VIEW FROM THE PENNINES: ON ART AND CAUSAL SETS

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There are only two roads across the valley, and so very few street lights illuminate the hills opposite the house. Further east the lights become more frequent, pouring along the valley bottom into the lake of light that is Huddersfield. On dark winter nights it is hard to tell where the sky and stars meet the land and lights, but the occasional headlights of cars coming over Scapegoat Hill or Moorside Edge help to make a transient but precise determination of this boundary. I find the view peaceful, ordered, even Newtonian in its simplicity and beauty.

This February sees the opening of an art installation at Queen Mary, University of London, which is the antithesis of my night-time view. In an EPSRC funded project proposed by the physicist Fay Dowker, Matthew Tickle will create an artwork that explores the ideas of quantum mechanics in the urban setting of the Mile End Road, a busy dual carriageway in the East End of London. In *What the eye cannot see the heart cannot grieve for*, Tickle will place Geiger counters in the offices of the Department of Physics and other university buildings overlooking the road. Every click of the Geiger counter will set off a photographic flashbulb, briefly illuminating a room. My mental image of the net effect is that the viewer will see, or at least register, a series of uncorrelated images made visible by the sudden flashes in different parts of the buildings.

Until it is constructed it is hard to guess the impact of this piece, but the idea is sufficiently powerful for me to be able to imagine a work of art that may (or may not) correspond to the realization of the idea by Tickle. My imagined installation evokes several trains of thought. First there are questions about cause, effect and the objects that will be illuminated. What is creating the flashes and what triggers these events? Knowing that the source is a microscopic event may lead to musings on the nature of quantum reality, the measurement problem (how does one move from the quantum mechanical probabilistic view of events to the classical yes or no of a given measurement or flashbulb)

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and similar thorny issues. On the other hand, the object illuminated, an academic's office, is hardly a work of art, and is unlikely to provoke more than a momentary voyeuristic frisson if it can be consciously registered at all. The juxtaposition of the ordinary rooms and the extraordinary thoughts of their occupants is one of the motivations for Tickle's eventual decision to create the work in the Department of Physics: as Fiona Russell has put it [9]

> [he] was struck by the contrast between the the ambition of Dowker's theorising and the everyday nature of her working environment.

This is a very interesting take on intellectual activity in general: how can the inner world of thought, with no obvious physical expression, create such an impression? Moreover, Tickle has clearly been fascinated by the quantum world opened up by conversations and outreach activities with Dowker, although he is, perhaps, more comfortable with metaphysics. To quote Russell again [9]

> Tickle sees it [the world described by modern physics] as directly concerned with questions that are the focus of his work: what is real and what is meaningful about that reality? what is there when you are, and what remains when you are gone?

which brings to mind eighteenth-century preoccupations with the existence, or otherwise, of a tree in a deserted Oxbridge College quadrangle [5].

These responses are expected, and clearly intended in one way or another. On further consideration they now appear somewhat shallow. On reflection, my imagined version of Tickle's installation leads me to be acutely aware of a more subjective sense of time; to feel the artificiality of the apparent uniformity of time that it is all too natural to impose on experience. There will be periods of intense flashing between sloughs of inactivity. Why? Is this important? Is there a natural time scale to the events on view? We seem to have an emotional need to impose patterns on disorder, and to regularise or intellectualise anything apparently random. These thoughts resonate with my response to another work of contemporary art which I saw in an exhibition of work by Tatsuo Miyajima at the Haywood Gallery in 1997 [7]. I sat for half an hour in front of *Time in Blue* trying to guess the algorithm used and the meaning of the different components. It took me that long to realise that this really was not the point, and that the random appearance of numbers counting down to zero at random rates and then disappearing had forced me to try to impose order but had ended (after some time) by allowing me to accept the loss of uniform time implied by the work.

What the eye cannot see the heart cannot grieve for is the result of a collaboration between Tickle and Dowker (now at Imperial College) and Tickle's work has been influenced by, and is informed by, conversations with Dowker. In some ways my second response to this work – the essential role of time – is also closer to the recent work of Dowker than the more obvious interpretation through quantum mechanics as expressed by Tickle. Dowker is currently working on a new universal theory of everything [3]. This approach to the unification of general relativity and quantum mechanics takes time, or more accurately causal relations, as the fundamental generator of models of the universe.

Although it is usual to think of general relativity as a theory about geometry, it can also be phrased in terms of whether different points in spacetime can affect each other. The geometry of spacetime is represented by a metric which endows the events of spacetime with a causal order: it specifies whether event B can be influenced by event A. This is equivalent to asking whether a light signal or material object could be sent from A to B, or whether B lies within the light cone of A. The starting point of the approach taken by Dowker and others, and led by Rafael Sorkin at the University of Syracuse in New York State, is the recognition that this logical order (from geometry of spacetime to causal orders between events) can almost be reversed: a complete description of the light cones of events is equivalent to the specifications of general relativity – except that no absolute length or time scale is determined [6]. This means that knowing the causal relations between events is enough to determine the geometry of spacetime up to multiplication of the metric by an arbitrary smooth function.

