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Common Origin Inferences and the Material Theory of Induction

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Abstract

The outstanding problem for common origin inferences ("*COI*s") is to understand why they succeed when they do, and why they fail when they do. The material theory of induction provides a solution: *COI*s are warranted by background facts. Whether a *COI* succeeds or fails depends on the truth of its warranting propositions. Examples from matter theory and Newton's *Principia* illustrate how *COI*s can fail; and an example from relativity theory illustrates a success. Hypotheses, according to the material theory, can be posited as a temporary expedient to initiate an inductive enterprise. This use of hypotheses enables *COI*s to serve as incentives for further research. It is illustrated with the example of the Copernican hypothesis.

Keywords: *COI*; common origin inference; material theory of induction

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1. Introduction

Michel Janssen [1] has identified an inductive inference form, the common origin inference, "*COI*," that has played a central role in the support of many important discoveries in science. They have a simple and appealing form. According to Janssen [1], p. 459 (his emphasis):

> *COI*s trace striking coincidences back to common origins. This then provides an *explanation* for these coincidences, which is counted as *evidence* for the explanation. *COI*s are thus a subspecies of what Gilbert Harman... dubbed *Inference to the Best Explanation* (IBE).

The argument form has an immediate appeal from everyday applications. When the lights go out across the city at exactly the same moment, we immediately infer to the origin as a city-wide power failure, as opposed to the unlikely coincidence that all city dwellers just happened to switch off their lights at exactly the same moment. This same argument form, it is shown in [1], has been employed successfully in scientific discoveries of great importance, such as Copernicus' heliocentrism, Darwin's theory of evolution and Einstein's special theory of relativity.

My goal in this paper is to give an account of the origin of the inductive potency of *COI*s. Just how is it that they can succeed? Section 2 below will briefly dismiss some efforts to account for the success before reviewing how the success is accounted for by the material theory of induction [2,3]. A successful *COI* is warranted by a fact or facts, that is, truths particular to the domain in which the *COI* is applied.

A direct way to see the warranting role of background facts is through examination of cases in which *COI*s fail. Section 3 provides examples from older matter theories and from Newton's *Principia*. These *COI*s fail by relying on a false background proposition for their warrant (matter theory) or for the lack of a background fact of sufficient power (Newton).

Section 4 recalls a successful *COI* that supports Einstein's special theory of relativity over Lorentz's competing ether theory. It illustrates how the success of a *COI* is recovered by the material theory of induction through the identification of the background warranting fact. The *COI*, understood as an inference to the best explanation, also conforms with the account given of inference to the best explanation in [2], Chapters 8–9.

Janssen [private communication] now characterizes *COI*s as less about inference and more about providing incentives for further exploration. This role of a *COI*, it is shown in Section 5, conforms with the account within the material theory of hypothesis as provisional posits used to allow an inductive project to launch, as described in [3], Chapter 2. Since these hypotheses are introduced provisionally, they come with the obligation that further independent evidence must be provided for the hypothesis. This obligation is the incentive for further exploration. This role of hypotheses is illustrated with a *COI* supporting Copernicus' heliocentrism.

2. Why COIs Succeed When They Do and Don't When They Don't

2.1. Accounts of Success That Fail

The simplest account of the success of *COI*s is their naturalness. We almost automatically infer to the common origin of a power failure when, city-wide, the lights go out. It is too easy to let the matter rest there. Our instinctive senses are just an expression of what we now find comfortable. They do not provide the sort of justification that tight philosophical argumentation requires. Instincts are fragile. A resting Earth was long thought instinctively unchallengeable until Copernican heliocentrism showed otherwise. Determinism was similarly taken instinctively to be necessary in any cogent science, until quantum theory showed otherwise.

A more sophisticated account is to conceive of *COI*s as a version of inference to the best explanation, as we saw above in the summary characterization of *COI*s. Once again, there is a visceral appeal. Does not a power failure best explain why all the lights went out at the same moment? At a general level, there is clearly something right about this approach. The project undertaken in [2], Ch. 8–9, was to determine just how inferences to the best explanation secure their results. It found that the successes of these inferences do not derive from any special inductive powers of explanation. Rather, they derive from a comparative argumentative structure sketched in Section 4.2 below that does not depend on any special inductive powers of explanation. Two problems preclude a rich notion of explanation accounting for the success.

