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# A Structuralist Account of Laws of Motion in Classical Dynamics

Kyuong-Eun Yang†

This essay is concerned with laws of motion within classical dynamics involving both Newtonian and Einsteinian physics. This essay criticizes Huggett's account of the nature of laws of motion following the Mill-Ramsey-Lewis (i.e., modern Humean) account, and provides my modified account following structural realism. Huggett views the laws as being supervenient on the relational regularities. Comparing with Huggett's account, my view on the nature of the laws of motion also considers the relations of regularity between events as the essential elements that explain the success of classical dynamics. Yet, my structuralist account of laws emphasizes the dispositional properties represented as the geometric relation between events without specifying micro-physical foundations underlying the relationships between events. By employing my structuralist acccount of laws, I attempt to clarify the nature of laws of motion, such as the laws of inertia and acceleration, the relativity and the equivalence principles within classical dynamics.

【Key Words】 Nature of Laws, Classical Dynamics, Mill-Ramsey-Lewis Humean Account of Laws, Structural Realism, Dispositional Property

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† Korea National University of Education.

# 1. Introduction

This essay is concerned with the nature of laws of motion within classical dynamics[1] which involves Newtonian dynamics, Einstein's special and general relativity. Newtonian dynamics, according to Newton, is "the science, expressed in exact propositions and demonstrations, of the *motions* that result from any forces whatever and of the forces that are required for any motions whatever." (Newton 1726, 382, *my own italics*) Both Einstein's special and general relativity are also founded on axiomatic principles on motions, which involve the light postulate, the relativity principle and the equivalence principle. The main engines of classical dynamics are the laws of motion, which describe the relationships of regularity between non-simultaneous events. A recent interpretation suggested by Brown (2005), DiSalle (2006) and Huggett (2006), entitled the "dynamical perspective", endorses this view explicitly. It is dynamical laws, rather than the structure of space-time, that provide the foundation of classical dynamics. The advocates of this view criticize the traditional understanding on the structure of classical dynamics, that is, the relationship between dynamical laws and space-time. The traditional interpretations have placed space-time as the foundation of classical dynamics. (Norton 1989, Janssen 2002) On the other hand, the recent dynamical perspective claims that space-time is a merely coordinate which makes sense of the laws of motion, such as the law of inertia and acceleration. Although the dynamical perspective presents a clear relationship between the laws of

[1] Classical dynamics here denotes non-quantum mechanics, which involves both classical particle mechanics (Newtonian mechanics) and classical field theories (electrodynamics, special and general relativity).

motion and space-time by overturning the traditional interpretations, it is yet unclear about the nature of laws of motion, which provide the foundation of classical dynamics. This essay attempts to clarify this issue.

In spite of their common position endorsing the laws of motion as the foundation of classical dynamics, advocates of the dynamical perspective have different views on the nature of the laws of motion. Brown views the laws of motion as supervened and ultimately reduced by the micro-physical structures of matter ("the laws governing material systems"). DiSalle views dynamical laws as phenomenological laws constraining the spatio-temporal measurements ("law-like aspects of our experience"). On the other hand, Huggett views the laws of motion as being supervenient on the relational regularities along Humean lines. While DiSalle and Huggett are concerned mainly with Newtonian dynamics, Brown's account is based on Einstein's special and general relativity. The common issue here is *how* the laws of motion are codified within space-time geometry. Yet the aforementioned authors hold different interpretations on the nature of laws. By mediating strengths and weaknesses of their views, I will attempt to argue that the laws of motion are basically based on structural constraints between events, which specify the relationships between events. These constraints exhibit space-time geometry. These structural constraints between events are characterized along the line of structural realism, in the sense that structural constraints between events involve the dispositional properties represented as the geometric relationships between events without specifying micro-physical foundations underlying the relationships between events as "Nature will eternally hide from us." (Poincaré 1905, 161)

