Space Worries and the Several Debates

As we have learnt up till now, the problem of space has given rise to an everlasting argument in the field of philosophy of science. Many related problems emerged, especially metaphysical, epistemological or physical ones, which have fascinated philosophers over generations. Thanks to their dedication, physics, as well as philosophy of science, has been developed greatly into what we take for granted nowadays.

Different problems were presented around the three aspects above. For metaphysics, typical questions include what kind of thing space is, and whether it's the same thing as matter or not. Vital epistemological problem is how we can know space due to its invisibility, through experience or reason. As for physics, we should determine if there is any interaction between space and matter. Here we'll have a summary of significant efforts made by pioneers to work these questions out.

The Elements by Euclid, which is a systematic compendium of all geometrical knowledge from ancient Egypt and Greece, can be regarded as an important development of theory of space. However, the most tremendous contribution is not the geometrical knowledge it contains, but the paradigm of the axiomatic and deductive method of reasoning it presents. One can logically derive the entire body of Euclidean Geometry from a few, namely 5, fundamental posited statements by following this. Based on this, Euclidean Hypothesis, that Euclidean Geometry correctly describes physical space, is proposed. Therefore, it implies that space is a fundamentally geometrical object.

Many arguments were presented about the hypothesis. Gauss set up an experiment to test it and finally confirmed the proposition within experimental errors. A Zeno's paradox, which was proposed much earlier than Euclid, is nevertheless a great challenge of the Euclidean theory. Cauchy's theorem by Augustin-Louis Cauchy helps to eliminate this paradox. Another paradox, called the plurality paradox, caused by the problem of the sum of an infinite number of infinitesimals, was solved by Cantor's theory about different sizes of different types of infinities.

Before Euclid, a conception of space was developed by Aristotle. It's filled with a great deal of his theory of motion as well as comprehension of space. In his cognition, some common beliefs must be accepted. Accordingly, a few theories about space were rejected. Finally, he took space as the extremities. In his system of theories, he regards it as an internal nature that the elements tend to seek out their proper final places. And he distinguishes two kinds of motion based on this. One is nature motion that occurs in the absence of forces, and the other is unnatural motion that occurs when forces act. Space is the cause of natural motion in his view, and external forces are to prevent objects from moving naturally. To match his theories, Aristotle presented his own cosmology, which regards the universe as a finite three-dimensional sphere. His theory system, which is completely wrong in today's perspective, was almost uncritically endorsed until the Scientific Revolution.

Before we discuss the debates between substantivalism and relationism, one last famous philosopher we should introduce is Renè Descartes, who made remarkable contributions to geometry as well as the philosophy of space. Descartes' methodology is rationalism rather than empiricism. He claimed that all things (except God) are made of mind and matter. In his opinion, objects are not located in a matter-independent space, but in mutual relations. Distinct reference frames depend on the objects taken as reference points. He believes that Euclidean geometry correctly describes space, and invented Cartesian axes to help distinguish spatial points. With the belief that all reference frames are equivalent, his theories encountered clashes with the principle of inertia, and we'll talk about it during the following outline of the battle of substantivalism and relationism.

Substantivalism

Newton

Issac Newton, who is a faithful advocator of substantivalism, made full use of absolute space in his theories. He conceives space as an absolute immutable container for material objects, which it's independent of. In other words, he considers space distinct and separable from matter. Besides, he totally accepts the Euclidean Hypothesis that physical space is supposed to have a three-dimensional Euclidean structure.

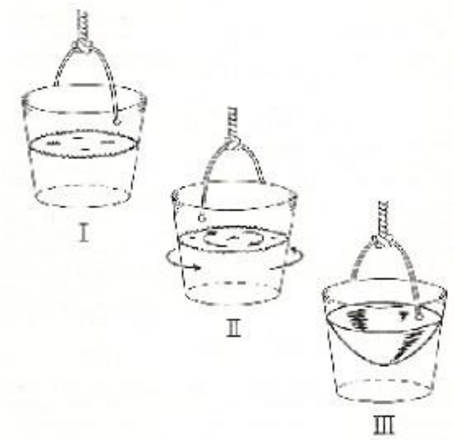
Descartes' theories fail to reconcile the contradiction of the motion of the earth in the solar system. Therefore, to refute Descartes' theories, Newton formulated his own notion of absolute motion, which is contrary to relationism, to explain inertial effects. In his opinion, it can only be explained if we postulate that there is just one absolute motion. Absolute space determines the preferred reference frame, with respect to which for all bodies one defines absolute position and absolute motion.

According to the container view, space is a real substance and a container for the material universe, which follows Euclidean Hypothesis, and that is independent of matter and immutable. Newton considers such a space to be absolute, therefore provides a proper inertial frame, relative to which an object's acceleration as well as position and velocity must be defined. But this argument is an inference since space is not observable.

Newton proposed the bucket experiment (shown in the figure below) as an objection to relationism. Since the rotation that causes the curvature of the water cannot be relative to the bucket, the water itself, the observers or the earth, relationism has no way to explain this phenomenon. Therefore, Newton concluded that it's flawed and presented absolute space to provide a fixed reference frame for true motion.

Kant

Immanuel Kant is also in favor of absolutism, i.e. substantivalism, by conceiving Euclidean space in terms of a priori synthetic knowledge. Based on the geometrical phenomenon of reflection, he offered an argument that relationism is unable to account for the property of chirality. That is, when we take a map and its mirror image, the relative distances between objects remain the same, thus in the view of relationism, they should be one and same. However, undoubtedly only one of them is correct. The difference here is definite, but relationism cannot explain it.