First, judgements of which are the best explanations are fragile as are intuitions. Starting in the 1930s, J B Rhine at Duke undertook a prominent series of experiments in parapsychology with striking, positive results. For Rhine, the best explanation of the success of his experiments was the reality of parapsychology. For skeptics, the best explanation was procedural error in the experiments or just plain fraud[1] [4].

Second, we might resort to philosophical accounts of explanation to adjudicate such differences. We then find that there is no univocal account of explanation in the philosophy of science literature. Explanatory narratives are so variegated that the literature has been compelled to offer a correspondingly variegated account of explanation. We are to suppose, implausibly, that each of these conceptions of explanation share the same inductive potency.

Another possible account depends on a judgement that, without the common origin, it would be very unlikely or improbable that the evidence would have arisen. This will tempt some to replace the informal notion of what is likely or unlikely with the probabilistic formalism of Bayesian analysis. I share the reluctance of other authors, such as Janssen [1], p. 514, and Parsons [5], p. 10 in draft ms., to pursue this approach.

In my view, Bayesian analysis does little more than to interpose a smokescreen of superfluous mathematical formulae between the problem and what might be a viable solution. Insofar as its probabilities are purely subjective, they only express some agent's prejudices and have no inductive merit. If the probabilities have been modified by the bearing of relevant evidence, we do well to identify and isolate that evidence. We should then assess it on its own merits, independently of the entanglement with an overarching probability space that is supposed to embrace all our beliefs.

2.2. The Material Account of Success

The material theory of induction asserts that inductive inferences are warranted by facts that obtain in the domain in which the induction is implemented. The inductive inference may conform with a formal rule that applies within that domain. However, there are no formal rules that apply universally. In this sense, all induction in local. That a successful *COI* is dependent on background facts to some degree was part of Janssen's analysis in [1], p. 467:

> It is important that a *COI* at least provisionally identify some structure or mechanism that can be held responsible for the connection between the phenomena it ties together.

The simple argument for this view proceeds from the character of inductive inferences. They are ampliative, which means that their conclusions are logically stronger than their premises. It follows that there will be some circumstances in which any given rule of inductive inference will fail. A very general way of formulating the applicable warranting fact for the rule's successful application is that, as a factual matter, the rule is not being implemented in one of these adverse circumstances.

We can see how these very general considerations apply to the examples so far by considering how they might fail, if the background facts are inhospitable[2] [1]. The inference to a city-wide power cut would be defeated if we knew in addition that, on this day, there happened to be a plan to douse all lights at the same moment as a city-wide statement of opposition to some proposal. Similarly, we might defeat the skeptic's inference against parapsychology by painstakingly implementing conditions such that procedural errors and fraud are precluded.

It may seem that some rule of inductive inference can be protected from these sorts of failures by examining the circumstances that led to the failure and then adding clauses to the original rule that exclude them. It is easy to see that this strategy cannot work. No matter how many clauses we add, as long as what results is a rule of inductive inference, its ampliative character remains. It follows that there must always be scenarios in which it fails. If we persist by repeatedly adding new clauses to respond to newly discovered counterexamples, we initiate a process that generates ever more complicated rules but can never successfully terminate in a universally applicable rule. Chapter 4 in *The Material Theory of Induction* [2] illustrates this process in the case of analogical inference.

What these examples do show, however, is that our inductive prospects improve when we add more factual considerations to the analysis. Those additions cannot terminate in a universally applicable rule of inductive inference. Rather, these very facts constitute the entirety of what controls the success or failure of an inductive inference. This last statement is the core claim of the material theory of induction. Inductive inferences are warranted by background facts.

A way to see the importance of hospitable background facts in warranting *COI*s is to examine cases of *COI*s that fail, and to identify the source of the failure in a guiding background assumption that proved to be false, or was missing. The following section reviews such cases.

