From Einstein to Barbour: A Brief History of Shape Dynamics

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Furkan Semih Dündar (FSD): *You are known as the founder of shape dynamics. What is shape dynamics and how did it all begin?*

Julian Barbour (JB): Shape dynamics is a general framework for the description of possible universes. It developed out of the desire to eliminate from dynamics the potentially redundant elements that Newton introduced into dynamics in 1687: absolute space and absolute time. We call the result relational dynamics (not to be confused with relativistic dynamics).

The fundamental concept in shape dynamics is shape space, which consists of all possible shapes that the universe can have. In the case of a Newtonian universe of point particles that interact gravitationally, the difference between conventional theories and shape dynamics can be illustrated by a model universe of just three particles in Euclidean space. At any instant, they will always be at the vertices of a triangle, which will have a size and a shape. But to speak of the size, you need, in addition to the three point particles, a ruler to measure the size of the triangle that they form. Without that, you can only speak meaningfully about the shape of the triangle. This is defined by the *ratios* of the lengths of the triangle sides. From the three side lengths, one can form two dimensionless numbers. They determine two internal angles of the triangle and its shape. In shape dynamics, these and only these are the variables that describe the system.

Moreover, because clocks are physical systems within and not without the universe, shape dynamics not only eliminates size but also external time, or rather absolute duration (the supposed `amount of time' between successive shapes of the universe). Instead of asking how the shape variables change as time passes, one merely asks how they change relative to each other.

It is important to say that shape dynamics does not aim at complete replacement of either Newtonian theory or general relativity but to eliminate all redundant elements and thus lay bare the irreducible inner structure of both theories. This has two important consequences: first, many solutions of both theories are eliminated because they are not properly relational; second, important aspects of the remaining relational solutions are more clearly revealed and light is cast on the possible nature of the big bang and the problem of why the past, present and future are so different (the problem of the origin of time's arrows). Moreover, representation of the solutions in explicit shape-dynamic form may facilitate the creation of quantum gravity.

FSD: *Mach's Principle is the key starting point for relational physics. Was Einstein loyal to Mach when positing his theory of relativity? Is general relativity Machian?*

JB: Einstein was very keen to implement Mach's Principle; it was the main stimulus that kept him searching for his wonderful theory. He thought that his principle of general covariance had deep physical significance and ensured his theory would automatically be Machian. However, soon after its creation, Einstein was forced to accept Kretschmann's objection that general covariance had no physical content and was merely a reflection of nothing more than mathematical consistency. In fact, Einstein got in a real muddle in his discussion of Mach's Principle and finally abandoned the whole idea at the end of his life.

There are very understandable purely historical reasons for this, above all the fact that Einstein discovered special relativity in 1905 before he made any attempt to implement Mach's ideas. In 1907 he then had the brilliant idea of the equivalence principle (the "happiest thought of my life"). These two things together with the desire to create a field theory of gravitation along the lines of Maxwell's theory of the electrodynamic field led Einstein to attempt the implementation of Mach's Principle in an indirect way. This is what led to great confusion.

In contrast, Bruno Bertotti and I attempted to create a relational theory in a pre-relativistic setting and published the result in 1982. This showed that the key principles of a Machian dynamics are realized very well in a subset of the solutions of general relativity for which three-dimensional space is closed like the two-dimensional surface of the earth. The paper of 1982 only considered the relativity of position, motion and time. However, beginning in 1999 Niall O Murchadha and I together with Brendan Foster, Bryan Kelleher and Edward Anderson explored the consequences of the relativity of size and showed that this too is realized, very beautifully in fact, in general relativity for the spatially closed solutions. Our work was taken further in 2010 by Henrique Gomes, Sean Gryb and Tim Koslowski. Since then shape dynamics has been attracting increasing interest among relativists.

FSD: *It is known that general relativity and shape dynamics have some common solutions. However, has anyone found an interesting solution that is specific to shape dynamics and not found in general relativity?*

JB: In accordance with the famous singularity theorems of Penrose and Hawking, many solutions of general relativity cannot be continued beyond certain surfaces in spacetime because at them densities and curvatures become infinite. This is argued to be unphysical. However, it may be that the concern is unfounded because the singularities are manifested in the scale factor of the solutions. It is because this goes to zero that the curvature and density become infinite. If, as is postulated in shape dynamics, only the shape of the universe (and not its size) is physical, the singularity theorems need to be reconsidered. The mathematics that leads to them is correct but the interpretation may be wrong. In particular, in a paper published in 2015 Tim Koslowski, Flavio Mercati and David Sloan showed that there are solutions of general relativity for which the shape can be continued through their big-bang singularity, either side of which one has normal spacetimes. Moreover, the direction of experienced time flows in opposite directions on the two sides of the solution. This is something new that has emerged within shape dynamics.

FSD: *What is the role of shape dynamics as regards finding a quantum theory of gravity?*

JB: Nothing definite as yet. However, shape dynamics does suggest alternative ways to attack the problem of creating a quantum theory of gravity. This applies above all to what should be regarded as observables, which is a key issue in quantum gravity. We think only shape variables should be regarded as observables. The notorious `problem of time', which arises from the disappearance of time in the canonical approach to quantum gravity, may also be affected. However, quantum gravity has proved resistant to resolution for over 60 years and we cannot expect a breakthrough at any time soon. For all that, my intution does suggest to me that the breakthrough might come from one simple idea. That has happened so many times in the history of science. Perhaps the idea that only shape counts together with just one further simple idea will do the trick. It might be along the lines that Tim Koslowski suggested in a talk at the Perimeter Institute in Canada in 2017 (online at PIRSA/Koslowski).