Philosophy of Science (2025), **00**, 1–23
doi:10.1017/psa.2025.10185

ARTICLE

Origin Explanation

Christophe Malaterre

Département de philosophie and Centre interuniversitaire de recherche sur la science et la technologie (CIRST), Université du Québec à Montréal (UQAM), Montréal H3C 3P8, Canada
Email: malaterre.christophe@uqam.ca

(Received 22 June 2025; revised 30 October 2025; accepted 01 November 2025)

Abstract

Numerous phenomena prompt inquiries into their origins, spanning from the cosmos and life, to species, civilizations, and pandemics. Answering these questions entails offering origin explanations. Here, I explore the distinctive characteristics of origin explanations that distinguish them from other types of explanations. I explicate the concept of an origin phenomenon and suggest conceptualizing an origin explanation as a specific form of causal explanation—one that reveals a bottleneck in the causal network leading to an origin phenomenon. The resulting framework highlights the specificity of origin explanations across disciplines, pinpointing distinctive topological features within the causal structure of the world.

1. Introduction

The exploration of origin questions is a pervasive aspect of our intellectual enquiry, delving into the genesis of various phenomena, probing the very start of their existence and development. Origin questions span a diverse array of domains, encompassing natural phenomena like the origin of the universe, life, and species. They extend into sociocultural phenomena with investigations about the origins of language, customs, civilization, religion, economic systems, political structures, ethical principles, or artistic movements. Origin questions also arise in applied sciences, medicine, and technology: Think about the origins of epidemics and inventions like the steam engine or the Internet.

As with any scientifically significant phenomenon, investigating origins may shed light on underlying causal processes, reveal recurring patterns across systems or contexts, and contribute to the broader aims of explanation, understanding, and sometimes even prediction or control. In this sense, origin questions participate in the general epistemic ambitions of the sciences at large. And yet, origin questions also appear to possess a particular salience that sets them apart from other forms of inquiry. If this were not the case, the persistent use of the term "origin" to describe a specific kind of phenomena would seem unwarranted.

Part of what gives origin questions their distinctive character is that they appear to target a *coming-into-being*: They aim to explain how something came to exist when, prior to a certain point, it did not. Intuitively, an origin marks the starting point of something previously nonexistent—the onset of a process, entity, or concept.[1] It signals the moment at which a phenomenon begins to exist. Origin questions thus seem to capture an interest not just in how something works or what its components are, but in the foundational conditions that make its existence possible. Yet, at the same time, origin questions do not apply to just any transition from nonexistence to existence. Consider the appearance of ice when water freezes or the coming-into-being of a newborn: Asking about origins in these cases appears ill-formulated. Origin questions thus have specificities that go beyond probing a coming-into-existence. But how best to understand what is epistemically special about origin explanations?

Philosophical theories of explanation have paid little explicit attention to what makes origin explanations distinctive, focusing primarily on general explanation without isolating the explanatory demands that arise from origin questions. Classical approaches such as Hempel's deductive-nomological (DN) and inductive-statistical (IS) models (Hempel 1965) conceived of explanation as the subsumption of particular phenomena under laws or statistical regularities. These models treat origin questions on a par with any other explanatory target, provided the explanandum can be derived from relevant premises. Causal models of explanation, such as those associated with Wesley Salmon's causal-processes approach (1998) or James Woodward's interventionist theory (2003), also do not specifically address origin explanations. While focusing on how things work or what makes a difference in their functioning, these accounts offer limited traction for capturing the specificity of origin questions.

The same holds true for other influential accounts of explanation which in turn emphasize unification (Kitcher 1981), pragmatic aspects of explanatory context (Van Fraassen 1980), mechanisms (Glennan 1996; Machamer et al. 2000; Bechtel and Abrahamsen 2005), explanatory depth (Strevens 2008), or even a pluralistic approach to explanation (Potochnik 2017). While these accounts enrich our understanding of explanatory practices, they do not isolate any salient epistemic structure that may characterize origin explanations.

Historical and narrative models of explanation have attended more closely to explanatory practices in domains where origin questions are possibly more central—for example, evolutionary biology, geology, anthropology, and archaeology (Dray 1977; Tucker 1998). And yet, debates in this field have not addressed the specificity of such origin questions, centering on the role of narratives (White 1973; Ankersmit 1983; Kuukkanen 2015) and the characteristics of narrative explanation (Hull 1981; Roth 1988, 2008, 2017; Velleman 2003). What makes narratives explanatory has also received specific attention—some focusing on narrative possibility and causal difference makers (Beatty 2006; Beatty and Desjardins 2009; Beatty 2017), others on how robustness, "thickening," and "tightening" might contribute to structuring

[1] Besides this meaning as beginning, source, or starting point of something, the term "origin" may also refer to the location something or someone may come from (as in "What is her country of origin?"). It is also used in a technical sense, notably in medicine/anatomy to denote the more fixed portion of a muscle, and in mathematics/geometry to refer to the fixed reference point in a coordinate system (e.g., the origin in Cartesian coordinates).

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

causal trajectories in intelligible ways (Currie and Sterelny 2017; Currie 2018; Ereshefsky and Turner 2020). Still, while origin questions can be framed as a special case of historical question, the distinctive features of origin explanations remain largely unaddressed.

