Gravity from a Probabilistic Point of View

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Abstract. Intended as an introduction of the author's research questions, this paper is a further exploration of "probability as a physical motive", an attempt to entertain an alternative to causal, deterministic explanation in science. According to this approach, explanation need not be an account of what *forces* dynamics; explanation may be found in the correlations of dynamics to *possibilities*.

Uniform distribution of mass (near-zero Weyl tensor of space-time curvature) has been suggested by Penrose as that initial condition which accounts for the second law of thermodynamics, as the physical expression of the "MaxEnt" principle. A distribution of mass with respect to gravity is taken as a certain space-time topography, and inquiry is made into how there might be more ways for space-time topography to be irregular than for it to be flat. The attempt to understand the counter-intuitive circumstance of *uniform* distribution representing *dis*-equilibrium, in the case of gravity, leads to discussion of the Machian question of how a configuration may affect, or even effect, the very space in which it is supposed to reside. This leads to speculation on the idea that even state space might depend on state.

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INTRODUCTION

Einstein is said to have remarked, "What really interests me is whether God had any choice in the creation of the world" [1]. I'm inverting the question and proposing, "What really interests me is whether God has anything *but* choice in the creation of the world."

It is to be expected that participants of this MaxEnt conference will be inclined to favor the "observer ignorance" interpretation of probability, and perhaps even to regard thermodynamic entropy as "an anthropomorphic concept" (after Jaynes [2]). Yet I am rather inclined to think that we ought to regard probability (or possibility), not strictly as a tool of inference, but as the fundamental basis of physical dynamics [3].

In the spirit of a workshop submission, this paper is meant to be a contribution to a suggested alternative scientific viewpoint, in which the figure of interest would be probability, interpreted physically, rather than cause, interpreted deterministically. Attention is given to freedom instead of constraint. I see this as consonant with the intent of Jaynes' MaxEnt, where "least-biased inference" depends on the assumption of maximal freedom for an unknown quantity, consistent with known constraints. The radical conjecture underlying my research is that constraints may themselves arise from the realization of freedoms: *choice* may account for *law*.

This is a tentative presentation of some ideas, rather than a traditional presentation of research results. The basic ideas will be presented, leading to a sketch of their attempted application to gravity and their extension to some Machian ideas concerning phase space.[1] The author claims to be neither physicist nor philosopher, but offers these ideas with an invitation for workshop participants' feedback and corrections.

BACKGROUND OF ENTROPY DYNAMICS

This research comes after considerable reflection on the apparent fundamental importance of *difference*, very generally speaking, in dynamics, together with years of observation that life is eminently opportunistic, rather than competitive, as it is traditionally supposed to be. Although the notion of "difference" may seem too vague or general to be of much use, the idea that it is fundamental, both in logic and in physics, has been expressed in various ways by many prominent scholars.

George Spencer-Brown, in a work on the foundations of logic [4], begins simply by drawing an abstract distinction, noting that, "there can be no distinction without motive, and there can be no motive unless contents are seen to differ in value." Although his work is the exposition of a calculus conceived as a foundation of symbolic logic, he states that his theme is that "a universe comes into being when a space is severed or taken apart"—that is, when a distiction is made, or when a difference exists.

Pierre Curie argued (in an 1894 paper) that "it is asymmetry that produces phenomena" (Curie's symmetry principle) [5]. Asymmetry represents *difference*, or disequilibrium, and hence the potential to move toward equilibrium. Symmetry is *in*difference, formally speaking, with respect to some transformation, and, as Rosen has shown, can be understood as a concept parallel to that of entropy, or equilibrium [6].

Sadi Carnot, in an early 19th-century work that is generally regarded as the founding work of thermodynamics, stated that "wherever a difference of temperature exists, motive force can be produced" [7]. *Difference* is of the essence here, I claim, not temperature.

The second law of thermodynamics

My study in "the quantification of spatio-temporal order" (i.e. *difference*) has much to do with the second law of thermodynamics. The second law is commonly understood as the law of increasing entropy (the "running down" of the world) but I am trying to understand it as the law of possibilities being realized, via the equilibration of differences. Since thermodynamic entropy is commonly associated with "disorder", I tentatively borrow the term "order" to refer to disequilibrium, or to the sum of differences which might afford the dynamic opportunity for equilibration processes.

