Proceedings of the Annual Meeting of the Cognitive Science Society

Requisite Variety, Cognition, and Scientific Change

Proceedings of the Annual Meeting of the Cognitive Science Society, 42(0)

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2020

Requisite Variety, Cognition, and Scientific Change

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Abstract

Multiple theories of scientific change have been prominently promulgated since Kuhn. A quasi-discipline "Scientonomy" has even been proposed to formalize these theories. The cybernetics principle known as "The Law of Requisite Variety (LRV)" when combined with cognitive science insights regarding categorization and its ilk can be used to chart one such formalism. LRV holds that control/prediction can only be assured when the internal complexity of a system matches the external complexity it confronts The key indicator of an activity directed at scientific change comes from examinations of the models which scientists deploy in attempting to link pre-existing explanations with new problems to be explained. Normal science is a reductive activity – limiting the variety encountered. Innovative science is the process of expanding such variety, and scientific change is what happens when the innovative crosses the threshold for normal.

Keywords: scientific change; requisite variety; cybernetics, scientonomy

Cognizing Scientific Change

The traditional or "normal" sciences often bracket away ambiguity through the imposition of ‘‘enabling constraints’’—making a set of assumptions and then declaring ceteris paribus. Normal science's successes and failures can be traced to a common root: how well does ceteris paribus hold, thereby allowing the simplifications, chunking, modularity, isolation, and other forms of reduction on which traditional scientific research is based to flourish? The ability of a researcher to reduce complicated problems to a set of well-defined tasks is the key to success. Doing so often means ignoring the manifold layers of inter-related systems of which a given organization, its participants, users, resources, and context are a part. In short, complexity is ignored so that the many techniques of reductionism can prevail. Each goal, challenge, or task thereby gets reduced to another "simple" object. Complex systems theory, with its focus on the very inter-weavings, cross-dependencies, and context-dependence, suggests an alternative: embrace the very nature of the complexity itself. But such an embrace seldom leads to easily implementable tools, easily communicated explanations, or easily embraced decisions.

Cybernetics is about how we learn how to learn to steer. It is one of the precursors to cognitive science. Cybernetics is the study of feedback and its effects in purposive systems. "Cybernetic systems are complex, interacting, probabilistic networks- such as brains, markets, living organisms, industries, battles." (Beer, 1959) Cybernetics is a thinking and decision-making approach designed to deal with such observations as: (1) many of our interactions cannot be described with direct relationships, (2) our environments are neither fixed nor completely exogenous, (3) our actions and communications have multiple order effects and further time-delayed effects, and (4) our goals regarding the very actions we pursue are often in flux.

Scientific research only happens within a context of assumptions – many of which are designed to remove ambiguity and allow ceteris paribus. Assertions of assumptions to bracket ambiguity function as what cybernetics calls ‘‘enabling constraints’’ (Juarrero, 1999)—narrowing the degrees of freedom of the subject items to match or be below that of the suggested controller—the proclaimed ‘‘rule’’ or ‘‘law’’ or ‘‘heuristic’’ which supposedly allows the underlying ambiguity to be dealt with. Cybernetics suggests that the enabling constraints function to allow ‘‘science’’ to make predictions and to offer ‘‘explanations.’’ The use of these enabling constraints amounts to what Lakatos (1970) called a ‘‘protective belt,’’ blocking inquiry into fundamental questions of how the constraints are chosen and what happens when they are altered. This dynamic—that of ignoring ambiguity in the interest of efficiency and greater predictive reliability—is captured in the seeming omnipresence in scientific practice (though not in declared philosophical outlook) of ‘‘model-dependent realism.’’ This kind of realism has become the basis for applied science, in which each situation is afforded its own efficient, reliably predictive model:

> The only meaningful thing is the usefulness of the model…. [Model-dependent realism] is based on the idea that our brains interpret the input from our sensory organs by making a model of the world. When such a model is successful at explaining events, we tend to attribute to it, and to the elements and concepts that constitute it, the quality of reality or absolute truth. (Hawking and Mlodinow 2010)

Cybernetics warns us that we live in a complex world where ambiguity is ever-present in our world despite our oft-exercised option to ignore it. We assert the simple in lieu of the complex, the direct in lieu of the nuanced or the subtle, the label or category in lieu of recognizing the portfolio of choices that label/category represents. As Heisenberg (1959) told us: "The world is not divided into different groups of objects but rather into different groups of relationships…. The world thus appears as a complicated tissue of events, in which connections of different kinds alternate or overlap or combine and thereby determine the texture of the whole."

