Operational verification of the existence of time and space

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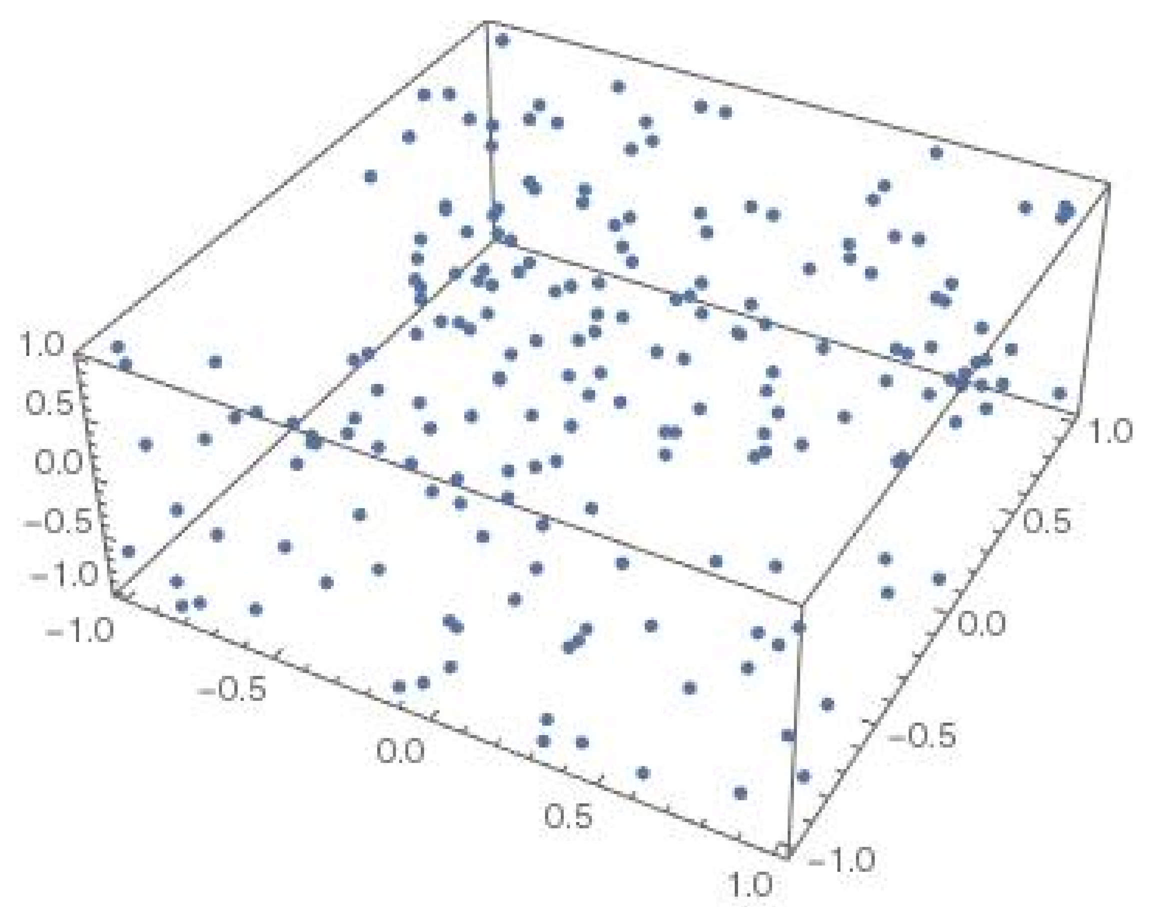
Abstract

