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The debate over absolute and relational space in the history of physics

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Abstract: This essay aims to demonstrate the thought trajectory from Newton's absolute space to Einstein's theory of relativity, and it will also emphasize the pivotal role of Leibniz's concept of space and Mach's philosophical extension of that. At first, Newton described space and time as eternal constants, providing an unchanging framework for physical phenomena. On the contrary, Leibniz argued that space and time cannot exist without the relations among objects and sequences of events. This argument formed one of the most significant philosophical disputes in the early scientific world. Philosophers began to scrutinize the subtle connection and conflict between substantivalism and relationism. The debate continued until the 19th century, when physicist Ernst Mach challenged the unobservable assumptions of Newtonian mechanics. He supported Leibniz's opinion and proposed that inertia and motion must be understood in relation to the total distribution of matter in the universe. According to his opinion, absolute space and time are unnecessary, since emphasis should be placed on observation and experience. This also provides a foundation for people to think about physics in a new way. Einstein later built his special and general theories of relativity based on these philosophical ideas. His theory offered a new understanding of the universe by combining space and time into a system. In this system, changes depend on matter and energy. His conclusion and achievements are inseparable from the conflicting contributions of the previous scientists.

1. Introduction

In the earliest days of philosophy, the concept of space stood at the center of how people viewed the natural world. Ancient Greek philosophers such as Aristotle and Plato debated whether space was an independent object or a kind of property that objects possessed. For Plato, space described in the *Timaeus* was like an invisible container that could hold all things and give form to material reality.[1] In contrast, Aristotle saw space as the position and relation among things, rather than defining it as an independent container.[1] This early disagreement established two ways of conceiving the universe: one regards space as an independent existence, and the other treats it as a network of relationships. A few centuries later, with the rise of modern science, some scientists like Copernicus, Kepler, and Galileo revived and reshaped this debate.[1] These discoveries changed how humanity understood the universe, turning "space" into a serious subject for scientific and philosophical debate. In the seventeenth century, this debate continued and reached a new height with Newton and Leibniz. Their opposing ideas about the nature of space would eventually shape Einstein's revolutionary theory of relativity centuries later.

For a long time, human understanding of the universe has depended on how we view and define space. "Space" is a point of deep intersection between physics and philosophy. It concerns motion and gravity in physics, and it also raises questions about existence and reality. Since the 17th century, a major debate about the nature of space has been initiated by the conflicting views between Newton and Leibniz. In Newton's account, space is an absolute and immovable background created by God, providing the fixed stage where all physical events take place.[2] It exists independently of objects and is unaffected by their motion. Leibniz thought that space does not exist independently but only as a system of relations among objects;[3] in his view, if no matter existed, space would not exist, since there is no reality independent for objects to occupy independently.[4] It influenced our understanding of motion, the nature of reality, and the fundamental structure of the universe. This debate included both physics and philosophy, engaging questions for each discipline. It questioned not only how space works, but also argued how God's will shapes the structure and meaning of the world.[3] However, it is shallow to see only the surface of their conflict, and will simply ignore their deeper philosophical reflections, as well as the developing path of their ideas. This thesis will demonstrate how the ideas of Newton, Leibniz, and Mach can have a significant influence on Einstein's development of the theory of relativity. Newton thought that space and time are absolute entities created by God, forming a fixed stage on which all motion could take place. Leibniz was opposed to Newton, arguing that space and time exist only through the relations between objects, which means they cannot exist independently. Centuries later, Mach criticized Newton's idea and proposed that motion and inertia are derived from the interaction of matter throughout the universe.[5] According to these ideas, Einstein transformed the discussion by creating the theory of relativity, claiming that space is not fixed but dynamic, and can be influenced by matter and energy.[6] Their unique views of space in philosophy and physics laid the foundation for the new conception of space and motion in modern physics.

The development of the space concept is not only important for the history of science but also for the philosophical understanding of reality. The tension between absolute and relational space reflects how humans have tried to connect physical observation with metaphysical explanation. This essay will trace the intellectual journey from Newton's divine absolute framework, to Leibniz's relational logic, to Mach's empiricist critique, and finally to Einstein's synthesis in general relativity. Through each thinker's redefinition of the meaning of space, the question of space is never only about purely scientific or purely philosophical; it stands at the intersection of both. Ultimately, the essay will argue that Einstein's relativity was not created in isolation; it emerged from centuries of philosophical struggle about the nature of existence and the structure of the cosmos.