Normal science tends to isolate itself from this kind of uncertainty. As the cybernetician Ranulph Glanville (2006) noted: "What we do is we add observations (what some might call evidence) that we collect through our existence in the stream of our experience, and we build understandings, testing them in a process of confirmation and enrichment. If, after a bit, we find ourselves facing observations that we cannot account for, we handle them in one of several ways: we ignore them (are blind to them, a process sometimes known as denial); we dismiss them as anomalies; we find a way of changing the observation so that it fits what we expect; or we have to change our explanation (a constant object) - a process that gets harder the more we have invested in it, or have built on it, as we find reflected in the progressive difficulty of changing our concepts."

Most theories of scientific change look at the concepts employed in the articulation of the science itself. This article will take a very different tack. The focus will be on the processes the researchers use to match the phenomenon they desire to explain with the tools for explanation at their disposal. The assertion is that scientific change happens when a community of researchers finds new phenomena to which some tool or class of tools can be applied, and they are successful in articulating a match between the perceived complexity of the phenomenon so examined and the simplification abilities of the explanatory tools deployed. When this occurs, the scientists have succeeded in re-cognizing the concepts which define the problem itself.

Requisite Variety

Foremost amongst cybernetic principles is the Law of Requisite Variety. In its original form, that law goes like this: "The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate." (Ashby, 1958) Informally—practically—it says that in order to deal properly with the diversity of problems the world throws at you, you need to have a repertoire of responses, which is (at least) as nuanced as the problems you face. The Law of Requisite Variety in practice tends to be constrained by a second principle: that of least action. When confronted with a choice regarding energy or resources expenditure, we will usually opt for the choice that we can reasonably foresee will lead to the expenditure of the least resources in the aggregate.

In general, we have two methods for dealing with this constraint: we decrease the number of items we pay attention to in the world to a level of variety, complicatedness, and complexity that our control system is able to deal with, or we increase the range of our control system to match the level of complexity, complicatedness, or variety present in our attended to environment. The principle of least action suggests that too often we (or the research scientist) will opt to do a simplification – adopting blinders or constraints to limit the number of stimuli to be attended to because that is easier and requires less effort than the opposite which is to embrace the need for developing new responses as contexts change.

These possibilities can be shown in what is called the Ashby Space (adapted from Boisot and McKelvey, 2011) illustrated in figure 1 below. The basic concept is simple: graph the relationship between the variety of the stimuli present in a given situation and the variety of responses available. The law of requisite variety suggests that prediction and control are best achieved when stimuli and responses are in balance (one is requisite to the other). The Ashby Space illustrates this concept.

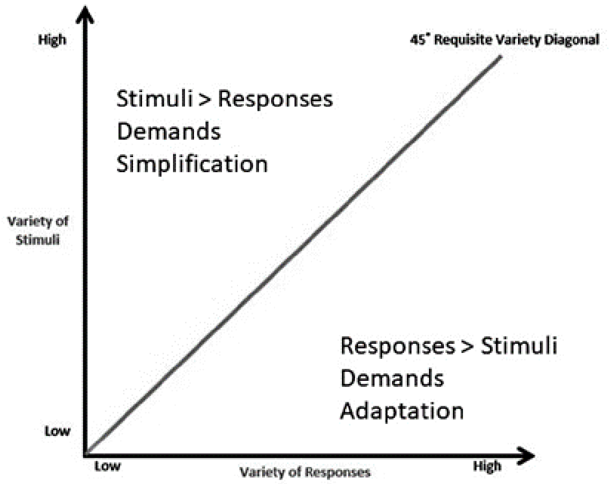

Figure 1 The Ashby Space

In Science the notion of "control" is transformed to the notion of "meaningful prediction." When re-described for science, the vertical or stimuli axis takes on the label "variety of phenomena to be explained" (operationalized as items thought to be subject to our response), and the horizontal or response axis takes on the label "variety of explanatory tools available" (operationalized as number of processes that enable us to make meaningful predictions about the response). Tools are displayed on the horizontal axis in order of chronological development; thus, each new explanatory tool (or proposed tool) is added to the right.