Statistical mechanics was conceived to provide a deterministic explanation for thermodynamics, and in particular for the second law. According to Boltzmann, one of its founders, and others, the essence of the second law of thermodynamics is that systems

[1] Ernst Mach questioned absolute frames and suggested that inertia may be the effect of the rest of the mass in the universe on a given mass. By "Machian" I mean more generally the view that configurations might determine laws rather than *vice versa*, that space might depend on what is in it.

progress from less probable states to more probable states [8, 9, 10, 11]. The meaning of “less probable” and “more probable” here refers to the number of specific ways (*microstates*) that an observed *macrostate* may be realized. The definition of a macrostate, or “thermodynamic state” may seem unsatisfactory for its arbitrariness, yet we cannot do science without lumping particular states together; science is essentially perception of symmetries, and we proceed by recognizing *equivalence classes* [6]. A macrostate is thus an equivalence class of particular microstates.

The second law of thermodynamics can be understood in terms of the path of a particular system in state space, or phase space, with respect to equivalent states: however you partition the phase space into equivalence-class regions, defined in terms of any thermodynamic parameters, such as temperature or pressure, which are typically averages, the system is expected to progress from smaller regions to larger regions. For this reason Campbell suggested that entropy could be associated with a geometric *measure* (generalized volume) of phase space [12], actually an extension of Boltzmann’s original insight (engraved on his tombstone) that the entropy S of a macrostate should be a simple monotonic function of the number W of consistent microstates: $S = k \ln W$, where k is Boltzmann’s constant.

Penrose derives the second law of thermodynamics as a *consequence* of the extraordinarily unlikely state of the early universe (located in an exceedingly small region of the phase space of the universe), exhibiting the spatio-temporal “order” (in my proposed sense of the word) of near-zero *Weyl* tensor of space-time curvature [11]. This describes a uniform distribution of mass, with the greatest sum of *differences* in locations of centers of mass, and hence the greatest gravitational potential. The second law of thermodynamics is thus seen as the physical realization of MaxEnt inference applied to the location of the universe in phase space. The apparent primacy of the “spatial order” of gravity, cosmologically speaking, motivates the inquiry into how it might be understood in terms of configuration (phase) space *possibilities*, without presupposing any *force*.

Causality and explanation in science

The larger intent of my research is to explore the idea of considering possibilities, or opportunities, as the reason that things happen, rather than insisting on explanation based on causal forces (like gravity).

Such an idea is not without precedent. In a 2003 paper Anandan has argued that “there are no fundamental causal laws but only probabilities for physical processes” [13]. Almost sixty years before, Schrödinger had remarked that “physical laws rest on atomic statistics and are therefore only approximate” [14]. It is apparent that the second law of thermodynamics stood as the first sign (in the tradition of modern science) that there is more to scientific explanation than deterministic causation; quantum mechanics stood as the second sign that the very criteria for acceptable explanation should be expanded.

Ancient Greek philosophy recognized four types of cause (Aristotelian cause): *formal* cause, *material* cause, *efficient* cause, and *final* cause. Modern science (of the past several centuries) has focused on *efficient* cause, or “push”, to explain what is observed. But the second law of thermodynamics appears more in the role of *final* cause, or "pull", even if a sense of "aim" or "purpose" is not assumed. Like other maximal principles, such as the Le Chatelier-Braun principle, least-action principle, or Maximum Entropy Production (MEP), such explanations seem unsatisfactory to some, insofar as a deterministic mechanism is not described, even though these principles qualify as "laws" insofar as they describe "rhythms or patterns" that are observed in nature [15], and fulfill the Popperian criteria of scientific theory with respect to prediction and refutation.

Recognizing that scientific law is essentially summary of observations, Solomonoff and Chaitin introduced a formal theory of inductive inference based on algorithmic information theory [16, 17]. In this formalism, scientific laws are certain minimal-length "strings"—instructions for generating all the actual or potential observation "strings" about which they speak. Regarded thus as information compression (*describing* rather than explicitly *exhibiting* strings), scientific laws are relieved of the requirement that they contain any mechanistic or temporal reference.

By the latter I refer to the idea that an explanation must provide a temporally prior cause. But as Rosen points out, there need not be any temporal import even in a cause-effect relation; it is rather a relation of logical implication between members of equivalence classes [6]. To the extent that an event at one time logically determines another event at a previous time, we might as well say that the consequent event *caused* the antecedent event. Moreover, if two events bear a necessary-and-sufficient logical relation of mutual implication to each other, one might say that they are both "cause" and "effect" of each other.