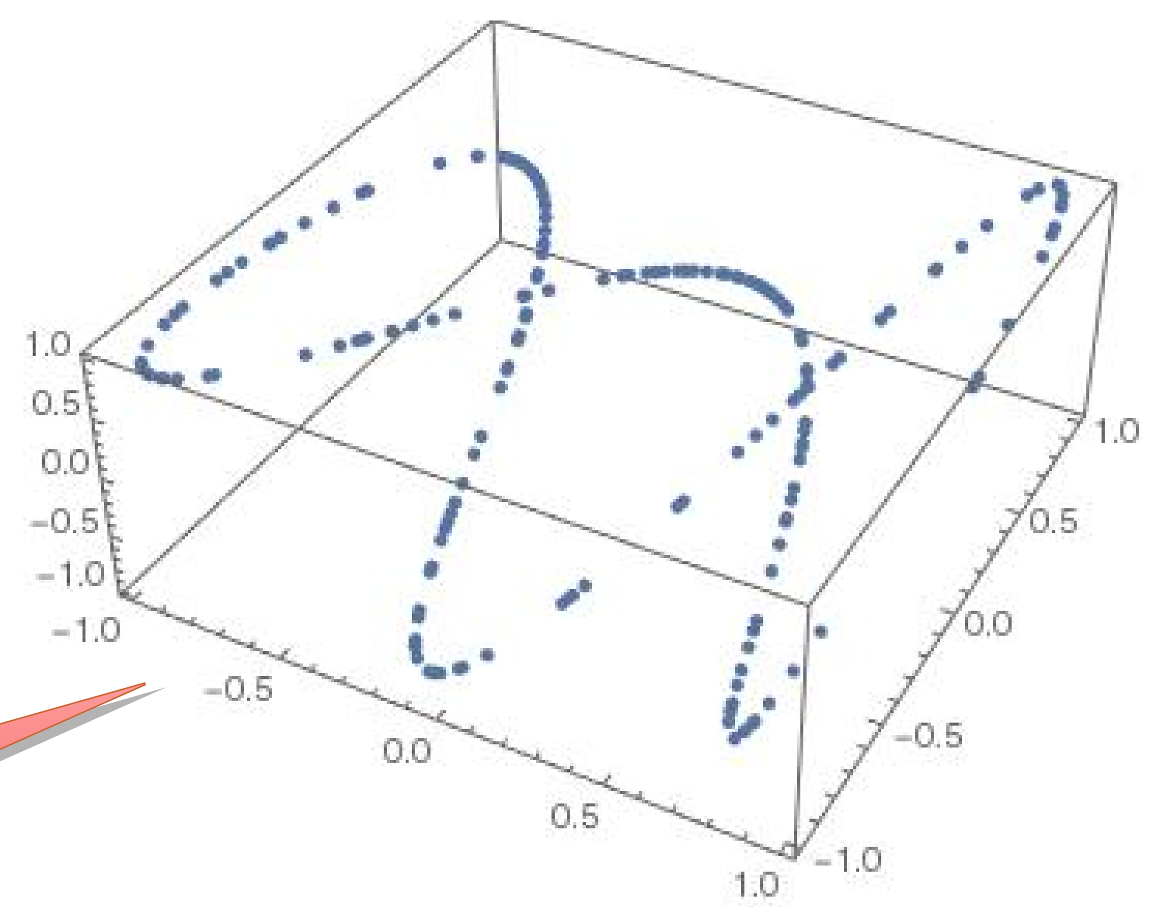
We argue that there exists an operational way to establish the objective reality of the notions of space and time. Specifically, we propose a theory-independent protocol for a gedanken-experiment, whose outcome is a signal establishing the observability of the spacetime manifold, without a priori assuming its existence. The experimental signal contains the information about the dimension and the topology of spacetime (with the currently achievable precision), and establishes its manifold structure, while respecting its underlying diffeomorphism symmetry. We also introduce and discuss appropriate criteria for the concept of emergence of spacetime, which a tentative theoretical model of physics must satisfy in order to claim that spacetime does emerge from some more fundamental concepts.