That said, an early attempt to characterize origin explanation is found in the work of Ebersole and Shrewsbury published more than sixty years ago (1959). Reflecting on cases such as the origin of life and social customs, they distinguish two modes of origin explanation: One that appeals to historical facts and another grounded in general plans or patterns. While the first can be seen as an early articulation of narrative explanation, and the second as aligned with the DN model, I argue that neither captures what is characteristic about origin explanations—namely, that they are explanations directed specifically at *origin* questions.

In this article, I build on and depart from these traditions by proposing a framework for understanding origin explanations. I argue that origin explanations are best conceived as a specific form of causal explanation, one that reveals a bottleneck in the causal network leading to an origin phenomenon. This "bottleneck account" captures how origin explanations often isolate a crucial juncture through which multiple causal pathways converge at one point in time and then expand. These explanations are thus marked by a strong temporal or historical dimension, as they reach back to the conditions that enabled the emergence of a given phenomenon. By characterizing origin explanations in terms of their causal topology, this framework accounts for why origin questions command special attention and why their answers cannot be reduced to standard causal, mechanistic, or narrative forms. As such, it contributes both to the philosophy of explanation and to our understanding of the explanatory logic behind origin questions across domains of enquiry.

The article proceeds as follows. In section 2, I examine Ebersole and Shrewsbury's account. Section 3 introduces and characterizes the concept of an origin phenomenon. In section 4, I develop the bottleneck account of origin explanation, showing how these explanations locate the origin phenomenon within a broader causal network. Section 5 extends this framework to type-origin-phenomena, which are explained by identifying recurring causal patterns across multiple instances of similar origin phenomena. Section 6 responds to possible objections while section 7 discusses further implications of the bottleneck account.

2. Origin explanations according to Ebersole and Shrewsbury

Reflecting on origin of life studies, Ebersole and Shrewsbury (1959) examine what it means to formulate origin explanations. Questions about origins, they argue, come in two main types. Contrast for instance (A) the question of the origin of a particular social custom, such as the custom men used to follow to walk on the outside of streets when accompanied by women, with (B) the question of the origin of social customs in general. The questions will receive different explanations: An explanation of (A) may run as "In the Middle Ages, refuse was thrown from house windows. Someone walking close to the building was less likely to be splattered with it than someone walking on the outside. Hence, men wishing to protect the dignity and finery of their women, took to walking always on the outside. It became an item of chivalry, and men who did

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

not observe the courtesy were criticized," while an explanation of (B) will be that "At a certain time, people do things for what is, or is believed to be a good reason. These things become sanctioned, and violators are criticized, ostracised, or even killed. Because of the conservative nature of man in his society, these modes of behaviour are preserved even after the reasons non longer apply and are never again given, after no sanctions remain except the reminder, 'That's just the way it's done'" (1959, 105).

Ebersole and Shrewsbury's diagnostic is that origin explanations of type (A) work by appealing to "facts of history," while origin explanations of type (B) involve a "general plan or pattern" (1959, 105–6). Though each of these answers to origin questions appears to be a perfectly satisfactory type of origin explanation, the authors note a close relationship between the two: The general plan or pattern of type (B) explanations is tacitly assumed to be at work in explanations of type (A). In other words, the historical facts mentioned by (A) explanations follow the general patterns of (B) explanations.

Ebersole and Shrewsbury argue that, unlike social customs which have clear cases of (A) and (B) origin explanations, explanations of the origin of life seem to waver between the two explanatory modes. On the one hand, the question typically refers to a unique historical event—the emergence of life on Earth around four billion years ago—and it receives tentative answers of a similarly historical nature, such as reconstructions of early environmental conditions. On the other hand, it is also approached through abstract, pattern-based models drawn from physics and chemistry, for instance, by invoking general chemical pathways that could lead to the formation of complex organic molecules. This duality introduces a further complication, as Ebersole and Shrewsbury point out: There remains a conceptual gap between what is being explained—the formation of certain organic molecules—and what we truly want to understand—the origin of life.

Although the distinction they draw between these two explanatory types (A) and (B) is valuable (and I will return to it in section 5), I contend that Ebersole and Shrewsbury's account ultimately misses the mark. It fails to capture what is distinctive about origin explanations as such. Their framework suggests that origin explanations either consist in assembling historical facts or in applying general explanatory schemes. While the first type resembles early forms of historical or narrative explanation, and the second aligns with the deductive-nomological (DN) or inductive-statistical (IS) models, neither, I argue, captures what is specific about explanations that are genuinely about origins. More sharply put, Ebersole and Shrewsbury show that origin explanations can be subsumed under two broad types of explanatory models that apply to a vast array of phenomena—but in doing so, they overlook what makes origin explanations specific. If such explanations are no more than standard historical or covering-law explanations, then what justifies their persistent appeal across domains? What legitimizes the use of origin terminology in the first place? The beginning of an answer, I suggest, lies in recognizing that an origin explanation targets a particular kind of explanandum—what I will call an "origin phenomenon." In what follows, I will clarify what counts as such a phenomenon. Then, I will argue that explanations of origin phenomena exhibit a distinctive epistemic feature: They work by identifying a bottleneck in the causal network that leads to such origin phenomena.