While all the other laws of physical dynamics are apparently symmetrical with respect to the direction of time[2], the second law of thermodynamics introduces time asymmetry: movies of individual billiard-ball collisions may be run backward and appear sensible, but reversed movies of so-called "irreversible" processes encompassing the evolution of averages do not appear sensible.

Eddington [18], Popper [19] and Denbigh [20] have argued that irreversibility (time asymmetry) involves more than second-law effects; specifically time asymmetry seems to have to do with (or to coincide with) expansion, or "spreading out", quite generally speaking. This idea is key to my proposed ideas concerning the correlation of dynamics to *possibilities*, thereby providing explanation by reference to rules of expansion in *possibility space* (phase space), instead of by reference to deterministic causal laws that would constrain or motivate processes.

Weizsäcker and others argue that irreversibility (or temporal asymmetry) is "a pre-condition of experience" [21], more or less fundamental to consciousness and not to be taken up as something to explain.[3] Alternative to such Kantian ideas, that certain notions of time and space are fundamental to thought itself, are such Machian ideas as that of Barbour [22], that time merely emerges from the universal, timeless configuration space that he calls "Platonia".

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[2] Except perhaps decay of the long-lived kaon particle

[3] In fact these authors suggest that the temporal *symmetry* of dynamics is the figure that ought to be explained, against the ground of temporal *asymmetry* of conscious experience.

MaxEnt and MEP; "spreading out" in phase space

One of the useful ideas that has come out of non-equilibrium thermodynamics is that of Maximum Entropy Production, or MEP (see, for example, [23]). MEP is the tendency for open systems far from equilibrium to respond to imposed differences, or gradients, by evolving to a steady state in which the production of entropy is maximized. Flow induced by an imposed difference acts to organize the system of interest in such a way that it can conduct the flow as rapidly as possible.[4]

Recently the connection between MEP and MaxEnt has been elucidated by Dewar [24]. While I suppose that the intended interpretation of these results was that they prove that MEP is merely a matter of inference in consideration of "observer ignorance", perhaps they rather suggest the information-theoretic basis of physical dynamics, as possibilities being realized—"spreading out" in phase space. The reason I picked gravity as a case in point is that it seems harder, intuitively, to see why things would tend to collect, rather than to disperse, when "left to their own devices".

Often as an introduction to the concept of thermodynamic entropy, textbook authors present the model of a container with a divider in the middle, with some gas on one side and vacuum on the other. When you remove the divider, the gas molecules disperse, and the measure of entropy increases because of this dispersion, this equilibration of a difference and decrease in free energy.[5]

In the case of gravity, however, matter "wants to" collect; there is maximum potential for evolution (maximum free energy) when matter is evenly dispersed, and minimum potential for evolution (minimum free energy) when matter has condensed, say into a black hole. This picture is rather the opposite of the picture of the confined gas molecules that "want to" disperse.

So you can say, well, sure the matter wants to collect, because there is this force of attraction. You presume the force. My idea is, instead, not to presume the force, but to understand how there might be more possible ways for matter to be collected than for it to be evenly distributed. This involves the interpretation of gravity as curvature of space-time. The core idea is that any assumed space may not be absolute; it may be determined by what is in it.

SPACE AS A FUNCTION OF ITS CONTENT

Geographers are acquainted with the idea that the locations of things, for example cities and transportation routes, change the shape of certain abstract geographic spaces which might represent variant notions of "distance" or "area" (such as "travel time" or "resource consumption"), and moreover that the locations of things affect the future locations of things, because of the mutual relation between object configuration and

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[4] The "organization" of the system may itself be regarded as a difference—potential or gradient—generated by the preceding flow.

[5] This whole tendency toward dispersion depends of course on the presumed "random" (actually, equilibrated) motion of the gas molecules. From the classical point of view nothing would happen in this model if they were frozen, presumed to be somehow motionless!

abstract space. Considered only as a cartographic device for representation of geographic relationships, this idea of relative space may not seem terribly profound, but here I consider the intriguing idea that distribution of matter might affect the most basic space that we habitually presume to know, and hence might affect the future location of matter. This is the first of two radical ideas that I offer for consideration: that the effect of matter on space (or *vice-versa*—geometrodynamics [1]) might be sufficient to "explain" dynamics, from a MaxEnt point of view.