3. Unsuccessful COIs

3.1. In Matter Theories

Under Aristotle's influence, the ancient Greek tradition settled on four terrestrial elements: earth, air, fire and water; and a fifth celestial element: aether. With characteristic thoroughness, Aristotle laid out, in many careful steps, precisely why matter was composed of just these elements. His arguments commonly proceeded from the properties of bodies to the elements, or "simple bodies," that constituted them.

The Aristotelian natural motion of bodies was one such property. Since there are linear natural motions, up and down, and also circular natural motions in the heavens, Aristotle concluded in his *On the Heavens* [6], Book 1, 270b1–270b25, that there must be at least as many "simple bodies" as natural motions. It also follows that the heavens, where natural motions are circular, are composed of an element not found in the terrestrial realm, where natural motions are linear. In *On Generation and Corruption* [7], Book II, 330a25–330a29, Aristotle identified four irreducible properties of terrestrial matter: hot, cold, dry and moist. The four terrestrial elements, he continued, are those bodies produced by four compatible combinations of the properties: "For Fire is hot and dry, whereas Air is hot and moist. . .; and Water is cold and moist, while Earth is cold and dry." (330a30–330b21)

Aristotle then noted that these simple bodies are not to be confused with real instances of fire, air and other real bodies: (330b22–330b30)[3]

> In fact, however, fire and air, and each of the bodies we have mentioned, are not simple, but combined. The simple bodies are indeed similar in nature to them, but not identical with them. Thus the simple body corresponding to fire is firelike, not fire; that which corresponds to air is air-like; and so on with the rest of them. But fire is an excess of heat, just as ice is an excess of cold.

We can understand the general form of Aristotle's argument to be a *COI*. The premise is that there are many forms of matter that manifest a small set of irreducible properties, hot, cold, dry and moist; and the few natural motions. The presence of this small set is best explained by a common origin for them in five "simple bodies" that bear these properties and out of which all real matter is composed.

We see *COI*s of this general form reappearing in other, later work on matter theory. One example, celebrated in history and philosophy of science circles, is a familiar instance of "Kuhn loss." According to the eighteenth-century theory of phlogiston, metals consist of a compound of phlogiston with a calx—what we now call a metallic oxide. The commonality of properties of metals was explained by the presence of phlogiston in all of them. Here is how Kuhn described it [8] pp. 99–100:

> The much-maligned phlogiston theory, for example, gave order to a large number of physical and chemical phenomena. It explained why bodies burned—they were rich in phlogiston—and why metals had so many more properties is common than did their ores. The metals were all compounded from different elementary earths combined with phlogiston, and the latter, common to all metals, produced common properties.

In short, we infer to the existence and presence of phlogiston in metals as the common origin of their shared properties.

3.2. Why They Failed

Later research has established that the elements constituting matter are not earth, air, fire and water; and that there is no phlogiston. The *COI*s that sought to establish otherwise fail. How are we to understand these failures?

Might we just accept that a *COI* is an inductive inference and is fallible. That means that we gamble, we take an inductive risk, in accepting the conclusion of any inductive inference. In these cases, we lost the gamble. Not all swans are white. If that is the totality of our diagnosis, it is unsettling. It leaves us unsure of any *COI*. They are all fallible and can fail. What is unaddressed is that there are, presumably, better and worse, weaker and stronger *COI*s. Some should be embraced with confidence; and others should be approached with caution. If we merely say that any *COI* is fallible, we have no principled means of separating the cases.

The material theory gives us a more useful diagnosis. A successful *COI* is warranted by a background fact or facts. The *COI* fails if the background proposition assumed proves to be false, that is, it is not a fact. That is the case here. A key background assumption is that the properties of a composite body are inherited from those of its elementary constituents. A hot body is hot because it is rich in elemental fire. A metallic body is lustrous and combustible, because it is rich in phlogiston. This background assumption supports the reverse inference, from the properties of bodies to their elementary constituents. The *COI*s above in matter theory implement that reversed inference on the authority of this background assumption.