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

3. Origin phenomena

The exploration of origin questions encompasses a wide array of phenomena that I propose to refer to as "origin phenomena." It goes without saying that not all phenomena are proper targets for origin questions. Many physical, chemical, biological, and social phenomena—while certainly legitimate objects of explanation *simpliciter*—do not intuitively invite inquiries into their origins. Consider, for example, physical effects such as rainbows, electromagnetic laws like Ampère's law, superconductivity, or general relativity's account of gravitational distortion. Certainly, these phenomena can all be targets for explanations but framing them within the context of an origin explanation does not seem like the right type of approach. The same holds for many chemical reactions, biological processes, or sociological dynamics that are typically explained by uncovering the mechanisms, laws, or models that govern their operation. The nature of these phenomena is such that one would not intuitively think of them as origin phenomena in need of origin explanations.

A possible diagnostic criterion for these cases lies in their ahistorical nature. These phenomena are typically investigated and explained through repeated experiments or observations. In this respect, their occurrence at a specific moment in the history of the world is irrelevant to the explanation-seeking question we entertain about them. Instead, the quest for explanation concerns the intelligibility of the very unfolding of the phenomena, as opposed to their origin. In contrast, origin phenomena are marked by a form of historical situatedness, typically with a discernible start—the origin. Consider the example of social customs, such as the custom of walking on the outer side of the pavement that Ebersole and Shrewsbury mentioned: One can certainly inquire about this practice in terms of origin, presupposing a time before the practice existed. The same holds for phenomena like the emergence of the French Resistance during World War II, the outbreak and spread of the COVID-19 pandemic, or the appearance of life on Earth. These are paradigmatic cases in which origin questions seem not only natural but pressing: All exhibit some form of historical situatedness that seem inherent in origin phenomena.

Yet not all historical events qualify as origin phenomena. Many, in fact, are ill-suited to be framed in this way. For instance, Descartes's 1633 decision not to publish *The World* in light of Galileo's condemnation is historically grounded and explainable (Gaukroger 1995)—but asking for the "origin" of that decision feels off-target. One might explain the decision narratively, but the event appears too isolated to count as an origin phenomenon: It lacks the scale and structural development we typically associate with such phenomena. For a phenomenon to qualify as an origin phenomenon, I will argue, it must be of sufficient scale and complexity—typically involving a causal expansion over time.

The civil movement of the French Resistance exemplifies this: It arose historically in the early 1940s from the French civil society, gained traction following de Gaulle's Appeal of 18 June 1940, and gradually evolved into a more-or-less coordinated network of intelligence-gathering, sabotage, clandestine communication, armed resistance, and civil disobedience (Gildea 2015; Wieviorka 2016; Jackson 2018). The Resistance expanded across time, participants, actions, and strategic influence. A similar point holds for the COVID-19 pandemic. It likely began with a limited zoonotic spillover event but escalated rapidly into a global health crisis, involving international spread, government policies, economic disruption, and changes in social behavior (Ye et al. 2020; Banerjee et al. 2021; Lytras et al. 2021). Life on Earth too exemplifies this characteristic: Most scientific accounts begin with a lifeless early Earth, followed by a progression of chemical evolution during which chemical compounds complexified, protocells emerged, and a gradual diversification and expansion of living forms developed, ultimately giving rise to the vast integrated biosphere we observe today (Smith and Morowitz 2016; Sutherland 2017; Szostak 2017; Nghe 2025).

In all three cases, the phenomena can be seen as occupying relatively distinct and expanding causal regions of the world, characterized by internal causal density and external distinctiveness—what makes individuation of the phenomena possible in the first place. A significant characteristic of what we are drawn to call origin phenomena, I propose, is that they can be represented as causal networks capturing regions that not only emerge and stabilize but also expand in scope and significance over time. One way to visualize this is as a temporally unfolding directed graph: Nodes represent causal relata, and arrows capture the causal links connecting them across successive moments. In the case of an origin phenomenon, such a causal graph would be expected to display a marked increase in both the number and connectivity of nodes as time progresses.

Formally, such structures can be cast as directed acyclic graphs (DAGs), of the sort reconstructed in causal inference frameworks (Pearl 2000; Spirtes et al. 2000) and widely employed in interventionism and structural equation approaches to causation (Hitchcock 2001; Woodward 2003). These frameworks offer precise tools for representing causal dependencies, especially when causal relata are treated as variables connected through structural equations. Yet in many domains—including the historical sciences—causation can be studied without commitment to such formal machinery. In these cases, causal relata may be conceived not as values of variables but as events (Kim 1973; Lewis 1986), facts (Mellor 1995), or states of affairs (Armstrong 1997), while causation may be understood along alternative perspectives as afforded by diverse counterfactual theories (Lewis 1973; 2000), causal process theories (Salmon 1998), or conserved quantity approaches (Dowe 2000; Kistler 2006), not to mention more intuitive and practice-based conceptions.