Biologist Stuart Kauffman, considering questions of the evolution of life, advanced the conjecture that "living systems expand the dimensionality of the adjacent possible as rapidly as possible" [25]. The sense of this, I think, is that life, through evolution, maximizes its own opportunities for further evolution. This seems to be akin to the MEP principle insofar as it describes progress in a state space, not just following a trend but following the steepest trend. Although "the adjacent possible" presumably is a notion of proximity in a state space, the Kauffman conjecture, more radically interpreted, might be taken to suggest that life creates its own future, that the entire possibility space expands. This would seem to be nonsense, if the state space were taken, *a priori*, to encompass all possibilities in space-time. But perhaps we can question whether this notion is itself sensible. This is the second of two radical ideas that I offer for consideration: that states might affect their state space, that the field of possibilities might actually be a function of the configuration.

Toward a MaxEnt view of gravity

Following some ideas of Barbour about a timeless configuration space [22], I consider a first (metaphysical) law of dynamics: all configurations exist in some sense, but the more probable (*i.e.* highly represented as members of a class) configurations are the ones that are observed and considered to be reproducible. A general second law of dynamics might then be supposed: whatever configuration is observed now, we expect to observe a more probable configuration at another time. Finally it may turn out (after MEP) that we should expect to observe a natural expedition of this progress from the less probable to the more probable.

Mass shapes space-time, according to Einstein's general relativity, and a configuration of mass may be identified with a certain space-time topography. If there are more ways for space-time to be irregular than for it to be flat, then that is what one should expect to observe. I do not offer here a complete quantitative development of probabilistic geometrodynamics, but simply describe in general terms how this might be imagined.

Apparently we most readily visualize flat three-dimensional space, and hence we visualize curved space as a surface embedded in a space of higher dimension. In this way the gravitationally-curved space in the vicinity of a given mass may be visualized crudely as a depression in an otherwise flat two-dimensional surface. With this model in mind, one can then comfortably imagine that, the depth of the depression being dependent on the quantity and distribution of mass with which it is associated, there is a "stretching" of the gravitationally-curved space (imagined as a surface embedded in a space of higher dimension) as a consequence of the collection of mass, and this provides more location for mass to occupy, from this point of view.

Non-absolute phase space

Certainly one would expect that any imaginable distribution of mass (or equivalent space-time topography) could be considered as a point in a previously-defined phase space. But after the philosophical tradition of Leibniz, Mach, and Einstein, which has questioned the presumption that space and time should be taken as fixed or absolute frameworks, I wish to question the presumption of a fixed or absolute phase space.

Distinguishability of objects and number of states. By associating distributions of mass with space-time topography, implicitly we are not distinguishing between distributions wherein "different" mass of the same quantity is located in the same place. It is not clear whether it makes sense, even in quantitative analysis of probability, to imagine any individual identity attached to theoretically identical "objects".[6]

Moreover, since the number of possible states of a system depends on the number of objects in the system, and the distinguishability of objects may well depend on the state of the system, perhaps "system state" is an inherently self-referential concept. In that case the state space cannot be regarded as fixed or absolute.

Dimensionality and extent of state space. The dimensionality of phase space is taken to be the number of quantities that can vary, while the extent is taken to be the range of possible values for each of the dimensions. As Popper suggested (presumably referring to physical space), spatial extent must be fixed in order to define entropy [27]. Likewise this would be true in phase space. Yet as observers we have nothing but the present universe from which to infer other possible states; perhaps it is not unthinkable that both the dimensionality and extent of state space might depend on the present state.

Types of numbers used to specify state-space components. Clearly the measure of the field of possibilities in possibility space (state space) depends not only on the range, or bounds, for each of the dimensions, but also on the type of number assumed to specify a component. One might assume a discrete model or a continuous model, with state-space components specified by integers, real numbers, or complex numbers for example. Probability density of states between bounds in any dimension of state space would depend on this specification. If this specification could conceivably depend on the evolution of the system in question, then phase space could not be considered to be absolute.

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[6] In "What is quantum mechanics trying to tell us?"[26], Mermin offers the answer: "Correlations have physical reality; that which they correlate does not."

SUMMARY

The author's research agenda concerning dynamics regarded as equilibration of difference and realization of possibility has been sketched. Some thoughts on how gravity might be regarded in this way were offered, applying the idea that space depends on the configuration of its content. Finally, the suggestion has been introduced that this idea might apply to phase space itself.

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