In an attempt to unite general relativity with quantum mechanics, Sorkin and colleagues start with the assumption that in any description of quantum gravity, spacetime itself will be quantised, i.e. it will be discrete. The geometry of spacetime is then imposed by specifying the causal relations between points. This is simply a partial order, $\prec$, on the points of their spacetime, where $x \prec y$ indicates that x can influence y, i.e. that x and y are causally connected (time-like) with x 'earlier than' y. If x and y are space-like and cannot influence each other then they are not comparable under the partial order. The development of models of the universe then becomes a question of developing theories of partial orders on discrete sets, and the quantum aspects of the theory reside in the interference between the different realizations of the geometry implied by different causal relations.

A partial order can be represented as a graph: the points in spacetime are the vertices, with a directed edge from x to y if $x \prec y$. The partial order implies that this graph has no cycles and Rideout and Sorkin [8] were able to develop a model for the growth of such graphs which has some of the features required of a quantum spacetime. The partial order implies that any particular realization of their model corresponds to a random non-cyclic directed graph, and special cases of these have been studied pure mathematicians. Indeed, many of the results I described for small world networks last year [4] have analogues in this special case. Rideout and Sorkin's model involves the addition, one by one, of new vertices, with directed edges from earlier vertices added with a given probability that is consistent with the partial order and some physical principles. In this way probabilities can be assigned to the set of all possible such graphs, and some physical property of the system has a probability given by the total probability of all worlds that have this characteristic. These models have been developed further – for example Dowker and Sorkin, working with the pure mathematician Graham Brightwell at LSE and others, were able to show that results obtained from this model do not depend on the order of addition of points implicit in the description of the model [1]. In other words, results are co-ordinate free or covariant – an essential feature of any physical theory.

This directed graph model has one problem. The probabilities assigned to the different graphs (the different possible spacetimes) are classical. This means that if A and B are disjoint sets then their probabilities, or more accurately their measures, satisfy

$$P(A \cup B) - P(A) - P(B) = 0 \tag{1}$$

so the probability of a disjoint union of two sets is the sum of the probability of the two possibilities. This is unnecessarily restrictive for quantum mechanics and does not allow for quantum interference or entanglement, one of the defining features of the quantum world. Quantum measures satisfy two relations between any three disjoint sets [2]:

$$\begin{array}{c} P(A \cup B) = P(A) \ \text{ if } P(B) = 0, \text{ and} \\ P(A \cup B \cup C) - P(A \cup B) - P(B \cup C) \\ -P(C \cup A) + P(A) + P(B) + P(C) = 0 \end{array} \tag{2}$$

Note that these are satisfied by any classical probability measure, but that they do not imply the classical definition. Indeed, the first, apparently trivial, assertion is unnecessary for the classical case as it follows directly from the definition, whilst any attempt to prove the classical definition from (2), by setting C to be the empty set for example, simply reduces to trivial equations ($0 = 0$). One of the goals of current research is to prove results about causal sets on which non-classical quantum probabilities can be defined. To date there is some progress, but most of the results are from numerical simulations [2].

Time enters Dowker's work in many ways. Her preoccupation with the structure of spacetime and the fictitious time in the evolution of Rideout and Sorkin's model to name but two. Tickle's work reminds us that there is also a personal time, separate from the world of physics, and he does this by drawing attention to an intellectual perception of time. Paradoxically, by highlighting this particular attitude to time, it eventually becomes possible to discern what is in the background: a more unruly but relaxed time that is not measured by a Newtonian clock.

The old packhorse route directly across the valley is invisible in the dark, but street lights mark the path of the nineteenth-century road clearly. Changes to this night-scape are fitful, the 1750s left a lasting impression, and recent years have also created new features, but without other points of reference they are indistinguishable in the dark. We say that the night-scape changes slowly when we really mean that there are long static periods separated by abrupt periods of change. Our own experiences of time and history are highly nonlinear, so why am I surprised when an artist points this out?

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References

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[4] P. Glendinning (2003) View from the Pennines: Making Connections, *Mathematics Today* **39** 26-27.

[5] R. Knox (1927) on Berkeley's philosophical arguments:

There was a young man who said 'God
Must think it exceedingly odd
If he finds that this tree
Continues to be
When there's no one about in the Quad.'

A reply has also passed into legend:

Dear Sir,
Your astonishment's odd:
I am always about in the Quad
And that's why the tree
Will continue to be,
Since observed by yours faithfully,
GOD.

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