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Speculations on Dislocations in a Discrete Model of Space–Time

Thomas F. Knight, Jr.[1]

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The absurdity of the notion that a single real number can capture an infinite amount of information strongly motivates the search for models of physics where the information content of small regions of space–time is finite. The rejection of the continuum is one such approach, in which space is viewed as a cellular automation with fixed rules capturing the observed temporal evolution of particles.

In this note, I speculate on a somewhat different view, which revises our viewpoint of the fundamental relationship in general relativity

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

between the curvature of space–time and the stress–energy tensor. The standard way of viewing this equation is that the presence of matter induces a corresponding space–time curvature. In the discrete world, however, space–time cannot be simply gradually curved. If we adopt a crystalline vacuum structure, then curvature can only be induced by the presence of dislocations or disclinations in the crystal structure.

How might these imperfections in a space–time lattice play a role in physics? One approach might be to rethink the equation above. Perhaps what it really says is that the particles we see are the dislocations in a space–time crystal.

There are some suggestive hints. In a perfect crystal, the discrete distance between points depends only on identity of the points, and is path independent. In other words, the field is conservative, and the commutator between coordinate motions is zero.

[1] MIT Artificial Intelligence Laboratory; e-mail: tk@ai.mit.edu.

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In a crystal with dislocations, the distance is path dependent, and the commutator measures the density of dislocations enclosed within the pair of disjoint paths. This commutator is termed the Burger's vector.

A well-known theorem in dislocation theory states that dislocations cannot suddenly appear and disappear within crystals. There is an inherent conservation law of dislocations—specifically, a kind of Kirchoff's current law states that the Burger's vector can only be changed by interaction with another dislocation. Pair creation and pair anihilation of dislocations is inherent in the structure of these dislocations, matching well our experience with fundamental particles and their conserved quantities.

One could imagine, then, space–time as a crystal containing defects. The interactions of these defects automatically obey some of our important conservation laws. Specifically, the path of such a dislocation in the space–time lattice might encode the world line of a particle, reflecting its past history.

A crystalline model of the past may also help explain the temporal evolution inherent in physics. Imagine that the past is encoded in such a space–time crystalline structure. The present might be the temporal hypersurface of such a structure. Temporal evolution would correspond to net growth of the surface, extending the world line of particles into a growing domain of the crystal. But real crystal growth, we know, is an equilibrium process. While, under the correct conditions, net growth of the crystal occurs, microscopically the crystal can undergo local removal of structure. The statistical nature of this process is reminescent of the deep relationship between quantum field theory and statistical mechanics, wherein Wick rotation is used to convert one to the other. While currently largely viewed as a mere mathematical trick, introducing an i in the exponent of statistical mechanics, here we view that trick as a reflection of the fundamental statistical nature of the accumulation of the crystalline past.

Time, then, in this model is divided into a meta-time, in which crystal growth and retreat occur statistically, and a phenomenological time, which is the result of the net growth of the space–time crystal. While aligned in direction, there need not be a one-to-one relationship between these times.

In particular, the statistical investigation of potential futures takes place in meta-time, happens instantaneously (from a phenomenological stand-point), and results only in consistent histories. This provides meta-time for the extra computation which seems to be an inherent property of quantum interactions, and perhaps explains some of the quantum weirdness we attribute to the real world.

Kleinert (1987) has investigated the application of continuous models to discrete curvature ideas and dislocations in 3D crystals, but has not extended that work to space–time. Weertman and Weertman (1992) present a particularly simple discussion of dislocations in 3D crystals.

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