## 2. The Dynamical Perspective on the Nature of the Laws of Motion

There are two ways of interpreting the structure of classical dynamics by capturing the relationship between the structure of space-time and the laws of motion. According to the “space-time centered view”, which is the conventional wisdom, both Newtonian and Einsteinian space-times have its causal property of generating inertial structure. In other words, space-time is a causally efficient entity - it causes material bodies to follow their trajectories in accordance with the laws of motion, such as the law of inertia and acceleration. On the other hand, an alternative understanding of the workings of classical dynamics is suggested, entitled the dynamical perspective by Brown (2005), DiSalle (2006), and Huggett (2006). According to this view, it is dynamical laws, rather than the structure of space-time, that provide the foundation of space-time geometry. The advocates of this view criticize the traditional understanding of the relationship between space-times and dynamical laws, and defend that space-time is a merely coordinate which makes sense of the laws of motion, such as the law of inertia and acceleration.

Although both Brown and DiSalle emphasize the laws of motion as the foundation of classical dynamics, they differ over the nature of laws, which underpin the structure of space-time. Brown views the structure of space-time (especially within Einstein’s special and general relativity) as supervene upon and ultimately reduced by the micro-structures of matter (“the laws governing material systems”). On the other hand, DiSalle views dynamical laws (especially in Newtonian dynamics) as phenomenological laws constraining spatio-temporal measurements (“law-like aspects of our experience"). Although Brown and DiSalle have a different view concerning what constitutes this basic physical process, the common denominator is their emphasis on dynamical laws which underpin space-time geometry. Yet, they have not clarified their position on the nature of the laws of motion. Given that they emphasize the laws of motion as the foundation of classical dynamics, the dynamical perspective is required to clarify the nature of the laws of motion.

Huggett's recent attempt seems to remedy this shortcoming of the dynamical perspective. Huggett's view attempts to clarify the relationship between laws of motion and space-time concepts by means of the relations of the regularity between events:

> *A specification of the totality of relations, masses, and charges of bodies at a time I will call the 'relational state,' or more loosely the 'relations.'* Although it involves facts about non-spatiotemporal properties, it deserves that title because it excludes any non-relational … spatiotemporal properties; I take it that an honest relationist can endorse relational states as unproblematic relational objects. (Huggett 2006, 47, my italics)

While Huggett's main motivation here is to provide a relationist critique against substantivalists' interpretation of the law of inertia and acceleration, he makes this attempt by endorsing the dynamical perspective, rather than by following the traditional approach of the substance-relation controversy. (Huggett 1999, 2006)

Huggett views spatio-temporal properties as stemming from the laws of motion, which are supervenient on the relational regularities between events. He explicitly states that his account is based on the Mill-Ramsey-Lewis account of laws, which is essentially Humean. According to this view, the laws of nature are "a theorem (or axiom) in each of the true deductive systems that achieves a best combination of simplicity and strength." (Lewis 1973, p. 73) Ramsey also claims that the uniformities of laws of nature are "consequences of those opositions which we should take as axioms if we knew everything and organised it as simply as possible in a deductive system." (ibid.) This MRL approach considers laws as the best – simplest and most informative – summary of information about the given phenomena. Huggett characterizes the laws of motion exactly along these lines: "when we attribute lawfulness to a statement we attribute *no more* to it than being a theorem of the 'strongest' (that is, most informative) and 'simplest' axiomatization of the totality of events in the history of the world, past, present and future." (ibid., 43) Along these lines, Huggett endorses both Humean and the dynamical perspective given that he views spatio-temporal properties as being supervenient upon bodily behaviours, not the other way around.[2)]

Given the relations of regularities between events specified by the law of inertia or of acceleration, an inertial frame of reference can be constructed by designating a certain rest reference body (such as a fixed star) as the origin of coordinates whose orthogonal axes measure the distance from the reference body: "a frame is 'adopted' to some reference body if it is at rest at the origin of the frame, the axes are orthogonal and distances along the axes equal to the distances from the body." (ibid., 46) We can see, then, that inertial frames are supervenient on the relations of regularities between events. Although the above account assumes the existence of a moving body in order to characterize inertial frames, Huggett