In the Ashby Space, when one encounters a situation located above the 45-degree line, the least action principle kicks in. Remaining in a situation where stimuli outnumber available responses is both uncomfortable and produces a high cognitive load when we are trying to determine how to react. How research scientists go about achieving requisite variety differs depending on whether one finds the situation to be above or below the 45-degree diagonal. When the stimuli in the environment or context exceed the number of available responses (when the variety of phenomena to be explained exceed the variety of explanatory tools available), simplification is necessary. Unfortunately, all too often, many of us adopt the same strategy for situations on the underside of the diagonal. Here, available responses outnumber the stimuli which evoke them (the variety of explanatory tools available exceeds the variety of phenomena to be explained). The correct approach is to test, filter, and adopt – not, pick one and run.

The right hand below the 45-degree diagonal region of the Ashby Space is where the Law of Requisite Variety has importance. The Law asserts that we cannot understand, predict, nor control any item of a complicated or complex nature unless we have developed a means of modeling that item and its interaction with relevant contexts. (Conant and Ashby, 1970) If a system (think research project or phenomena under examination) is to be the subject of meaningful predictions, the researcher must have a good model of the system on which to test potential interventions. Model here does not mean a picture or anything static. It means a dynamic representation where the actor/observer has the possibility of exploring interventions before committing to them (thus capital M Model). The concept is derived from Robert Rosen's (1985, 1991) modeling relation and is illustrated in figure 2 below.

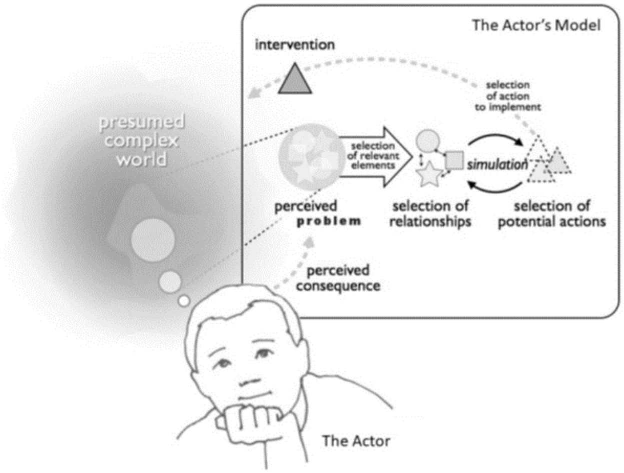

Figure 2 The Kind of Model Called for by the Law of Requisite Variety

Normal science tends to make use of this Model to reduce the variety of examined phenomena through categorization, labeling, and other forms of like-kind glomming. Inductive reasoning is the process of inferring a generality from a set of particulars and then asserting one or more groups/categories to which the generality can be applied. These activities occur in the above-the-diagonal-region of the Ashby Space. (see figure 3) The other approach of normal science is to reduce the explanatory toolset by asserting that a chronologically later tool works better than a chronologically earlier tool. This means a reduction in the variety of explanatory tools available and is accomplished by removing the earlier tool (found to the left of the later tool) from the diagram. Note: "response" as shown in the figure is a stand-in for "activity which is the subject of theorizing." Such activities occur in the region of the Ashby Space below the diagonal. Reducing their number is a means of achieving a match. Fischer (2019) refers to both of these normal science activities as variety reduction.