For instance, in contexts where narrative explanation is central, events often provide the most fitting causal relata, particularly when paired with counterfactual analyses. Beatty's account of evolutionary possibility exemplifies this approach, relying on counterfactual events and their dependencies (Beatty 2017). What matters for my argument is that, once actualized and traced across temporal stages, these counterfactual dependencies yield causal networks. Such networks, when represented as directed graphs, make visible the temporal unfolding that characterizes origin phenomena.

Consider also cases like pandemics or the diffusion of social habits, where the central task is to trace how phenomena propagate through individuals. Such processes are often modeled as contact networks, with nodes representing individuals and edges capturing pathways of transmission or influence, thereby revealing communities and hubs that structure the spread (e.g., Cauchemez et al. 2011; Kumar et al. 2021). Yet they can equally be represented as temporally unfolding directed

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

graphs, where each time-slice indicates who infects or influences whom. This dynamic representation makes their expansion over time explicit and illustrates a distinctive feature of what we are drawn to call origin phenomena.

For these reasons, by "causal networks" I do not mean to restrict the analysis to DAGs in the narrow sense of causal inference theory. Rather, I use the term more broadly to designate structured sets of causal dependencies, however construed. In this broader sense, causal networks serve as the scaffolding through which origin phenomena can be identified across domains, from molecular pathways to social dynamics. What matters for the account advanced here is that such networks can be represented as or translated into temporally directed graphs because it is in this form that the topological features of origin phenomena become most salient.

Of course, the relevance and scale of what counts as significant within such networks varies depending on the epistemic context, including the framing of the inquiry, the granularity of the research question, and the level of explanation sought. This context-sensitivity explains why de Gaulle's Appeal of 18 June, while often understood as one of many triggering events for the Resistance, does not by itself constitute an origin phenomenon at the same high-level scale, especially when compared to the Resistance. The Appeal was a singular event, not a sprawling causal process. Yet, in a finely grained epistemic context—for example, one concerned with political communication or the psychology of leadership—the Appeal might be shown to fit within a reasonably well-delineated and expanding causal network at that very fine scale. In that context, the speech becomes the phenomenon of interest, and its origin may turn out to be a meaningful question. In this way, origin questions, like all explanation-seeking questions, are shaped by the epistemic context in which they are asked. Whether something qualifies as an origin phenomenon depends not just on its historical emergence but also on its perceived significance, expansion, and internal causal density relative to the aims and granularity of inquiry.[2] In other words, an origin phenomenon is not merely something that began and grew, but something that did so in a way that matters considering a specific epistemic context.

Thus, I propose to construe an origin phenomenon in the following way:

> **Origin phenomenon.** Given an epistemic context *K*, a phenomenon *P* qualifies as an origin phenomenon in so far as: (i) *P* did not exist prior to a certain historical time t_0, and (ii) *P* unfolds or unfolded into a relatively distinct and expanding causal network, as judged relevant within *K*.

This view acknowledges that, given the structuring role played by the epistemic aims of inquiry, the identifiability of origin phenomena rests on their historical situatedness and their causal development.

[2] This is not to say that anything can be an origin phenomenon given an appropriate epistemic context and granularity level: a specific leaf falling from a tree, a particular photon emitted by the sun, or even Descartes's 1633 decision as far as I can tell, are all phenomena with negligible downstream causal network. Maybe more importantly, given a specific epistemic context, not all phenomena give rise to similar downstream causal networks in terms of scale and duration; therefore, while some of them may qualify as origin phenomena, others will not.

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

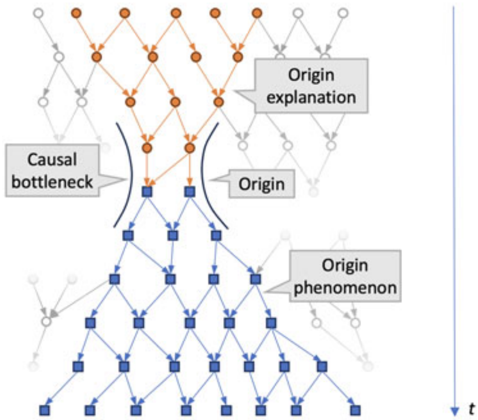

Figure 1. Causal bottleneck in an origin explanation. An origin phenomenon (blue/squares) is characterized by a lasting and expanding causal network. An origin explanation (orange/dots) identifies a preceding causal region that converges at a bottleneck—interpreted as the origin of the phenomenon—before proliferating downstream. Additional parts of the causal network are suggested in gray/white dots.

4. Origin explanations and causal bottlenecks

I propose to think of an origin explanation as a specific kind of explanation: One that targets an origin phenomenon as just defined. Given that origin phenomena are typically understood in causal terms, origin explanations are, in turn, typically causal explanations: They situate the causal network underpinning the origin phenomenon within a broader upstream causal network. What distinguishes them, I argue, is that they end up revealing a bottleneck in the causal network: a narrow convergence region from which a proliferating causal trajectory unfolds—that downstream network corresponding to the origin phenomenon. This bottleneck, I contend, is a defining—and possibly unique—feature of origin explanations. In other words, an origin explanation explains by showing how an origin phenomenon results from a convergence of causal lines and initiates a downstream expansion of causal interactions (see Figure 1).

