference: no background (lattice) structure!

- Spin foam amplitudes: 'atoms of spacetime'
- Study effective dynamics – coarse graining:

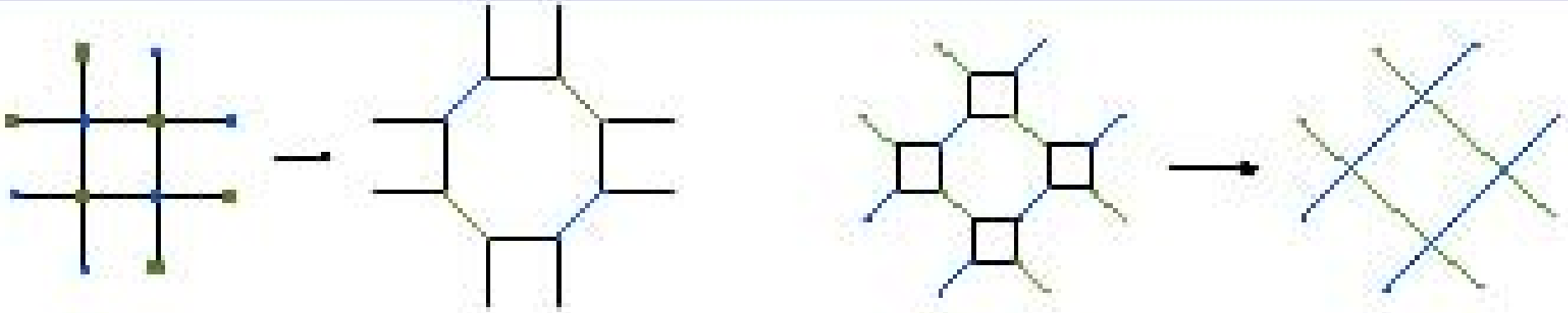


$$Z^{T}_{\text{finer}} \approx Z^{T'}_{\text{coarser}} \quad .$$

- Identify relevant degrees of freedom, truncate irrelevant ones.

Real space renormalization techniques –
Tensor network renormalization

The algorithm - General description [illegible]



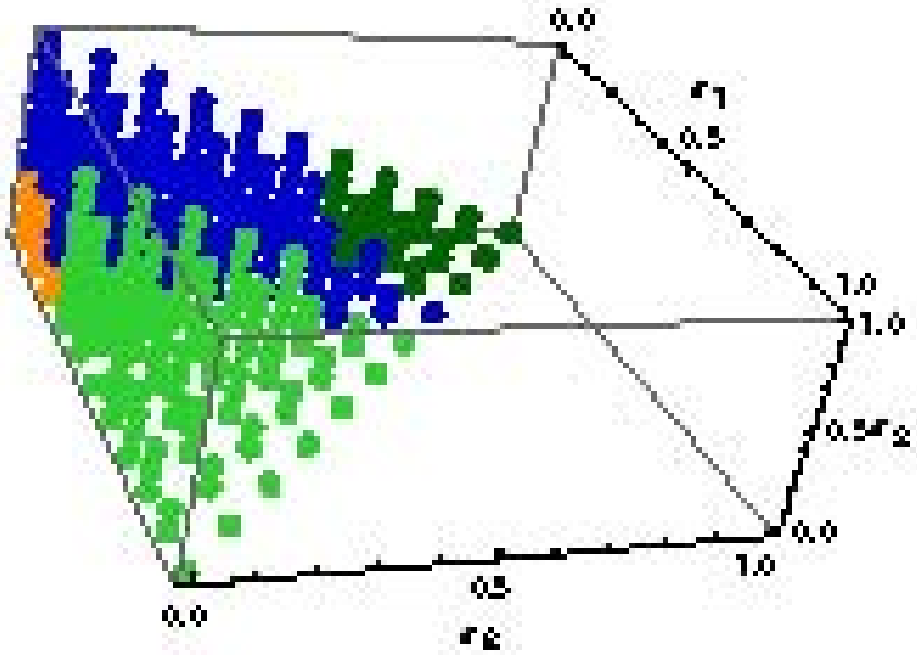
- Split the 4-valent vertices into two 3-valent vertices via Singular Value Decomposition (SVD):

$$T_{(ab)(cd)} =: M_{AB} \approx \sum_{i=1}^{\chi<N} U_{Ai} \lambda_i (V)^{\dagger}_{iB} \quad .$$

- Truncation in the number of singular values $\chi < N$, bond dimension.
- Contract 3-valent tensors (along black edges) to obtain a new effective tensor on a new 4-valent lattice.

SVD identifies the relevant degrees of freedom.

Results: phase diagram (for $SU(2)_8$)



- Rich non-trivial fixed point structure beyond (analogue) LGT.
- Each fixed point has an extended phase.
- Indications of second order phase transitions.

Much more structure than in LGT!

Conclusions

- HPC opens a new door in Quantum Gravity.
- Encouraging results!
  - Explore the phases of (analogue) spin foam models via tensor network renormalization.
  - Rich fixed point structure with extended phases
- Long way to go...
  - Develop algorithm for spin foam models
  - Study phase transitions in more detail
  - Study $SU(2)_k \times SU(2)_k$
  - Couple matter to the spin foam model
  - Compute expectation values of observables

Thank you for your attention!