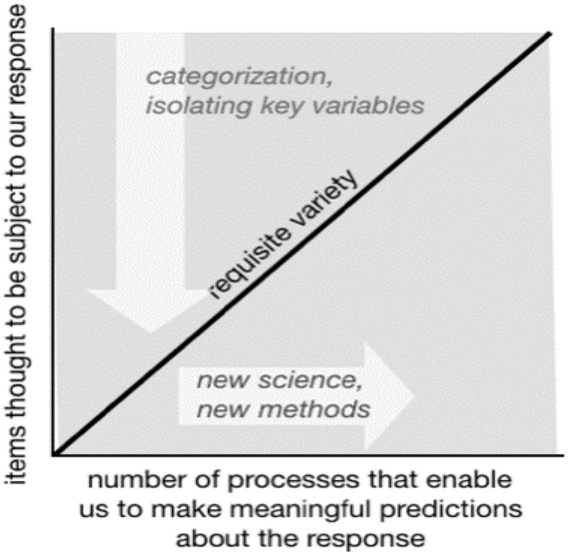

Figure 3 Reductive Activities of Normal Science

Both the hard sciences and the anticipatory sciences make use of these reductive techniques. In Lissack and Graber (2014), two kinds of science were distinguished: "Objectivity and a goal of reliable predictivity are the hallmarks of what we shall label Science 1. These are the hard sciences as traditionally taught and as used as references by philosophers of science. Physics is the exemplar of Science 1. In the Science 1 world we label and categorize via deduction, probabilistic inference, and induction. Science 1 excludes context dependence, thus when it is forced to deal with the possibility instead asserts ceteris paribus. Discovery and attunement to context are the hallmarks of what we shall refer to as Science 2. In the Science 2 world we instead seek to identify relationships, affordances, and potential actions. We ask questions rather than seek to label or categorize. Science 2 explicitly makes room for the context dependencies that Science 1 has excluded. These can be characterized as emergence, volition, reflexive anticipation, heterogeneity, and design."

The ''hard'' sciences are Lissack and Graber's Science 1, and the ''anticipatory'' sciences are Science 2. Much "normal" science is of the Science 1 variety, while much "physics envy" regarding prediction and control is found in Science 2.

Scientific change demands that there be acceptance of new explanations. The generation of new explorations ("innovative science") occurs below the diagonal in the Ashby Space. In Science 1, these new explanations take the form of a newly articulated theory, which is then tested for applicability and explanatory power. If this new theory can explain a sufficient variety of phenomena to rise to the diagonal itself, it holds the possibility of acceptance as a true scientific change. If the practitioners making use of the new theory, find themselves needed to reduce the variety of the phenomena being explained by the theory, they are then evidencing the theory's crossing over the Ashby diagonal. Scientific change happens when an explanatory theory crosses the diagonal from right to left. This is shown in figure 4 below.

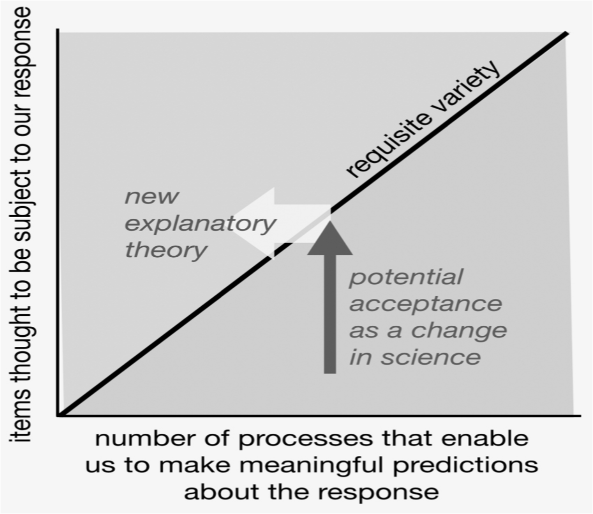

Figure 4: Typical Innovation in Science 1

The process is a bit different in Science 2 (see figure 5). Here a lot of circular activity will occur located below the Ashby diagonal. Particulars will be observed, prospective inductive explanations proposed, categorizations, labels, and assumptions will be challenged. The kind of "test it and find out" methodology to examine new explanations deployed will be less well accepted. Scientists who practice in Science 2 have a much deeper conceptual habitus (Bourdieu, 1967), which needs to be overcome by the researcher doing the work and by the community receiving it. Science 2 has a high degree of dependence on what Lissack (2016a, and 2016b) called unexamined critical presuppositions – outlined in the following section. When these presuppositions are examined, the possibility of greater explanatory power is potentially afforded.