We now know that this very plausible background assumption is false. The celebrated example[4] is that table salt, sodium chloride, does not reflect the physical properties of its constituent elements. Ordinary table salt is relatively unremarkable in its properties. Elemental sodium is a metal that explodes in water; and elemental chlorine is a noxious gas. Their combinations can manifest in many different properties, such as when chlorine combines with carbon. Phosgene gas, $COCl_2$, is a highly poisonous gas used in chemical warfare. Carbon tetrachloride is a relatively inert cleaning solvent. Polyvinyl chloride is a useful plastic.

The matter-theory *COI*s fail because their warranting propositions turns out to be false.

3.3. In Newton's Principia

In his magisterial *Principia*, in Book III, *System of the World* [9], as noted by Janssen [1], p. 464, Isaac Newton stated a "Rule of Reasoning in Philosophy" that is tantamount to the rule of a common origin inference: Newton wrote (p. 398, his emphasis):[5]

> RULE II
>
> *Therefore to the same natural effects we must, as far as possible, assign the same causes.*
>
> As to respiration in a man and in a beast; the descent of stones in *Europe* and in *America*; the light of our culinary fire and of the sun; the reflection of light in the earth, and in the planets.

The rule is illustrated with the four *COI*s shown. It is the third that we can see is unsuccessful. The light of our culinary fires and that from the sun do not have the same origin. The first results from a chemical process of combustion. The second results from thermonuclear fusion.

3.4. Why It Failed

We can see why this third *COI* failed if, following the material theory of induction, we ask for the warranting fact. We can now see that there is no background fact that could sustain the inference to a common origin. It also seems likely that Newton himself had no richer proposition that he might find plausibly to serve as a warrant. Newton is widely known for his corpuscular theory of light. It dominated theorizing about light until the early nineteenth century. However, Newton seems to have advanced no detailed account of how these light corpuscles are generated by fires. Presumably Newton had little more than the mere fact that culinary fires and the sun both happen to produce light, even if their respective lights are of different constitutions.

This third *COI* fails for lack of a warranting fact; and a lack even of a rich enough speculation in Newton's work for a plausible warranting fact.

The remaining three *COI*s are successful. Yet, in the case of the first two, Newton likely also could not call up facts of any detail about respiration and the descent of stones to warrant them. One might imagine that the material theory would have to judge these *COI*s as unsuccessful also. This is not so. There are background facts that warrant these inferences. The material theory of induction does not require inferring agents to be aware of these warranting facts. All that matters is that the inductive inferences are warranted by facts, whether or not those facts are known to those inferring.

The situation is similar to inferences in deductive logic. Agents that infer in conforming with the rule of *modus ponens* or the law of the excluded middle are inferring validly, even if they know nothing of this rule or law.

Further similarities carry over from deductive to inductive inference. There is no insoluble mystery as to which deductive inferences are valid. A logician can affirm or deny the validity of some candidate inference by checking whether it conforms with an applicable deductive rule. Similarly, whether an inductive inference, such as some particular *COI*, is cogent can be decided by investigating whether it is warranted by background facts in the domain of application.

3.5. The Material Advantage

We have just seen how the material theory of induction enhances our understanding of *COI*s. It enables us to distinguish successful from unsuccessful *COI*s according to which are warranted by a background fact; and the security of the *COI* can in turn be assessed from the inductive security and strength of the warranting fact.

A further advantage is heuristic. If we are able only to find weak inductive evidence for some sought-after result in science, it is rarely productive to seek help from a more thorough analysis of the rules of inductive inference. The material theory directs a different course: undertake more empirical investigations. The more facts we know, it tells us, the better we can infer inductively. For then we know more warranting facts and thus we can advance more, secure inductive inferences.

An example of this strengthening of our inductive reach arises in matter theory. It concerns the element of fire, or its later incarnation as caloric. In the late eighteenth century, Antoine Lavoisier successfully replaced phlogiston with oxygen in accounts of combustion and, more significantly, produced something close to the modern inventory of chemical elements. Yet his inventory included caloric as an element. Its elemental character persisted in major works, including the document founding modern thermodynamics, Sadi Carnot's 1824 *Reflections on the Motive Power of Fire*, and in William Thomson's 1848 introduction of the absolute thermodynamic temperature scale. Joule and others at this time recognized that heat was not elemental but interchangeable with work and thus what would soon come to be called a form of energy[6] [10]. That recognition enabled the identification by Maxwell and Boltzmann of the heat within a dilute kinetic gas as its kinetic energy; and that identification subsequently enabled independent physical support for a founding idea in early nineteenth century chemistry, Avogadro's hypothesis[7] [3].