[2)] Although Huggett's approach to laws is based on his case of Newtonian dynamics, he admits that his account also applies other theories of classical dynamics, i.e., Einstein' special and general relativity. (Huggett, private communication) generalizes this perspective to the case where no inertially moving body exists:

> Consider then the class of all frames related by arbitrary continuous spatially rigid transformations of the co-ordinates of adopted frames; this class contains frames in arbitrary states of motion with respect to any reference body, including all the inertial frames. (Huggett 2006, 46)

In contrast to the traditional account of the concepts of inertial frames and of acceleration as spatio-temporal properties, Huggett maintains that these concepts are founded on the regularity relations between events comprising the "relational history":

> [S]ince these laws supervene on the relational history and since they pick out the inertial frames, I claim that the inertial frames (and hence absolute accelerations) supervene on the history of relations: inertial frames are the frames in which the laws that supervene on the history of relations hold; absolute acceleration is acceleration in the frames in which the laws that supervene on the history of relations hold. Thus nothing but relations are needed to give an account of the absolute quantities, and hence dynamical state, of Newtonian mechanics. (ibid., 48)

## 3. A Structuralist Account on Laws of Motion

This section attempts to criticize and modify Huggett's account of the nature of laws of motion. Comparing with Huggett's account, my view on the nature of the laws of motion also considers the relations of regularity between events as the essential elements that explain the success of classical dynamics. Yet, there is a major difference between my view and Huggett's. Although I agree of course that inertial frames are determined by the law of inertia, it is difficult to accept that these laws of motion are *nothing but* "theorem[s] of the strongest and simplest axiomatization of the totality of events in this history." (ibid., 43) Heggett follows Humean Mill-Ramsey-Lewis (MRL)'s approach in holding that laws only summarize our observations. Therefore, his view faces the same problem as MRL's own approach – the inability to distinguish accidental generalizations from genuine laws. According to Dorato:

> Is this [summarizing observations, which best combine simplicity and strength] the only reason that accidental generalizations would be excluded from axiomatic systems? I do not believe so, because the concept of strength is unfailingly dependent on our cognitive purposes.[3] The selectivity that we are attempting to clarify is in fact not only tied to the "compressibility of information" permitted by a scientific law, … but also to the fundamental, although too often overlooked assertion that *the truths to which we aspire, whether in science or in daily life, must be interesting.* (Dorato 2005, 91)

Hence, it seems that regularities between events – merely based on epistemic foundation – are too weak to characterize the law of inertia. For example, consider a sentence that 'all bachelors are male.' As for this sentence, all criteria of a Humean law are satisfied but it is by no means a genuine law. It is an accidental generalization. How can we distinguish such generalizations from

[3] Given that both standards to be genuine laws, simplicity and strength, characterize "the axiomatization of the totality of events" essentially relative to our knowledge, rather than to the real physical world, it seems that Huggett's approach depends essentially on epistemic foundation.

real law statements? At this point, Humean Huggett bites the bullet and claims that regularity is all we need to capture a law since the only difference between a genuine law and an accidental generalization is our epistemic attitude. However, with only observed phenomena which Humeans depend on in order to characterize laws, it is impossible to capture important properties such as the differentiability of Newton's law of acceleration and even the continuity of Newton's law of inertia. Actual observations cannot capture these properties, which are essential for encapsulating bodily motions within classical dynamics.

These weaknesses become more manifest if we consider Newton's own account of the law of inertia, which is easily seen to be inconsistent with Huggett's account. According to Newton, the law of inertia attributes "the power of resisting by which everybody … perseveres in its state either of resisting or of moving uniformly straight forward." (Newton 1726, 404) Here, the law of inertia postulates a tendency or a disposition of inertia – a disposition that resists acceleration inertial mass and arises from a body's inertial mass. Its disposition is a power of inertia that make certain things happen and its potentials to react in specific ways in various counterfactual circumstances. The laws as dispositions are also captured as capacity by Cartwright (1999), who provides electric charge and mass (or inertia) as its typical example. She claims that what is essential in the operation of science is reference to capacity. Scientific laws in fact is about which capacities exist and how they are superposed together. My account attempts to provide the foundations of dynamics by means of some realist properties and dispositions of material bodies. Although the mechanism of inertia could be further analysable in terms of the body's atomic structure, it is not necessary in our context because of Newton's own weak equivalence principle (this will be discussed shortly). Yet, the dispositional property of inertia can be further clarified. A simple clarification can be found in Dainton (2001):