To explain an origin phenomenon is thus to identify the portion of the broader causal network that converges toward the causal structure underpinning the phenomenon, thereby revealing a bottleneck. As with the characterization of origin phenomena, the epistemic context here too determines the appropriate level of causal detail (i.e., its epistemic granularity), including how far back one must go to produce an explanatorily adequate account. I thus propose the following characterization of an origin explanation:

> **Origin explanation.** Given an epistemic context *K*, an origin explanation is a causal explanation that (i) targets an origin phenomenon *P* as its explanandum, (ii) identifies a subset of the causal space that converges toward the causal network underlying *P*, and (iii) thereby reveals a causal bottleneck, all of which is relevant according to *K*.

Under this framework, it is crucial to note that an origin explanation isn't just any causal explanation; rather, it is a causal explanation tailored to elucidate an origin phenomenon as per the characterization outlined in the preceding text (section 3). In

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

doing so, an origin explanation uncovers a bottleneck within the causal landscape. The origin of an origin phenomenon is precisely that bottleneck:

Origin. Given an origin phenomenon *P*, its origin *O* is the causal bottleneck revealed by a proper origin explanation.

A natural question is what, exactly, characterizes the causal links that constitute a bottleneck. Importantly, causes at bottlenecks are not to be understood in terms of sufficiency, that is, as a small set of factors jointly guaranteeing the production of the phenomenon. Nor should they be reduced to an arbitrary or pragmatic choice of salient causes. Rather, bottlenecks are defined structurally, as convergence points within a temporally unfolding causal network. Such a network is identified at a particular level of granularity, one that is appropriate to the research question and the way the explanandum has been framed as an origin phenomenon. Within that context, all causes in the network already carry explanatory salience; what distinguishes those at the bottleneck is their structural position. Bottlenecks are sites where otherwise diverse or proliferating causal lines are funneled through a narrower set of dependencies, making subsequent developments hinge upon them. The causes located at such junctures thereby acquire a particular epistemic status: Their significance derives not from intrinsic strength or necessity in isolation, but from their role as connectors within the network's topology. This confers on them a special interventionist relevance. They may serve as strategic levers for preventing undesirable origin phenomena—such as in public health interventions designed to block zoonotic spillovers—or for intentionally triggering new ones, as in laboratory research aimed at reconstituting minimal pathways to life. Thus, bottlenecks mark privileged sites where explanation, prediction, and intervention can be brought into alignment.

To illustrate this, consider the (very) simplified historical reconstruction of the emergence and development of the French Resistance during World War II. As previously argued, in a suitable epistemic context (e.g., World War II historiography), the Resistance qualifies as an origin phenomenon—it did not exist prior to a certain time and unfolded into a significant and expanding causal network. Explaining its origin involves tracing an upstream causal network composed of wartime events, the unique role of Charles de Gaulle, the broadcast of the Appeal of 18 June, and other historically salient factors. This upstream causal network intersects with the downstream network of the Resistance, and that intersection reveals a bottleneck—a key moment or set of conditions that initiated the emergence of the Resistance (Figure 2A). In this sense, explaining the origin of the Resistance is a paradigmatic case of origin explanation.

A similar structure appears in origin-of-life research. Though far from settled, leading hypotheses propose that life emerged from the convergence of three prebiotic systems: self-assembling vesicles, self-replicating RNAs, and molecular linkers—likely other RNAs—enabling integration and coupling (Sutherland 2017; Joyce and Szostak 2018; Benner et al. 2020; Nghe 2025). These systems emerged from

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

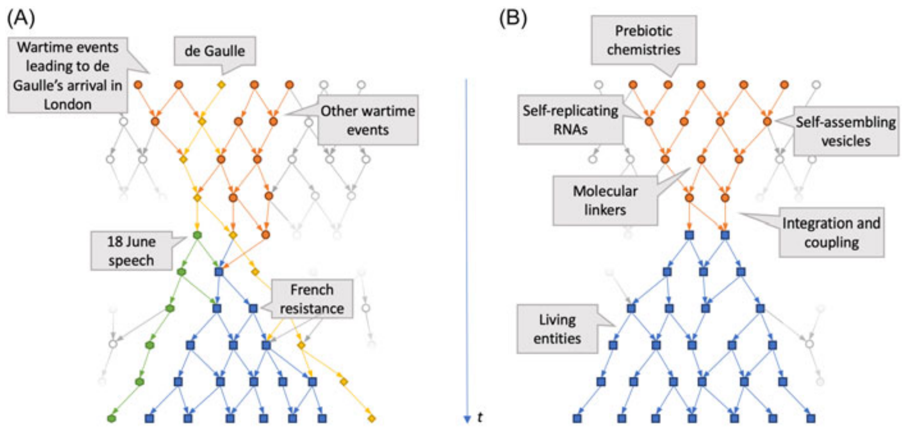

Figure 2. Bottlenecks in origin explanations. (A) Origin of the French Resistance during World War II. The causal network of the Resistance (blue/squares) connects backward to multiple causal threads: de Gaulle's trajectory (yellow/lozenges), the 18 June Appeal (green/hexagons), and broader wartime events (orange/dots). (B) Origin of life. Three causal strands converge—a vesicle formation pathway, the emergence of a replicase ribozyme, and molecular linkers—followed by diversification of living entities.