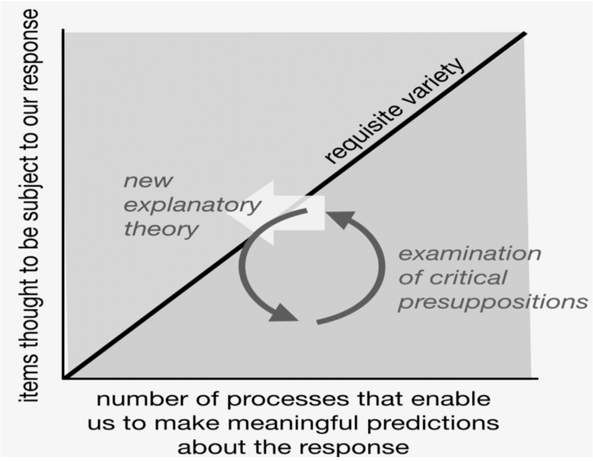

Figure 5: Typical Innovation in Science 2

Fischer (2019) defines these innovative science activities as variety amplification. Requisite variety (the defined state by which meaningful prediction is optimally afforded) is achieved through combinations of variety reduction and variety amplification. Scientific change is evidenced when with respect to a particular process of scientific explanation the activities of researchers shift from variety amplification to variety reduction. Radder (1991) would amplify this by suggesting that scientific change is evidenced by researchers first accepting that change requires removal of the enabling constraint of the correspondence principle (i.e., engaging in variety amplification) followed by attempts to deductively apply that same principle (thus a form of variety reduction).

Formalizing Scientific Change

Scientonomy is an emerging discipline that seeks to formalize the process by which scientific change occurs. Its founder Hakob Barseghyan (2015, 2018) perceives it as a bridge between the History and Philosophy of Science communities. What is important for Cognitive Science is that Scientonomy provides a formal framework against which anecdotal perceptions regarding scientific change can be tested. Scientonomy seeks to "uncover the actual general mechanism of scientific change" (Barseghyan, 2018) Its practitioners have, to date, focused on the content of science – producing a few general laws concerning behavior and acceptance of a "scientific mosaic." These "laws" provide a basis for determining that a scientific change has occurred but, at present, lack an accepted sense of dynamism to help recognize change in the midst of its occurrence. As Fraser and Sarwar (2018) note: "How does a theory, which is first conceived by an epistemic agent, become scientific, accepted, and perhaps, ultimately rejected? Currently, Scientonomy lacks a detailed description of this process, which we believe is fundamental to understanding the process of scientific change. Providing such descriptions would provide a strong, clear-cut explanation of a significant part of the process of scientific change."

Fraser and Sarwar's quest for a clear process description can be more easily met in Science 2 compared to Science 1. In Science 2 it is possible to examine the content of scientific research and determine if Lissack's presuppositions are themselves the subject of inquiry. When that kind of activity is present, one can then further examine the extent to which the Ashby Space crossing the diagonal notions described above are part of the mosaic surrounding the inquiry. If yes on both counts, then not only is the scientific endeavor one of innovative versus normal science, but it is reasonable to cognize that activity as being part of an effort intended at accomplishing scientific change.

A list of these presuppositions helps to illustrate the potential implicit should pre-existing assumptions regarding them be changed. 1) Context (for the experiment and the observers of its results) -- context dependence is the extent to which observations, data, or interpretations are dependent upon the context in which they occur -- i.e., inside a lab, out in the field, in a highly restricted environment, amongst fellow researchers, or just out in the world. 2) Things that the researcher takes for granted (e.g., applicability of normal distributions). This can be seen as the extent to which observations, data, and interpretations shown are dependent upon the belief set and lived experience of the observer. 3) The ability of the researcher to depict the objects of study in numerical form subject to quantitative analysis. 4). Part/whole relationships asking if the objects of study can be expressed as parts/wholes or both and the ability of certain entities to be decomposed into subsystems or collected into aggregate systems. 5) Graining – the size of the unit(s) of analysis. 6) Clustering – how the objects of study are clustered together, i.e., the extent to which the units being examined are afforded the status of being clustered together as sub-systems, where the resulting sub-system is then ascribed "item" status in terms of graining. 7) Communication or its lack amongst the objects of study, which is the extent to which the items in the system are afforded the ability to exchange information (both within and outside the system). 8) Anticipation & prediction by the objects of study -- the extent to which either individual items or the system as a whole is afforded the ability to anticipate what a not-yet-incurred interaction might do with regard to a stated variable or condition. 9) Memory by the objects of study -- the extent to which a prior state of an item, the system, or a data point treated as information by either an item or the system is preserved for access and afforded some ontic status. In turn, that "memory" is allowed to be recalled, labeled, or brought forth as a current input. 10) Statistical independence amongst and between the objects of study. 11) Mutual awareness or lack thereof amongst the objects of study noting that awareness can be peripheral, and a requirement of non-awareness should be regarded as dependence.