> What do inertial effects consist of? Typically, they consist of internal stresses between the component parts of a body. Objects follow inertial paths unless acted on by a force (which is created by gravity, magnetism, or an expenditure of energy). When objects are forced off their inertial path, this is typically achieved by applying force to one part of the object only, which sets up tensions *within* the object: that is, some parts of the object start exerting forces on other parts. In the rotating globes case, the tension is registered in the cord, which exerts a force on the globes (whose inertial motions are tangential to their circular motion). (Dainton 2001, 191-2)

This dispositional property is what distinguishes genuine laws of nature from accidental generalizations. As Bigelow, Ellis and Lierse (1992) put it:

> We claim that among the essential properties of a property there is the propensity or disposition of anything having it to show a certain kind of behaviour in a particular context. What science studies and codifies are the manifestations of these dispositions. (Bigelow, Ellis and Lierse 1992, 378)

This claim that genuine laws involve dispositional properties, then, overcomes problems that endanger MRL approach. And given that the law of inertia involves this dispositional property, which is over and above regularities between events, I reject Humean approach to dynamical laws advocated by Huggett.

I should emphasize that just as Huggett views that the regularity relations between events as characterized by a "relational history," these dispositional properties are also characterized by "the relational structure of the world of experience and of science." (Dorato 2005, 111) Because of Newton's weak principle of equivalence – "the accelerative gravity, or the force that produces gravity is the same in all bodies universally." (Newton 1729), the micro-physical structure of the inertia of a given body is irrelevant in the context of the law of inertia. Yet, the relational histories of events specified by the law of inertia, as Newton implied, stem from the dispositional property of inertia, which makes succeeding events occur. Yet, its underlying micro-physical structure is not necessary due to the weak equivalence principle, which captures the universality of gravitation. Instead, he law of inertia stems from the property manifested by *geometric* relations between events:

> Suppose we are given the trajectories of the particles whose world-lines T attempts to specify in its laws of motion (including, perhaps, the trajectories of light rays) and the matter fields or source variables (mass density, charge density, and so on) giving rise to the interactions described by *T*. *These entities are relatively observable, and they are precisely the entities that the traditional relationist is willing to admit.* (Friedman 1983, 152, my italics)

We can say the same thing within both Einstein's special and general relativity. Just as inertial frames become meaningful by providing an inertial system in which the law of inertia is satisfied, Einstein's special relativity employs the behaviour of the light pulse in order to make sense of the required system of reference in which the light postulate is satisfied. (Torretti 1983, 55) As a fundamental principle, the light postulate plays a role of an axiom of Einstein's special relativity, which does not require further analysis of micro-foundations of the light pulse. What is the issue in the light postulate is the dispositional property maintaining the specific relations between events. And Einstein's equivalence principle, which is the fundamental axiom of general relativity, works in the same way. While both local and global inertial frames in Newtonian physics are determined by inertially moving bodies due to the law of inertia, only locally inertial frame within Einstein's general relativity is determined by free falling bodies due to Einstein's equivalence principle. Given the role of the equivalence principle as the axiomatic one, the principle does not require any micro-physical foundation. Free falling motions as inertial ones within Einstein's general relativity, just like its Newtonian counterpart, is based on the dispositional property relating a set of apparently different events.

Accordingly, I suggest that this relational history of events, which is manifested by a dispositional property involved within the laws of motion, captures the essence of dynamical laws. I call this the structural constraints between events.