4. A Successful COI: Special Relativity

We have seen how the material theory of induction treats unsuccessful *COI*s. This section and the next will turn to how the material theory treats successful *COI*s.

This section will review the decision between Einstein's 1905 special theory of relativity and the kinematics of Lorentz's ether theory. The decision has been recounted so frequently that a briefer recapitulation is all that is needed here[8] [1,11].

4.1. The Relativistic COI

In brief, Einstein recognized a crucial property of the empirically measurable quantities in the Maxwell-Lorentz theory of electrodynamics. All measurable lengths in space, intervals of time and field quantities conformed with the requirements of his special theory of relativity. This agreement included measurements made in inertially moving systems of reference. They respected both the principle of relativity and the light postulate.

In the reconfiguration that gave his theory of 1905 its distinctive character, Einstein inverted this relationship. He elevated the principle of relativity and the light postulate to axioms that must hold for all experimental investigations. It followed from them that any experiment, using any materials at all, must always reveal laws that treat all inertial frames of reference as equivalent; and find the speed of light in any inertial frame of reference to be the same constant value. That could only be the case if moving systems, realized in any form of matter, conform with the kinematics of special relativity: the lengths measurable in such systems contract and the times of processes in such system dilate.

Lorentz agreed with Einstein that all measurable magnitudes would conform with Einstein's special theory of relativity. He could hardly do otherwise since his celebrated theorems of corresponding states provided the mathematical structure needed to prove this result. He also accepted that measurable magnitudes arising in other matter theories would also conform with Einstein's special theory of relativity. However, Lorentz believed that these measurements coincided with the true lengths of space, true intervals of time and real field magnitudes only when measured in the unique rest frame of the ether. Measurements taken in inertial frames of reference moving with respect to the ether rest frame had to be corrected to recover the true quantities.

The basis of Einstein's thinking is a straightforward *COI*. All the different forms of matter return measurements of spaces and times conforming with special relativity because they share a common origin. It is that they are measuring the actual spaces and times as specified by his special theory of relativity. The warranting fact for the inference is just that spatio-temporal magnitudes, measurable according to physical theories like electrodynamics and any other matter theory, reflect the spatio-temporal magnitudes truly possessed by space and time. This is one of the simplest and strongest *COI*s in science.

4.2. The Relativistic COI as an Inference to the Best Explanation

What can the material theory say of Lorentz's analysis? Following [1], we can conceive of Einstein's *COI*, like all *COI*s, as an instance of inference to the best explanation. Then Lorentz's analysis has a definite role in the material account given of successful inferences to the best explanation in Chapter 8–9 of *The Material Theory of Induction* [2]. According to this account, successful inferences to the best explanation do not rely on any special inductive prowess of explanation. The account has no place for a philosophically well-developed notion of explanation.

Rather an examination of many standard examples reveals a simple structure, common to all the examples. The inferences in the standard examples are comparative. There is a favored theory or hypothesis that is adequate to the evidence. Most commonly, the favored theory, with suitable auxiliaries, deductively entails the evidence. In the present case, it is inductively well supported by the evidence, in a manner that accords with the material theory of induction. The favored theory is judged better than a competing foil, since the foil fails in one of two ways. Either it is contradicted by the evidence; or maintaining the foil requires its proponents to take on an unsustainable amount of inductive debt. The inductive debt lies in assumptions whose truth are required for the foil but whose support remains to be provided. Crucially, all the components of this structure are compatible with the material theory of induction.