2. Newton's Physical Stage: Absolute Spacetime

The concept of absolute space was introduced to help Newton as the fundamental framework for describing motion and acceleration in his physical universe. His concept of absolute space is fundamentally different from the relative space that most people perceive through their senses. Newton defined absolute space as an immovable and self-existing framework that can exist eternally without relation to any other objects. A fundamental problem with Newton's concept is its unobservability. This means it cannot be directly detected or measured by human beings. To defend his view, Newton introduced the bucket experiment.[7] Newton observed that when water spins in a bucket, it forms a concave surface and even remain there, although there is no relative motion between the water and the bucket. Newton proposed that the concave shape of the spinning water demonstrates that centrifugal force depends not on relative motion but on an absolute frame of reference.[2] This experiment turned his abstract idea into an observable physical effect. Therefore, in Newton's framework, absolute space was not merely a philosophical belief but an important part of his physical theory.[6] It gives a fixed stage for the law of motion and inertia, which makes them possible. There is no clear way to determine if an object is truly moving or remains at rest without absolute space. Newton used this idea to prove that forces like rotation or acceleration are real, even if they are unobservable. In this way, absolute space became the foundation of classical mechanics. Although Newton regarded absolute space as the true framework for defining motion, he did not fully reject the relevance of relativity in practical observation. He understood that it is unavoidable to use relative motion in describing phenomena. In general, while absolute space provided the framework and foundation for inertia and acceleration, Newton acknowledged that relative motion is also important, playing a significant role in describing or analyzing physical phenomena.

3. Leibniz’s Counterattack: Relational Spacetime

While Newton viewed space as an absolute and independent framework--and presented the bucket experiment as strong evidence for his hypothesis--its metaphysical foundations were immediately challenged by his contemporaries. Leibniz challenged Newton's concept by denying the necessity of the"absolute space" and arguing that space can only exist as a network of relationships between objects.

In contrast to Newton's absolute space, Leibniz identified space as the order of relations among objects. For him, if there were only one object or no objects, there would not be space. In his opinion, space represents the relationship between objects and how they relate to one another. To justify his statement, he designed some thought experiments based on principles like the “Principle of Sufficient Reason, which holds that everything must have a reason for why it is the way it is.[8] According to this principle, there would be no sufficient reason for the universe to occupy one position rather than another in empty absolute space. There is no reason why it should be in that new position rather than its original one. In this case, everything within the universe would remain identical in relation to each other. Therefore, believing in an absolute space that distinguishes between two indistinguishable situations breaks the Principle of Sufficient Reason. Leibniz also used the Identity of Indiscernibles: if two things have the same properties and are identical in everything, then they are not two things but actually one.[9] To support his view, he claimed that if two universes are completely the same in anything except their positions among the absolute space, they would be the same reality. This challenges the philosophical significance of absolute space because it is unobservable and unmeasurable. By looking at Leibniz’s perspective, Newton’s concept of absolute space has clear limitations, and because absolute space cannot be observed or measured directly, it creates confusion in the understanding of motion. If everything only moves compared to other things, there is no need for people to posit an invisible and eternal framework. This idea goes against Leibniz’s principles because it creates an invisible difference that cannot be perceived. In this case, Newton’s absolute space is more like a theoretical framework rather than a physical feature.

However, Leibniz's ideas also have some limitations. His opinion relied only on logical reasoning, such as using the Principle of Identity of Indiscernibles and the Principle of Sufficient reason. Without enough physical and real experiments to support, it is hard for him to explain some real physical phenomena like rotation or acceleration. Leibniz was unable to disprove Newton's bucket experiment, which shows that rotation can be detected without relative motion between objects, because the lack of empirical evidence.[6]

4. Mach's Physical Revolution: Challenge to the concept of Absolute Space and A philosophical Bridge

The debate between Newton and Leibniz continued until the 19th century, but the issue is that it remained divided between philosophy and physics, which means they were debating on different planes. Newton's view was grounded in physics, while Leibniz approached the question from a metaphysical perspective. Later, Ernst Mach revisited this issue in a more scientific way and explained it by the connection of motion and inertia through the physical relationships between masses.

