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Imperial College
London

Supervisor: Prof Fay Dowker
Theoretical Physics Group

ON THE ENTROPY OF A DISCRETE BLACK HOLE

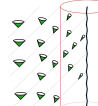
Vid Homsak, Stefano Veroni

The Causal Set Approach to Quantum Gravity

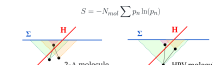
GEOMETRY = ORDER + NUMBER!
Causal structure and the discreteness scale uniquely define spacetime (HRTM theorem^{2,3}).
Causal Set Theory³ assumes that the continuous spacetime emerges as a macroscopic approximation to an underlying causal set, a discrete (partially ordered) set of events C with an order relation \prec . A causal set (causet) satisfies $(\forall x, y, z \in C)$:
• Transitivity: $x \prec y \wedge y \prec z \Rightarrow x \prec z$
• Irreflexivity: $x \prec x \Rightarrow x = x$
• Local finiteness: $\{z | x \prec z \prec y\}$ is finite.
Hasse diagram of a generic causet

How to study it? **Poisson Sprinkling!**
To embed a causet in a spacetime region of volume V :
1. Pick the sprinkling density $\rho = C^{-1}$.
2. Distribute $N \sim \text{Pois}(\rho V)$ points uniformly such that the probability of having n points in a volume V is:
 $\text{Pois}(n, V) = \frac{(\rho V)^n}{n!} e^{-\rho V}$.
Note: $dV(x) \propto \sqrt{-g} dx^3$.
3. Connect the elements according to the causal structure of the spacetime region.

Black Holes: the Testing Arena of Quantum Gravity

Black holes arise from **General Relativity** and combined with **Quantum Mechanics** yield a full set of **Thermodynamic** laws.

(2+1)D black hole: looks like horizon, light cones. Causal set of a (2+1)D Schwarzschild black hole corresponds to the molecules (for each parallel slice). Construction sets within the light cone.

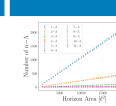
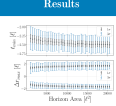
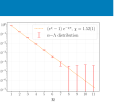
From Entropy to Horizon Molecules

"If your theory is found to be against the second law of thermodynamics, I can give you no hope; there is nothing for it but to collapse in deepest humiliation."
Arthur Eddington, 1955.
The entropy^{4,5} of a black hole with event horizon area A is given by
 $S_{BH} = \frac{1}{4} \frac{A}{\ell_P^2}$ $\ell_P = \sqrt{\frac{\hbar G}{c^3}} \sim 10^{-35}$ m.
Where is the **black hole entropy**? On the horizon⁶, embedded by "horizon molecules". In analogy to statistical physics, we can define
 $S = -N_{mol} \sum p_i \ln(p_i)$


Aims

• First-ever study of causal sets in **Schwarzschild spacetime**⁷ (7Dd, classical).
• Test different molecule models of black hole entropy.
• Compare our simulations with analytic results⁸ in the spacetime (for Rindler horizon).

Results


Number of causal set elements
Horizon Area A
Discrete scaling: $N_{CS} \propto A$

Entropy S
Horizon Area A
As we increase A , the entropy S increases.

Probability
Distribution of n : $p_n \propto e^{-n}$
 $p^2 \sim 1 - e^{-n} \approx 1 - 0.37$


Further Work

• Discretise more complex black holes.
• Investigate other entropy models (BMP, SSG^{9,10}).
• Explore curvature features and corrections in causets¹¹.

References

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