The decision between Einstein and Lorentz's accounts has this structure. Einstein's special theory of relativity is adequate to the evidence. That bodies contract spatially and temporal processes slow when they are near the speed of light is entailed by the theory. The theory itself is inductively supported by this evidence through the warranting fact noted above. Lorentz's theory provides the foil. The theory insists that, beneath the measurable magnitudes is a single preferred reference frame of the ether state of rest. Yet precisely because of the conformity of all measurable magnitudes with the principle of relativity, no empirical measurement can reveal which among all inertial states of motion is that special ether state of rest. In this sense, Lorentz's theory takes on the worst kind of inductive debt. It is one that, according to Lorentz's own views, can never be discharged by empirical evidence.

5. A COI as a Successful Incentive: Copernican Heliocentrism

A second example illustrates how the material theory of induction allows a *COI* to serve as an incentive to further research, as Janssen now understands to be the function of *COI*s. The example concerns Copernicus' introduction in the sixteenth century of a heliocentric account of planetary motions. Once again, the example has been recounted so often in the existing literature that only a brief statement is needed here[9] [1,3].

5.1. The Copernican COI

Planets, when observed from the earth, exhibit some regularities. The planets Mercury and Venus are always within the same region of the sky as the Sun and, over weeks and months, move back and forth across it. The planets Mars, Jupiter and Saturn, over a period of weeks, generally move eastward against the background of the stars and can be closer or farther from the Sun. Occasionally, their motion is retrograde. That is, they move westward. These retrograde motions occur when the planets are in opposition to the Sun.

The Copernican system identifies a common origin for these regularities. They arise from the specific placement of the planetary orbits in a heliocentric configuration. The orbits are organized by their annual periods. Closest to the sun is Mercury (80 days); then Venus (9 months); then Earth (one year); then Mars (2 years); then Jupiter (12 years); and finally farthest from the sun is Saturn (30 years)[10] [12]. It follows that Mercury and Venus never stray far from the Sun because they are orbiting the Sun with orbits within that of the Earth. The orbits of Mars, Jupiter and Saturn lie outside that of the Earth. Their retrograde motion arises when they are in opposition to the Sun and the Earth's own orbital motion overtakes that of the planet. It is the subtraction of the Earth's own eastward orbital motion from that of the planet that manifests as retrograde motion.

The *COI* identifies a common origin in the specific configuration of these heliocentric orbital motions. The fact warranting the *COI* is the heliocentric hypothesis itself that merely asserts that the planets, including the Earth, orbit the Sun. Once this hypothesis is accepted, the common origin of regularities follows.

It may now seem artificial to separate the specifics of these orbital motions from the simple hypothesis of heliocentrism. The separation reflects how the *COI* was implemented historically. One had first to accept the heliocentric hypothesis before a common origin could be identified in the specific configuration of planetary orbits. Someone resisting the heliocentric hypothesis would not infer to the common origin indicated.

5.2. Hypotheses in the Material Theory of Induction

The material theory of induction, as developed in *The Large-Scale Structure of Inductive Inferences* [3], Chapter 2 and later, attributes a special role to hypotheses. They serve to solve a standard problem in inductive investigations. How are we to initiate inductive inferences early in the investigation of a new field, when, initially, we likely only know particular facts in the field? To infer to generalities, we need warranting facts of general scope. Yet we lack precisely those sorts of facts. The common solution is to suppose some proposition as a hypothesis that would serve as the needed warrant and use it to proceed with the inductive inferences.

The essential point for present purposes is that the security of the results so inferred are dependent on the as yet undetermined truth of the warranting hypothesis. To discharge their provisional status, we must return to the warranting hypothesis and provide independent empirical support for it. The incentive to further research resides in the need to provide this independent empirical support.

If that support cannot be found, the results also lack support and the inductive project may fail. An example of such a failure is the mid twentieth century, steady state cosmology of Bondi, Gold and Hoyle [13]. Its provisional hypothesis was the perfect cosmological principle, which entailed that the universe has maintained the same general aspect through both space and time. On its authority, the proponents of the cosmology inferred from the fact of cosmic expansion that new matter was being created continuously throughout space to maintain a constant cosmic matter density. When, over several decades, independent support could not be secured for the perfect cosmological principle, steady state cosmology was abandoned.

To preclude confusion, this use of hypotheses is *not* an instance of hypothetico-deductive confirmation. These provisional hypotheses are *not* to be confirmed by their deductive consequences. Instead, they must secure independent inductive support. The term hypothesis is used in conformity with a common, historical use.