Mach challenged Newton's ideas by arguing that the curved water surface does not result from rotation relative to absolute space.[5] He attempted to prove it conceptually rather than through physical experiment. Mach stated that the curvature of the water in the bucket is from the bucket's rotation relative to the distant stars and the whole mass distribution of the universe, instead of the bucket rotating in isolation. By this, if the entire universe rotates with the bucket, there would be no centrifugal force, and the water's surface would remain flat. He claimed that inertia and motion depend on the relationship between all objects, not just in an independent space. This bold assertion was later formalized as Mach's Principle.[1] Mach's principle states that the inertia of an object can only be determined by its interaction with all other masses in the universe. In other words, an object resists acceleration not because of absolute space but because of its connection to the total distribution of matter. By applying this principle, if we eliminate all masses in the universe, the water surface of the bucket would not be curved. This reflects that if the mass of the universe changed, the inertial properties of objects would also change accordingly. He therefore transformed Leibniz's ideas into a physically grounded hypothesis. His view helped move physics away from metaphysical assumptions toward empirical and relativistic thinking and inspired Einstein's development of general relativity later.[9] However, Mach's principle was also only a hypothesis since it does not have a clear mathematical model or physical experiment to support it. Although Mach's theory had its limitations, Einstein was inspired by these gaps and motivated to seek a fully relativistic description of gravity and inertia.

5. Einstein General Relativity: Transform Philosophical Debate to Physical Theory

One of the most important reasons Einstein developed general relativity was his recognition of the value of Mach's idea.[9] The lack of experimental support and the absence of a mathematical model became the biggest problem of Mach's theory. Einstein understood there could not be only a philosophical explanation, so he decided to research and develop a complete physical theory that could be calculated and tested. He combined Newton's mathematical treatment of gravity and Leibniz's relational view of space and Mach's opinion about the origin of inertia as a starting point to develop his own mathematical framework to explain how matter curves spacetime.[10] In doing so, Einstein accomplished an unprecedented feat—he transformed centuries of scattered philosophical debate into a unified, testable physical theory: general relativity. According to general relativity, the curved water surface in Newton's bucket is not caused by rotation relative to an absolute space but by the local structure of spacetime.[6] The water tries to continue its motion because inertia guides it to follow the path defined by the surrounding spacetime. Because the rotating bucket is pulling the water out of its original path, the water is experiencing resistance, which causes the curved surface. The core of general relativity is that the distribution of matter and energy determines the curvature of spacetime, and this curved spacetime then determines how objects move. It describes space as a dynamic structure shaped by physical interactions instead of an independent container. It shows that space is neither Newton's absolute space nor Leibniz's network of relations-- it is a physical, relational substance whose geometry evolves with the matter in the universe. The "distant stars" help determine the shape of spacetime. This curved spacetime is the new gravitational field, which tells the water how to move. The water in the bucket curves because it is being "forced" to accelerate against the "local spacetime geometry" defined by all the mass in the universe.

6. Conclusion

By tracing the intellectual trajectory from Newton to Leibniz, Mach, and finally Einstein, this essay shows how their unique and different ideas about space and motion build the long-term debate between the absolute and relational spaces. Leibniz's relational view of space seems like the losing side in the debate with Newton in the early times. However, Mach later revived and developed the idea that inertia can depend on the mass distribution of the universe. Einstein's general relativity ultimately demonstrated that space and motion are interrelated rather than set against an eternal fixed background.[11] Newton established the physical reality of inertial forces and acceleration with his bucket experiment. Leibniz opposed his idea and argued that space is not an independent container but a network of relations between objects. Mach then revised and developed Leibniz's idea by claiming that the inertia of an object can only be determined by its interaction with all other masses in the universe, which provides a physical interpretation to prove Leibniz's philosophical idea. Based on all these aspects and ideas, Einstein finally created general relativity. It shows that spacetime is a real geometric configuration that is shaped by matter and energy. Taken together, their ideas shifted the debates from a philosophical argument into a foundational part of modern physics. The ultimate significance of this debate went far beyond philosophy and physics themselves; it clarifies the nature of space and raises deeper questions about reality and highlights the limits of scientific explanation. The exchange between Newton, Leibniz, Mach, and Einstein's ideas highlights that progress in science arises not only from new experiments but also from philosophical reflection on previously unquestionable issues. Their debate illustrates that even abstract disagreements can reshape the entire scientific framework, which led humanity to redefine fundamental concepts such as inertia and motion.[12] When later scientists rethink the basic assumptions about space and motion, this centuries-long debate reminds them that philosophical ideas can guide science forward and even spark major scientific revolutions.

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