preexisting prebiotic chemistries (Figure 2B).[3] The explanation of life's origin is thus framed as a convergence of causal lines resulting in the bottleneck of protocell emergence, followed by an expansion of living entities. Again, the explanation qualifies as an origin explanation because it locates and accounts for a causal bottleneck initiating a distinctive and expanding phenomenon—life.[4]

This pattern, I propose, generalizes across a wide range of origin explanations in a variety of domains.[5] What characterizes them is not merely their historical

[3] In Figure 2B, arrows consistently denote causal relations. Preorigin, nodes typically represent chemical compounds/systems at a given time slice, linked by persistence or by production of new compounds/systems through reactions. Postorigin, nodes represent systems that are deemed to be alive, linked either by persistence or by some mode of (re)production. This portion of the graph should not be mistaken for a phylogenetic tree: Trees arise only after substantial coarse graining, whereas Figure 2B remains close to the origin and tracks fine-grained causal dependencies among entities. Depending on the epistemic context, nodes may represent individual tokens, sets of similar tokens, or aggregated quantities, but in all cases arrows mark temporally directed causal connections.

[4] Explanations for the origin of life remain, understandably, highly provisional and speculative. The hypothetical framing that has characterized the field since the 1950s still largely persists today, which may help explain the discomfort expressed by Ebersole and Shrewsbury. Part of this discomfort also stems from the fact that the question can be posed—and investigated in scientific terms—in multiple ways. In some cases, it is approached with strict historical constraints, such as when asking how life first emerged on Earth roughly four billion years ago. In other cases, the constraints are more flexible, as in efforts to synthesize life de novo in the laboratory. Depending on how the question is formulated, the nature of the answer will shift accordingly—ranging from historically grounded reconstructions to more ahistorical, possibility-oriented inquiries (Malaterre et al. 2022).

[5] For instance, this characterization is close to usages of "bottleneck" in evolutionary biology, notably population or genetic bottlenecks and their effects on genetic variability and novelty (Mayr 1963; Nei et al. 1975; Futuyma and Kirkpatrick 2017, ch. 7). Though not usually framed as shrinkages of causal networks, such bottlenecks are treated as salient explanatory factors for the emergence of new populations or traits (see also Godfrey-Smith 2009, ch. 5; Pedroso 2018).

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

situatedness and their causal character, but how they work: To explain an origin phenomenon is to show how this origin phenomenon arose through a bottleneck in the broader causal network of the world.

5. From tokens to types: Generalizing origin explanations

The bottleneck framework developed so far applies most directly to *token* origin phenomena—that is, specific, individual instances of origin events. Yet, as rightfully noted by Ebersole and Shrewsbury (1959), origin phenomena can also occur in multiple instances of the same *type*. Consider again the example of social customs: One might ask about (A) the origin of a specific custom, such as walking on the outer side of the pavement, or (B) the origin of customs as a general category. This distinction reveals two possible foci for origin questions: either on particular origin events in their specific contexts, or on general patterns shared across multiple instances of similar origin phenomena.

Take the case of zoonotic diseases—infectious diseases transmitted from animals to humans. Many specific instances of zoonoses, such as outbreaks of the rabies virus, have been well documented. Each of these constitutes a proper token origin phenomenon: a specific event occurring at a particular time and place, embedded in a concrete causal context. Each could, in principle, be the subject of a distinct origin explanation, as outlined in the preceding text. However, these cases often exhibit recurring causal structures. Rabies infections, for instance, commonly follow a pattern involving a reservoir host, pathogen spillover, human exposure, and disease transmission (Rupprecht et al. 2002; Hampson et al. 2007). These recurrent features suggest that the origin of rabies infections can be explained not only individually but also at a more general level—by reference to the causal pattern that characterizes their emergence as a type.

Furthermore, researchers have identified similarities across different zoonoses caused by distinct pathogens. For example, the causal pathways of rabies and Ebola outbreaks both involve analogous upstream factors such as host species distribution, pathogen prevalence, and human-animal interaction (Plowright et al. 2017). Such cross-pathogen similarities suggest the possibility of an even more abstract level of origin explanation—one that targets the type-phenomenon of zoonotic disease emergence in general (Figure 3). These regularities can be used to identify intervention measures to constrain the flow of pathogens, typically at bottleneck regions. They have also informed generalized models and frameworks for predicting and explaining zoonotic outbreaks (Ruan et al. 2021), as well as high-level pandemic emergence models. Crucially, even at this generalized level, what grounds the explanatory relevance of such models is their ability to identify bottlenecks—convergent points in causal space, such as pathogen release events—that recur across different instances of the type. These bottlenecks highlight the distinctive feature of origin explanations.