Gedanken-experiment



Perform N measurements of K observables, A, B, C, …, but deliberately without keeping track of their order. Arrange results into K-tuples $(a_3, b_7, c_4, \dots)$, where each k-tuple consists of a random permutation of the dataset. Plot these K-tuples as points in a K-dimensional space, and observe that they are distributed pretty randomly.

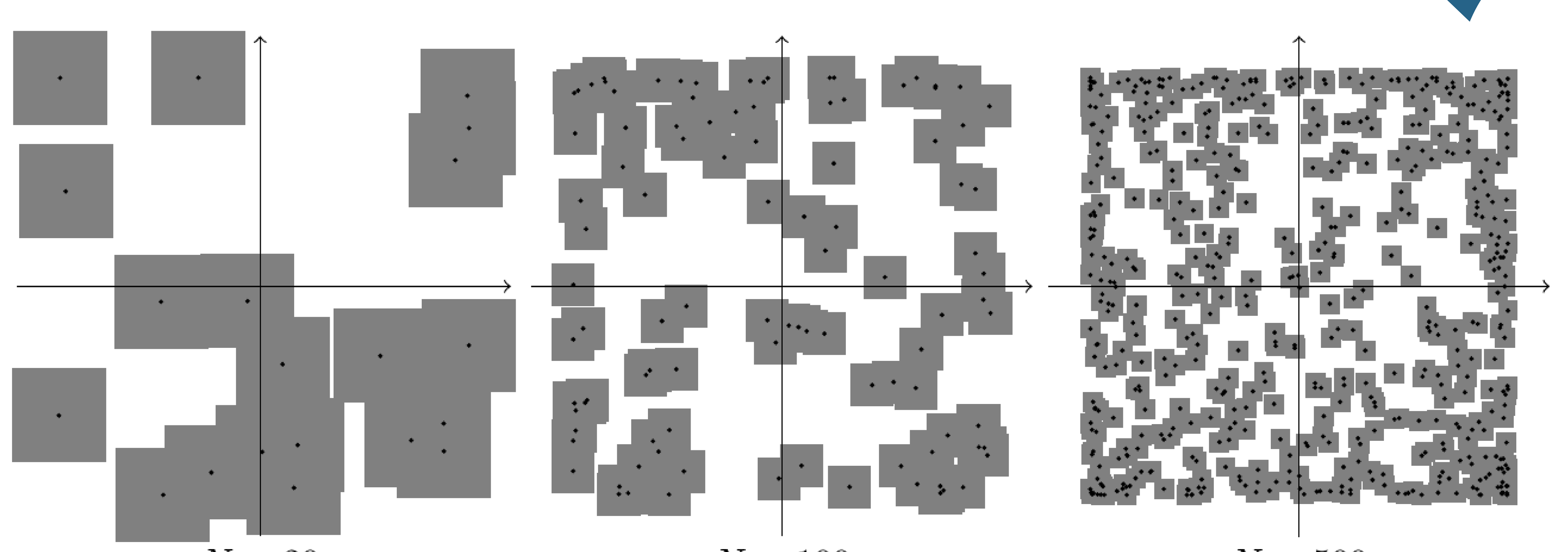
Experimental signal of the time manifold



MAIN INSIGHT !!!

But… The measured dataset is *special* (compared to a random computer-generated dataset): *there exists one special permutation*, whose plot reveals a very non-random structure — all datapoints lie on a 1-dimensional manifold in a K-dimensional space. This is the *time manifold*, and it appears to be present in all real-world experimental data!