> *The manifestation of dispositions codified by scientific laws essentially involves a relationship between different properties, in accordance with the fact that the kind of knowledge permitted by science is essentially relational and structural.* This affirmation is justified not only inasmuch as the meaning of theoretical terms is implicitly defined by the context of the theory in which they appear, but also because … the mathematical language we use to refer to theoretical entities furnishes essential information on the network of relationships that these entities exemplifies. (Dorato 2005, 115, my italics)

Along these lines, my modified view claims that what dynamical laws involve are the relational and structural constraints between events, rather than the relation of regularity between events. Structural realism asserts that although the contents of a given theory are discarded, its underlying mathematical structures are invariant (or structurally invariant) in the course of theory change. (Worrall 1989) If these well-supported mathematical structures (or relations) are maintained under theory change, then it is highly probable that they represent the true underlying structures of nature, which are the elements contributing to the success of theories. So, "what Newton really discovered are the relationships between phenomena expressed in the mathematical equations of his theory" (Worrall 1989, 122) Since Worrall's resuscitation of structural realism originally developed by Henri Poincaré, there has been several attempts to clarify what is structure. Poincaré (1905) is viewed as epistemic structrual realism claiming that all that we can know is the structure or the relations between things, rather than things themselves. On the other hand, Ladyman (1998) proposes his own ontic structural realism, which asserts that what exist are only structures while 'things' by no means exist. In contrast, van Fraassen (1997) defends an empiricist and non-realist version of structuralism. Among these various versions of structural realism, my account depends on epistemic structural realism, rather than the ontic one and the non-realist one. For, I admit that inertia could be further analysable by underlying micro-physical entities, the epistemic accesses of which are not yet required due to the weak equivalence principle. In accordance with the further development of micro-physics, underlying entities become approximately true, yet their central terms do not necessarily refer (I will discuss this in more detail shortly). (Saatsi 2005) If this characterizes the history of scientific change, it seems that the claim of ontic structural realism that what exist are not things but only structures goes beyond knowledge provided by the history of science.

By viewing these structural constraints between events[4] as the essential elements of the laws of motion, my view on the nature of law is produced along the lines of structural realism, rather than one that, like Huggett's, emphasizes epistemic constraints over events. Accordingly, the difference between Huggett's and my view can be found in the difference that what involves dynamical laws. Huggett views dynamical laws as involving the relations of regularity, while I consider the laws as involving the structural constrains between events. The relations of regularity mean that the relations between events are specified by means of empirical regularity of Humean line. On the other hand, my view on the structural constraint between events involves the dispositional properties represented as the geometric relation between events without specifying underlying micro-physical foundations.

Additional supports for my view, rather than Huggett's, can be found in the development of succeeding theories encapsulating the law of inertia. What Newton captured the propensity of inertia

4) The notion of "events in space-time" requires clarification. On my account, events are things occurring in the infinitesimal place and time. My account shares with substantivalism and relationism - a view of an event as an idealized concept being pointlike rather than having any spatio-temporal extension. But the account differs from those given by traditional substantivalism and relationism. From the perspective of substantivalism, events are occurring at given space-time points. And the spatio-temporal relations between events, according to Earman (1989:12), are "relations among substratum of … spacetime points that underlie events." On the other hand, for relationism, the relations between events are direct without depending on space-time points that underlies events. Yet, these traditional views by no means consider these relations between events as being constrained by dynamical laws. In my view, laws play an essential role in that events stands in spatio-temporal relations in accordance with dynamical laws.

without its micro-physical underpinning manifests its foundation within Newton's successors. Brown points out that within Einstein's general relativity, the law of inertia stems from the dynamical properties of the micro-physical structure of matter configurations. The micro foundations of the law of inertia can be revealed from the conservation principle within Einstein's general relativity, i.e., the vanishing of covariant divergence of the stress energy tensor field $T_{\mu\nu}$. Given that the conservation principle does not apply only to particular kinds of physical events but to all kinds of physical events occurring in the universe, the principle is universal in the sense that "the antecedent or referent class is a broad ontological category." (Bigelow, Ellis, and Lierse 1992, 385) Brown's account can also be interpreted as being at odds with Humean approach of dynamical laws endorsed by Huggett. The development of physics exhibits the weakness of Humean Huggett's account. With the development of physics, we see that the law of inertia is much more than "a theorem of the strongest and simplest axiomatization of the totality of events." Given that the relational history specified by inertial motion within the general theory is derived by an universal principle, it seems to be difficult to advocate Humean approach of dynamical laws. Instead, the law of inertia in the general theory can be viewed as the structural constraint between events, which stems from the micro-physical structures of material bodies. In other words, the law of inertia provides a dispositional property of the movement of a body, which is represented as the geometric relationships between events without specifying underlying micro-physical foundations.[5)]