Following Ebersole and Shrewsbury, then, it makes sense to acknowledge that origin explanations can also target what one may call "type origin phenomena," and can do so by appealing to patterns that emerge from analyzing multiple related token origin phenomena. In such cases, the explanation operates by generalizing over similarities in their upstream causal networks. Nevertheless, the feature that remains distinctive of origin explanations—at both token and type levels—is their focus on

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

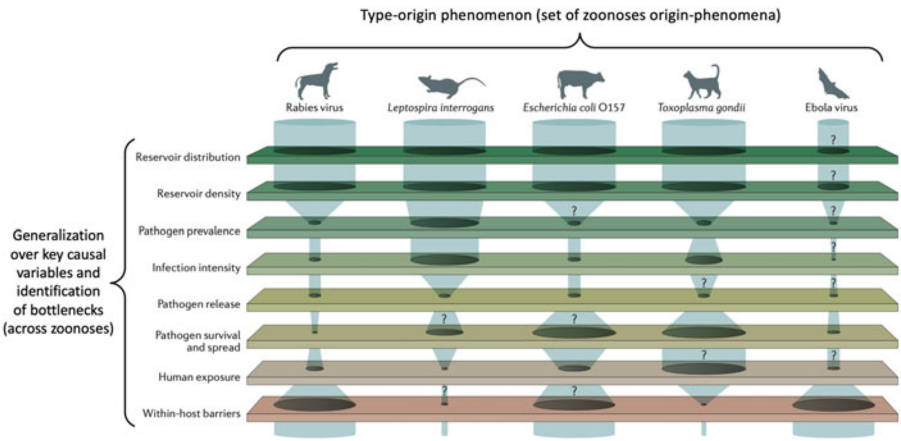

Figure 3. Causal bottlenecks in the origin of zoonoses. Influence of major causal factors (left axis) on the emergence of human infectious diseases (bottom axis) from animal sources (top axis). The variables on the left (e.g., "reservoir distribution," "pathogen prevalence") are coarse-grained aggregates of finer causal processes. Each oval represents a stage through which causal flow must pass, with its size indicating both the probability of passage and the effective number of causal connections. The diagram thus combines a high-level causal sequence with a schematic of how finer causal networks contract and expand around bottlenecks (adapted from Plowright et al. 2017, with permission).

revealing bottlenecks in causal networks. This motivates characterizing type origin phenomena as follows:

> **Type origin phenomenon.** Given an epistemic context *K*, a type *T* of phenomena *P* qualifies as a type origin phenomenon in so far as the *P* phenomena are origin phenomena that exhibit sufficient causal similarities, as judged within *K*.

To explain a type origin phenomenon is to detect and generalize over the upstream causal similarities across its instances. These include recurring causal factors and relations that, together, define a convergent causal structure. I will thus define a type origin explanation as follows:

> **Type origin explanation.** Given an epistemic context *K* and a type origin phenomenon *T* comprising token origin phenomena *P*, a type origin explanation is a generalization or model that (i) targets *T* as its explanandum, (ii) identifies similarities among the upstream causal networks of *P*, and (iii) reveals recurrent bottlenecks across those networks—judged relevant according to *K*.

What sets type origin explanations apart from generic pattern-based or statistical explanations is that they remain anchored in the logic of origin explanations: They aim to reveal recurrent bottlenecks that give rise to expanding downstream causal networks.

To illustrate this further, consider again the question of the origin of life. One might ask: (A) How did life arise on Earth?—a question that targets a specific origin

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

phenomenon. But one might also ask: (B) How does life emerge in general?—a question that targets a type origin phenomenon, should we one day identify life on Mars, on Enceladus, or on exoplanets outside our solar system. Although the existence of such extraterrestrial life remains hypothetical, ongoing research in astrobiology and exoplanet biosignature detection (Schwieterman et al. 2018; Enya et al. 2022; Wong et al. 2022; Dannenmann et al. 2023; Malaterre et al. 2023; McMahon and Cockell 2024; Seager et al. 2025) prepares the groundwork for answering such a question. If multiple instances of life's origin are found, a general pattern might emerge involving, for example, the synthesis of prebiotic building blocks, the emergence of informational molecules (e.g., replicating RNA), vesicle formation, coupling between information and compartmentalization, and metabolic complexification. The aim of fields such as universal biology is precisely to identify general principles or "laws of life" that could hold across diverse instances of life, independent of their specific biochemical makeup (Sterelny 1997; Mariscal and Fleming 2018; Cleland 2019). In such a scenario, the question of life's origin could be formulated not just at the level of token origin phenomenon (A) but also at the level of a type origin phenomenon (B), open to explanation by identifying shared bottlenecks across different instances. These might include key transitions such as the onset of Darwinian evolution or the emergence of autocatalytic networks (Higgs and Lehman 2015; Davies and Walker 2016; Goldenfeld et al. 2017; Adamski et al. 2020).

As with token origin explanations, type origin explanations are grounded in the targeting of origin phenomena—whether individual tokens or broader types. Token origin explanations trace the specific upstream causal network leading to a single origin event. In contrast, type origin explanations uncover causal patterns by identifying similarities across the upstream networks of multiple token origin phenomena. In both forms of explanation, the identification of causal bottlenecks remains central, serving as the key to understanding how origin phenomena emerge.

6. Three possible objections

6.1. Origins as phase transitions

A first possible objection to the bottleneck framework is that origin phenomena would be better characterized not by narrowing causal pathways but by the crossing of critical thresholds or phase transitions describing the appearance of a new order from collective interactions, as modeled notably by statistical mechanics and network theory. Accordingly, origins would be better explained through the accumulation of change in a system until some form of tipping point is reached, resulting in a qualitative transformation in the overall system structure or behavior, the origin thereby corresponding to this specific transition moment. Such a perspective underlies characterizations of, for example, the origin of life as an *emergent* transition from nonliving to living matter (Luisi 2006), or the appearance of pandemics as *tipping points* within epidemiological networks (Valler et al. 2011).