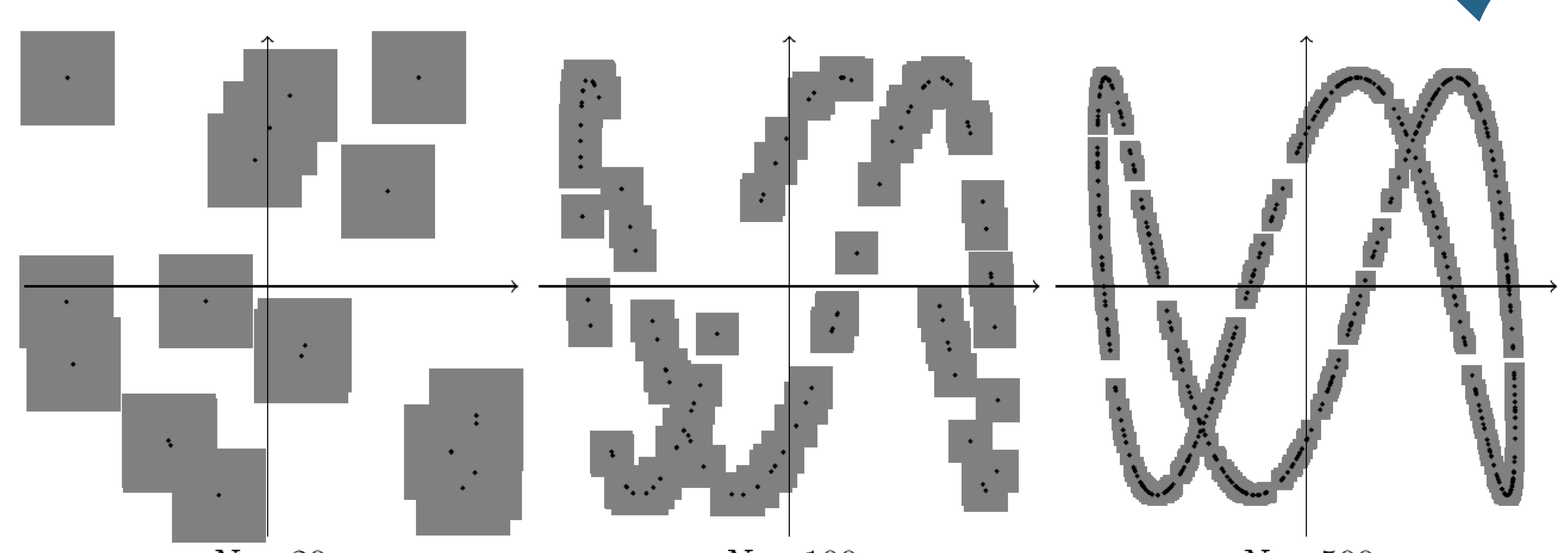
Generic permutation signature



For the case of a generic permutation, construct a small cube around each datapoint, choosing its size so that the sum of all cube volumes always equals the total volume of K-space. Due to overlaps, the total grey volume is somewhat smaller than the sum, but it remains finite, even as the number of datapoints N grows very large:

$$\alpha(N) \equiv \frac{V_{\text{grey}}}{V_K} \approx const, \qquad \text{even when } N \gg 1\,.$$

Special permutation signature



For the case of the *special permutation*, the ratio of grey volume over the K-space volume drops asymptotically to zero as N grows, indicating that datapoints lie on a subset of measure zero! One can then also deduce the formula for the dimension of the corresponding submanifold:

$$\alpha(N) \equiv \frac{V_{\text{grey}}}{V_K} = const \cdot N^{\frac{D}{K}-1} \to 0 \quad \text{when } N \gg 1\,, \qquad D = K\left[1 + \lim_{N\to\infty} \frac{\log \alpha(N)}{\log N}\right].$$

Properties of the special permutation

- *Existence:* the special permutation exists only in real-world data, but not in arbitrary data — it is *non-random!*
- *Dimension:* in all experiments humans have ever done so far, we always obtained $D = 4$ — spacetime manifold is *4-dimensional!*
- *Topology:* grey cubes define *open sets*, providing the manifold with a *topological structure!*
- *Self-reinforcement:* in contrast to all other permutations, for the special one the structure of the manifold becomes *ever more pronounced* as additional measurements are performed!

References

[1] N. Paunković and M. Vojinović, arXiv:2209.04783.

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