[5)] Brown's dynamical account takes a different choice in characterizing the nature of laws in that he views the laws as reduced essentially by micro-physical foundations, i.e., the quantum theory of matter. Yet

Given that the law of inertia by no means refer to the material constitution of a body in a motion, what underlies the relations of regularity between events is debatable. There have been attempts to explain the law of inertia by means of quantum field theories employing Hicks or string mechanism. Yet, these attempts have no guarantee that these theoretical speculations acquire firm empirical support. Some critiques such as Smolin (2006) and Woit (2006) claim that these theoretical attempts are comparable to "epicycle on epicycle." Given the lack of consensus, it is not unreasonable to doubt that these microscopic theories have reached ultimate micro-physical entities. Although it cannot be denied that inertia supervenes on a specific microscopic structure, it seems that what we can know are the relationships between events, which are specified by the laws of motion. Furthermore, given the fact that inertia is universal, i.e., does not depend on the material constitution of particles, the law of inertia needs no microscopic structure that plays a role in explaining the behaviour of a given body. In the case of classical theories, the advocates of the dynamical perspective, on the contrary, views that the structural constraint provided by the laws of motion is the essential part of space-time theories – the part which makes its empirical success possible:

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my view maintains that classical dynamics has its own generalization involving Newton's weak equivalence principle, which enables us do classical physics without its micro-foundation. Whether or not quantum theories of gravitation need the micro-version of the same principle depends on a specific context of quantum theory. Accordingly, the laws as dispositional properties needs only supervenence, rather than reduction. This distinguishes my view from Brown's.

> Like all physical geometry, spacetime theory explains phenomena of motion just to the extent that it exhibits the structural constraints to which the phenomena conform. (DiSalle 1995, 332)

In the same spirit, Brown and Pooley claim:

> [I]t will be instructive to acknowledge that in many contexts, perhaps in most contexts, one should not appeal to the *details* of the dynamics governing the microstructure of bodies exemplifying relativistic effects when one is giving a constructive explanation[6] of them. *Granted that there are stable bodies*, it is sufficient for those bodies to undergo Lorentz contraction that the laws (whatever they are) that govern the behaviour of their microphysical constituents are Lorentz covariant. (Brown and Pooley 2006, 82)

This structural characterization of the laws of motion can also be found in Eugene Wigner, who wrote that "the laws of nature

6) "A constructive explanation" is based on a "constructive theory," which Einstein characterized as an attempt to build up "a picture of the more complex phenomena out of materials of the more simple scheme." (Einstein 1919) The kinetic theory of gases that seeks to reduce thermal process to movements of molecules is a typical example. The aim of constructive theories is to achieve the underlying physical reality by understanding a group of natural process. In contrast, principle theories start from some general empirical regularities, which are elevated to the status of postulates. Special relativity and thermodynamics are typical examples. The elements which form their basis are not posited to show natural processes. Such a theory aims to explain phenomena by showing that they necessarily occur in accordance with the postulate. Since principle theories are concerned with a certain level of generalization of phenomena, their elements themselves do not necessarily correspond to underlying physical reality. Yet, it has been pointed out that this distinction is matter of degree, rather than absolute.

provide a structure and coherence to the set of events." (Wigner 1967, 17) And also:

> It is good to emphasize at this point the fact that the laws of nature, that is, the correlations between events, are the entities to which the symmetry laws apply, not the events themselves. Naturally, the events vary from place to place. However, if one observes the positions of a thrown rock at three different times, one will find a relation between those positions, and this relation will be the same at all points of the Earth. (ibid., 19)

## 4. The Nature of Laws and Principles from the Structuralist Perspective

This section employs my structuralist view of laws in order to capture the essence of the most well-known dynamical laws, such as the law of inertia and acceleration, and dynamical principles such as the light postulate and Einstein's relativity and equivalence principle.