5.3. The Copernican Hypothesis as an Incentive

We now find the Copernican *COI* to be quite convincing. That, however, reflects our tacit knowledge of the further evidence that was accrued in support of heliocentrism. When Copernicus proposed the heliocentric hypothesis, it was both adventurous and troublesome. It had a natural appeal at least to some astronomers in greatly simplifying the overall structure of planetary motions. However, it was harder to accept heliocentrism, physically. We were to suppose an Earth that both spins rapidly about its North-South axis and orbits the Sun once each year. Yet, there seemed to be no evidence of that motion in physical processes discernible on the surface of the Earth.

For this reason, in the decades after it was proposed by Copernicus in 1543, heliocentrism was routinely described by the word "hypothesis"[11] [3]. It was adopted by astronomers for its power to support inferences. One application was that it enabled a determination of the relative size of planetary distances. Chapter 12 of [3] records the difficulties astronomers faced for most of the history of their work to determine the distances to the Sun and the planets. Direct determination of these distances outstripped early astronomical instrumentation. They could only be determined if astronomers adopted some suitable hypothesis that would warrant the required inferences. Ptolemy had hypothesized that the Sun, Moon and planets were packed together as closely as their epicycle and deferent circles allowed, such that none intersected. The relative sizes of the planetary orbits were then fixed. The heliocentric hypothesis played a similar role. The geometry of the Copernican heliocentric orbits was specific enough that the size of each orbit, relative to that of the Earth, could be determined by simple geometry.

Its defenders recognized that the heliocentric hypothesis needed support. Providing it was a compelling incentive to further research for its proponents. Foremost of them was Galileo. His 1632 *Dialogue Concerning the Two Chief World Systems* reported how his telescopic discoveries in astronomy supported Copernican heliocentrism. He found that Venus exhibited phases in conformity with its orbit around the Sun[12]; and that Jupiter had moons, thereby deflecting the one oddity of Copernican heliocentrism that everything orbits the Sun except for our moon. Finally, Galileo introduced some version of the principle of inertia in order to establish that the Earth's motion would be undetectable in physical processes on the Earth's surface.

Galileo's *Dialogue* did not end the debate. Giovanni Battista Riccioli, an accomplished astronomer, published a massive work in astronomy, *Almagestum Novum*, in 1651. He took the debate to be undecided between Copernican heliocentrism and the geocentric system of Tycho Brahe. He offered 49 arguments for the Earth's motion and 77 against it. Notably, he challenged Galileo's physical arguments that defended the Earth's motion. He noted—correctly—that a Coriolis-like effect should be apparent on a rotating earth[13] [14].

The debate remained sufficiently open that, as late as 1674, Robert Hooke published *An Attempt to Prove the Motion of the Earth by Observations* [15]. In it, he named Riccoli: "The Inquisitive Jesuit *Riccoli* has taken great pains by 77 Arguments to overthrow the *Copernican* hypothesis." (p. 5) Here is it notable that, over 130 years after Copernicus published his *de Revolutionibus*, heliocentrism was still a "hypothesis." Hooke's response to Riccioli is rich in posture but weak in substance. He fails even to mention Riccioli's physical concerns, but offers in response only a single argument that he labels, loftily, an "*experimentum crucis*" (p. 2). It merely documents Hooke's careful astronomical measurements that indicate a cosmos so large that the parallax of distant stars due to the Earth's orbit of the Sun is unmeasurable.

My presumption is that Newton's 1687 *Principia* provided the definitive physical basis for heliocentrism and stifled further debate.

5.4. The Copernican COI as an Inference to the Best Explanation

The decision between Copernican heliocentrism and Ptolemaic geocentrism follows the comparative, argumentative structure already noted in the last section. The favored account, Copernican heliocentrism, is adequate to the evidence. With suitable auxiliary assumptions about the configuration of the planets in their heliocentric orbits, the above regularities follow.