Content and textual analysis can easily reveal whether a given researcher has within the context of a given scientific presentation merely accepted some set of values or assumptions regarding these 11 categories of presuppositions or, by contrast, has engaged in a process of questioning the assignment of a particular value/assumption and then engaged in an effort to determine the effects of making different assumptions. When the research described falls into the first description, the activities are those of normal science. When the activities are those of the second description, innovative science is at least some part of the research effort.

Scientonomy's second law (Patton, Overgaard, and Barseghyan, 2017) states "If a theory satisfies the acceptance criteria of the method actually employed at the time, then it becomes accepted into the mosaic; if it does not, it remains unaccepted; if it is inconclusive whether the theory satisfies the method, the theory can be accepted or not accepted." The third law (Sebastien, 2017) states: "a method becomes employed only when it is deducible from some subset of other employed methods and accepted theories of the time." Innovative science tends to be violative of this third law. Innovators often propose new inductive approaches, new definitions, new analogies, and new values regarding critical presuppositions. Scientific change as a process involves activities which violate scientonomy's third law while at the same time obeying the second law.

Scientific change at the content level involves acceptance by the community of relevant epistemic agents of an "explanation." The Ashby Space notion helps one identify which scientific efforts are part of a process intended to first represent change and second to trigger acceptance. The circular argumentation, reflection and critique shown to the bottom right of figure 4 would thus satisfy the first of these criteria and not the second. By contrast, the arrows showing movement toward and through the requisite variety diagonal in both figures 3 and 4 satisfy both.

The simplified formalism which results from this is as follows:

Scientific endeavors which involve the generation and examination of new problems to which already existing explanations can be applied are often at the forefront of scientific change.

This process-based formalism differs from the laymen's view of scientific change (heavily influenced by fifty plus years of post-Kuhnian philosophy of science): scientific change is the evolution of what is considered facts and truth by the science community. It also supplies a partial answer to the question of "how?" when applied to the more formal Scientonomy definition (Barseghyan, 2015): "Any change in the scientific mosaic, i.e. a transition from one accepted theory to another or from one employed method to another."

The formalism above is also consistent with the perspective of Cognitive Structural Realism (Beni, 2019) which claims "we can conceive of cognitive structures as embodied informational structures entwined with the causal structures of the world [such that] there should be meaningful representational connections between the structure of theories and the causal structure of the world [and further such that] representation underpins the entwinement between cognitive structures and causal physical structures in the real world." Cognitive Structural Realism thus argues that change happens in the application the existing to new things rather than in the ab initio creation of the new.

This process-based formalism further suggests that the generation of new explanations or new theories is but a prerequisite to the process of scientific change, rather than being evidence of the change itself. It also provides researchers from the Philosophy and History of Science a reason to look at the processes by which scientific exploration and explanation are linked rather than having a focus on the concepts and constructs which the scientists themselves deploy.

Conclusion

Scientific change is a process. To detect that process as it unfolds first means to reject as "change candidates" scientific endeavors whose main objective is reductive. Science aimed at categorization, labeling and like-kind glomming is normal science and not indicative of change.

Cybernetics suggests that understanding is best achieved when one recognizes the shortcuts, labels, or partial representations being used in communication and examines what it is in the context of that communication or the habitus of the observer which affords that simplified representation meaning in use. Understanding is thus a product of both content and context. It is achieved through process. Understanding that scientific change is in the process of happening (or is the aim of a particular arena of research) makes similar demands.

Scientific change may be retrospectively understood by its content. Facts and truths (or what at any given moment may pass for facts and truths) are seen as "changing" as science evolves. But content does not easily reveal the process of change as it is occurring. Reconceptualizing science as a set of activities to be plotted in Ashby Space allows the change process to be better cognized. The key indicator of an activity directed at scientific change comes from examinations of the Models which scientists deploy in attempting to link pre-existing explanations with new problems to be explained.

The search for new problems is suggestive of activity directed at change. The search for new explanations is not.

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