The law of inertia relates one event to another by specifying the geometric relationship between non-simultaneous events: "[E]very body continues in its state of rest, or of uniform motion in a right line,[7] unless it is compelled to change that state by force

[7] Within the modern geometric framework, Newton's inertial motions are represented by geodesics. A geodesic is defined as a body's curve that continues to parallel to itself. Accordingly, within this framework, the law of inertia states that a body unaffected by any external forces moves in a way that the tangent vectors to its trajectory remains parallel to itself. The thesis of my essay is that this structural constraint, which is expressed as the geodesic equation of motion plays an essential part that in Newtonian dynamics.

impressed upon it." (Newton 1729, 17) A given body's state of motion develops to other such states in accordance with the law. In other words, the law of inertia describes the evolution of physical systems by specifying the relationship between the states of a given body's motion over time, which originates from the dispositional property of inertia, as pointed out earlier. Yet, the law of inertia by no means involves underlying mechanism whatsoever which explains *why* a given body follows a straight trajectory.

The law of acceleration also dictates the relationship between the states of a given body's motion over time, which Wigner described as "the correlations between events." (Wigner 1967, 19) The law of acceleration is concerned with the change of motion subject to forces exerted on a given body, such that its acceleration is proportional to and in the direction of "the motive force impressed." Although the law of acceleration involves a set of forces exerted on a given body and its mass, it does not involve any specific detailed mechanism whatsoever explaining why the body follows a curved trajectory. The law of acceleration specifies, instead, just the relationship between events.[8]

These characteristics of the laws of motion could be employed to support either Huggett's or my view. Yet, along with his characterization of the law of inertia and acceleration, Newton considered the law governing gravity as *more than* "a theorem of the strongest and simplest axiomatization of the totality of events." He instead held that while the causal influence of gravity really

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[8] An accelerating motion of a body, within the geometric framework, is represented as a curve that is not geodesics. The curvature of its trajectory measures the magnitude of the acceleration of the body, and the total force acting on the body. In this way, the relationships between events codify all information encoded in the laws of motion.

exists, it is enough to explain the behaviours of bodies through the laws of motion specifying the relations between events without referring to any underlying mechanism:

> I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypothesis. … *It is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain all the motions of the heavenly bodies and of our sea.* (Newton 1726, 943, my italics)

This is well represented from Newton's own famous methodological dictum "hypothesis non fingo (do not feign hypothesis)."

Another dynamical principle, the principle of relativity, which plays a crucial role in the development from Newtonian to Einsteinian physics, can be characterized in a similar manner.[9] According to Wigner, the principle of relativity provides a constraint over the correlations between events in that it provides a further structure over the laws of motion: "the correlations between

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[9] Two ways of providing dynamic information are differentiated in this thesis: (1) dynamic laws and (2) dynamic principles. These two notions are different in two ways. The first involves the way they are expressed, rather than their contents. Dynamic laws, such as Newton's three laws of motion, are written quantitatively – so easily translated into mathematical equations, while dynamic principles, such as the principle of relativity, and equivalence, are written qualitatively. The second way in which they are different is that, while a dynamic law imposes a structural constraint on events, a dynamic principle, on the other, provides a further meta-level constraint over laws. Of course since the laws in turn constrain events, dynamic principles also constrain events – but unlike dynamic laws they do so indirectly via those laws.

events, are the entities to which symmetry laws apply, not the events themselves." (Wigner 1967, 19) This principle states that the dynamical laws obeyed by a given body cannot distinguish whether they are with respect to a rest or any uniformly moving frames. In other words, the physics of a body at rest and one moving uniformly is exactly the same. In this way, the principle of relativity provides additional constraints over dynamical laws, such as the law of inertia and acceleration, by identifying apparently distinct states of motion (the state of rest and uniform motion). This structural characterization is manifest in Einstein:

> The principle of relativity, or, more exactly, the principle of relativity together with the principle of the constancy of velocity of light, is *not to be conceived as a "complete system"*, in fact, not as a system at all, but merely as a heuristic principle which, when considered by itself, contains only statements about rigid bodies, clocks, and light signals. It is only by requiring *relations between otherwise seemingly unrelated laws* that the theory of relativity provides additional statements. (Einstein 1907, quoted from Brown and Pooley 2006, 74, my italics)

In the above account, Einstein also characterized the principle of the constancy of speed of light as a structural one. The principle of the constancy of speed of light imposes a constraint over the dynamics of a given body. According to Norton, the principle of the constancy of speed of light specifies "a special velocity at each event." (Norton 2000) Within Einstein's special theory, it is meaningless to ask which miro-physical structure causally inhibits material bodies to surpass the speed of light. Just as the law of inertia exhibits structural constraints between events, so does the light hypothesis.[10)]

As for Einstein's equivalence principle, the principle in fact plays the role of the law of inertia within general relativity. Unlike the electric-magnetic field, the gravitational field is universal, which cannot be eliminated within a specific region. As one cannot get rid of gravitation, inertial motions cannot be defined by emptying all the force that affects material bodies, as Newton did. Einstein's equivalence principle selects *motions under no force except gravitation* as locally inertial motions. Here, the dispositional property of locally inertial bodies are captured within the equivalence principle. Free falling motions as inertial ones within Einstein's theory, just like its Newtonian counterpart, stems from the dispositional property relating a set of apparently different events. Within Einstein's general relativity, we cannot ask micro-foundations of the equivalence principle since it is the axiom of the theory. Accordingly, we can say the same things on Einstein's equivalence principle as the law of inertia in Newtonian dynamics. The principle, without specifying its micro-foundations, encapsulates the dispositional property which relates non-simultaneous events, i.e., inertial motion. In this way, both dynamical laws and principles provide the structural constraints over the relationships between events.

## 5. Conclusion

This essay has elucidated the nature of laws within classical dynamics by criticizing and modifying Huggett's relational account.

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[10] Torretti presents a clear analogy between the law of inertia and the light postulate: "In this the LP [the light postulate] does not differ essentially from the IP [principle of inertia]." (Torretti 1983, 55)

My view is, then, quite different from the conventional wisdom of the space-time centered view in that it states that the structure of space-time stems from dynamical laws. It is also different from Huggett's view in that dynamical laws encapsulate the structural constraints over events. Although I am sympathetic to Brown's view which emphasizes the micro-foundation of dynamical laws, my view admits only the structural characteristics of dynamical laws and principles which involve the relations between events without referring to their underlying mechanism. Brown views that the laws, such as Lorentz contraction and the law of inertia, are to be reduced essentially by matter theories. However, my view emphasizes only structural properties without reduction. By providing a set of constraints over geometric trajectories of a moving body, dynamical laws specify the correlation between events. Thus, my view agrees with that of d'Espanat:

> A general agreement seems nowadays to exist among physicists that the aim of their scientific investigations is to discover structural relationships between individual "happenings." (d'Espanat 1971, 372, quoted from Dorato 2005)

By viewing these structural constraints between events as the essential elements of the laws of motion, my view on the nature of law is along the lines of structural realism, rather than one that like Huggett's emphasizes epistemic constraints over events. Accordingly, I am sympathetic to so-called structural realism in comprehending the essential elements of scientific theories. Yet, I oppose structural realism that emphasizes space-time geometry, which Dorato (2000) endorses. His structural space-time realism is based on mathematical structure that is by-products of dynamical laws of Newtonian and Einsteinian physics. The essential mathematical structures in these theories are the geodesic equation capturing the law of inertia within classical dynamics. And the law encapsulated by the geodesic equation is essentially about the structural characteristics which involve the relations between events without referring to their underlying mechanism.

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