The competing foil was some suitably updated version of Ptolemaic geocentrism. In comparison with Copernican heliocentrism, Ptolemaic geocentrism required many assumptions for which no evidence could be supplied beyond the brute fact that they gave good observational results. The centers of the orbits of Mercury and Venus had to be supposed, without further basis, to align with the Sun. The motions of Mars, Jupiter and Saturn had to be supposed, also without further basis, as coordinated with the motion of the Sun in just the right way so that their retrograde motion coincided with opposition to the Sun.

As new evidence emerged, successive corrections were needed. Where Ptolemy had assumed that Venus orbits beneath the orbit of the Sun, Galileo's telescopic observations had shown that a geocentric astronomy must shift Venus' orbit to surround the Sun. Eventually the most viable form of geocentrism was the Tychonic system, in which all the planets orbited the Sun and the Sun orbited the Earth. It was little more than the Copernican system, but with the motions of the Sun and Earth exchanged. The enduring and ultimately insurmountable problem for geocentrism was the inability to provide any reasonable physics for its motions. The triumph of Newtonian physics was inevitably its ultimate undoing.

6. Conclusions

Common origin inferences have repeatedly provided decisive support for some of the most important scientific discoveries. If we take the argument form as a universally applicable template and an endpoint of inductive analysis, it has weaknesses. There is no means within the form to determine when a *COI* will succeed or fail; or to assess the strength or weakness of a *COI*.

The goal of this paper is to show how the material theory of induction can address these shortcomings. The warrant for *COI*s, as is the case with all inductive inferences, lies in background facts, specific to the domain in which the inferences are realized. *COI*s can only be successful if there are suitable background facts to warrant them. To use *COI*s successfully, we do not need to know which are their warranting facts or even if they have them. If, however, we want to establish their cogency, we do this by identifying the warranting facts. We can then assess the strength of the *COI*s by the inductive security of the warranting facts and the extent to which the warranting facts do sustain the *COI*s.

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Notes

1. For example, George R. Price, [4], p. 360, writing in AAAS's journal *Science* reported: "My opinion concerning the findings of the parapsychologists is that many of them are dependent on clerical and statistical errors and unintentional use of sensory clues, and that all extrachance results not so explicable are dependent on deliberate fraud or mildly abnormal mental conditions."
2. Janssen [1], p. 467, fn. 19, gives the example of a failed *COI* that lacks the requisite mechanism. Lavoisier inferred from the presence of oxygen in acids that oxygen is the principle that confer acidic properties on compounds.
3. I believe the use of the terms "fire" and "air" is ambiguous and is used for both elemental fire and the composite fire of ordinary life. For example, my reading is: "Thus the simple body corresponding to [ordinarily experienced] fire is firelike, not [pure elemental] fire; . . .".
4. In spite of some effort, I have been unable to identify who first used this illustration.
5. Newton's reasons for stating this rule and other rules, we may suspect, were not entirely disinterested. He seemed to have been pre-emptively smoothing what would otherwise be a difficult step in his overall argument. He soon reported numerous cases of similarities: the forces of terrestrial gravity resemble those acting on the moon; and each of the Sun, Jupiter and Saturn have planets or moons orbiting them. (pp. 409–410) Newton now wanted to argue that all these similarities are manifestations of the same thing, universal gravitation. To state it directly would risk the appearance of an unsupported jump in reasoning. Instead, Newton merely recalled Rule II (and others) as the justification. In effect, he told readers that they already agreed to this step when they accepted the rules.
6. A standard history of this transition is provided by compilation [10].
7. The history of this episode is given in [3] Chapter 11.
8. See for example [1], pp. 497–507, and [11].
9. See for example [1], pp. 471–484, and [3], Chapter 12.
10. These periods are from Copernicus' *De Revolutionibus*, [12] Book 1. Chapter 10.

[11] For examples of this naming and further analysis, see [3], Chapter 12, Sections 10–11.

[12] This observation was sufficient to eliminate Ptolemy's hypothesis of closest packing of the circles in his astronomy, for it entails that the circles associated with the Sun intersected those of Venus.

[13] See [14] for a general account of Riccoli's *Almagestum Novum*, with this specific objection on p. 119. Riccoli's work was almost two centuries prior to that of Coriolis.

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