The Bucket Experiment[1]

Due to the chirality, objects can be classified as congruent ones or incongruent ones. The former sort of objects have no left- or right-hand side, while for the latter they have fixed left and right. Nevertheless, whether an object is congruent or not depends on the property of space. For instance, an object which is incongruent on a Euclidean plane may become congruent on a Mobius loop. And that leads to the necessity of absolute space: only it can account for absolute distinction.

For Kant, space is also correctly described by Euclidean geometry, which is a system of synthetic priori truths that adds information into our sensible intuitions. However, non-Euclidean geometries exist, namely Elliptical geometry and Hyperbolic geometry, which reject some of the postulates of Euclidean geometry, i.e. Parallel Postulate. Their feasibility demonstrates that the Euclidean Hypothesis isn’t an essence. Although this can basically support the proposition of Kant in some sense, it shows even more importance when it comes to the point of Poincaré, which we’ll discuss later.

Relationism

Leibniz

Gottfried Wilhelm Leibniz proposed a relational view of space. Like Descartes, he endorsed the philosophical school of rationalism, believing that reason alone can reliably discover the nature of reality. And all non-mathematical knowledge is derived by him from Principle of Sufficient Reason (PSR): There ought to be some sufficient reason why things should be in this way, and not otherwise.

In philosophy of space, Leibniz provided a classical definition of relationism as well as the most compelling objections against Newton’s absolutism. Based on the fact that any object can determine a reference frame, one defines relational space. In his opinion, space is a collection of objects at various relative distances from each other. Therefore, there can’t be an absolute reference frame, which is against substantivalism, but a democracy of equally valid reference frames determined by different objects.

According to Newton's substantivalism, absolute space has a Euclidean geometrical structure. Leibniz contended that we can't determine absolute velocity even though absolute acceleration can be defined with respect to absolute space. If Newton's laws of motion are true in one frame, they are true also in all other inertial frames. And given the equivalence of such frames, absolute velocity is undetectable, therefore we have no idea how to determine which frame is at rest relative to absolute space.

Besides PSR, Leibniz also employed Principle of Identity of Indiscernibles (PII), which implies that to suppose two things indiscernible is to suppose the same thing under two names. Even if the two things aren't identical, there is no difference one could observe. He then formulated a series of thought experiments to argue against substantivalism, namely static shift and kinematic shift, which show that if the universe is shifting, there is no practical difference before and after the shift and all relations remain the exact same. Since one can't measure absolute position and velocity in absolute space, such a fundamental concept becomes useless and meaningless.

Mach

Ernst Mach is an influential physicist and philosopher, who developed a theory of classical mechanics and gravitation which is an alternative to Newtonian one. The view of Mach is even more extreme, for he maintains that any metaphysical hypothesis about entities escaping sensorial experience, such as atoms, must be banned from science.

Mach's anti-metaphysical opinion led him to object to the concept of absolute space. He agrees with Leibniz that such a concept is meaningless, but from an empiricist viewpoint. And he believes that space is entirely dependent on the distribution of matter in the universe. To enable relationism to explain inertial effects, however, Mach maintained the concept of absolute motion, which is defined relative to the distant stars where most matter in the universe is concentrated. Absolute acceleration is thus velocity change relative to such a reference frame. Accordingly, inertial effects are explained in terms of matter distribution.

In Machian mechanics, matter is supposed to do all the work that absolute space does in Newtonian mechanics. There is no distinction between natural and constrained motion, and objects interact with each other in various ways, causing different motions. Unfortunately, his theory hasn't been completely developed by either himself or anybody else up till now.

Poincaré

Jules Henri Poincaré, a French mathematician, made contributions to physics and philosophy of science. He advocates conventionalism about Euclidean and non-Euclidean geometries and proposed a hierarchy of sciences: special sciences presuppose physics, which presupposes geometry, which in turn presupposes arithmetic. In his opinion, all geometries are conventions though they're about physical space, so a choice of one geometry rather than another is due to economy and simplicity, reflecting no truth.

He proposed the question, what experiments might observe if space were non-Euclidean, and tried to answer it through a thought experiment, namely Poincaré's disk. In this experiment, he imagined a world where creatures live on a two-dimensional disk with radius in the Euclidean plane. The length of any object decreases as it moves farther from the center in such a world, complying with a contraction law. If the beings on the disk hope to determine experimentally the geometry of their world, they need to measure the radius and the circumference. However, since both they themselves and their measuring device change when moving around space, they cannot realize the case. When they reach the boundaries of the disk, the length of their measuring device will shrink to zero accordingly. Therefore, the beings will never reach boundaries and conclude that their space is infinite.

For Poincaré, there is no way to settle the dispute between Euclidean and non-Euclidean geometries by experiments, none of which can determine which geometry is the correct one. Therefore, his conventionalism holds that physical space has no intrinsic geometrical structure, and that the choice of one geometry is no more than a matter of scientific convenience.

As a student who majored in Physics during my undergraduate period, I prefer relationism to substantivalism. Though Newtonian mechanics is still widely applied in physics nowadays, it doesn't include any concept of absolute space. On the contrary, relationism has been totally accepted in modern physics.

Relationism is significant in both the classical Newtonian mechanics and the more advanced theory of relativity. In detail, Newtonian mechanics approximates special relativity[2], and special relativity approximates general relativity[3]. For Newtonian mechanics, Galilean transformation is used to transform between the coordinates of two reference frames which differ only by constant relative motion within the constructs of Newtonian physics.[4] When it comes to special relativity, Galilean transformation is replaced by Lorentz transformation when not considering translations in space and time[5] and Poincaré transformations when considering them[4]. However, relationism has undoubtedly been regarded as common sense, regardless of circumstances considered.

In short, relationism dominates substantivalism a lot in the problem of space and has highlighted its great significance in both physics and philosophy of science. In my view, relationism offers a more promising foundation for the further development of science and philosophy.

References

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