This view certainly captures an important class of transformative events. Yet, I will argue that it does not align properly with the conceptual and explanatory distinctiveness of origin phenomena as outlined above. Many phase transitions—such as the melting of ice, the ferromagnetic ordering of a material, or congestion patterns in traffic networks—involve state changes within preexisting systems and

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

do not represent the emergence of novel, enduring structures that initiate new expanding causal lineages. These transitions do not exhibit the historical situatedness and causal expansion features that typify origin phenomena. As a result, explanations of phase transitions appear ill-framed as quests for origin explanations.

Conversely, many paradigmatic origin phenomena fail to display the hallmarks of phase transitions. The emergence of the French Resistance, the appearance of a cultural tradition, or the origin of a novel zoonotic disease are deeply contingent, historically embedded, and causally heterogeneous processes. They do not result from crossing a threshold in an order parameter, nor do they exhibit critical slowing down, symmetry breaking, or other signature behaviors of phase transition phenomena. In addition, many origin phenomena are marked by strong temporal asymmetry and irreversibility—features not well captured by the often-reversible nature of phase transitions. Even in cases like the origin of life, the invocation of a phase transition remains more metaphorical than explanatory. To say that life emerged via a phase transition from nonlife is a suggestive analogy, not an established model (Malaterre 2010). Prevailing origin-of-life scenarios point instead toward the contingent convergence of various causal factors: the appearance of informational polymers, compartmentalization, metabolic networks, and their coupling.

That said, phase transition models may offer local insights within some origin contexts. For instance, while not amenable to explanation by a single phase transition, the origin of life may involve the crossing of various successive thresholds (Jeancolas et al. 2020), such as chiral symmetry breaking (Hawbaker and Blackmond 2019) and Darwinian threshold (Higgs and Lehman 2015; Goldenfeld et al. 2017). Similarly, modeling pandemic emergence as tipping point in epidemiological networks can help identify critical moments in the spread of an infection (Keeling and Eames 2005). However, what makes a pandemic an origin phenomenon is not simply that a tipping point was crossed, but that its causal influence initiated a lasting and expanding lineage of global effects. The explanatory force of the bottleneck account thus resides in its capacity to identify the constrained causal junctures through which such expansive outcomes become possible.

6.2. Origins as singularities

A second objection may posit that origin phenomena are best interpreted as singularities in the sense used in systems theory—points of high sensitivity in a system's evolution, where small, often unobservable changes in initial conditions yield disproportionate, often irreversible transformations. This view draws on concepts from chaos theory, catastrophe theory, and complexity science. Here, origins may be construed as instabilities and ruptures: moments when a system escapes from one regime and enters another, typically becomes unpredictable, or even breaks down. This interpretation could be used to characterize events like the emergence of COVID-19: a single viral transmission event, perhaps involving a highly contingent animal-human interface, set off a cascade of global consequences (Jones and Strigul 2021).[6] Or in origin-of-life contexts, one may suggest that the formation of

[6] Contrary to the previous objection that explained pandemics through a phase transition taking place in an epidemiological network, explanation here focuses on the chaotic behavior of a highly sensitive system perturbed by a single event.

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

a single replicative RNA molecule in favorable conditions may have set off a cascade leading to all life (Horning and Joyce 2016). From this perspective, origin phenomena may be viewed as ruptures—singular points where the system unpredictably escapes from its prior regime.

This singularity perspective, I will argue, encounters limitations. First, singularities often depart from origin phenomena as defined in the preceding text. Many such points—like bifurcations in dynamical systems or abrupt behavioral shifts in physical models—represent transformations within existing systems without signaling the coming into being of something that did not previously exist before. For instance, a bifurcation point in a dynamical system such as a shift from periodic to chaotic behavior in a fluid flow is a singularity, but it doesn't mark the origin of the fluid system—it marks a change within it (Strogatz 2019). Furthermore, many singularities are typically not embedded in historically specific, causally unique contexts: As in the case of the shift from periodic to chaotic behavior in a fluid flow, singularities can be abstract, atemporal features of model behavior, often repeatable and not tied to unique historical conditions.

Conversely, not all origins exhibit the structural or dynamical properties associated with singularities. Many origin phenomena unfold gradually, through the incremental convergence of diverse causal threads, rather than through sudden, high-sensitivity unique events. The emergence of the French Resistance, for instance, cannot be pinpointed to a single triggering moment. It required the convergence of numerous political, social, and material factors (Gildea 2015). In such cases, a bottleneck framework—focusing on the converging intersections of causal pathways —offers a more fitting explanatory model than the singularity account.

Nevertheless, bottlenecks and singularities are not mutually exclusive. A singularity may occur at a bottleneck, such bottleneck representing the point where multiple causal conditions converge. In this context, the singularity may correspond to a dynamical behavior characterized by high sensitivity, discontinuous change, or amplification at or near that convergence, thereby generating contingency. Thus, a singular event—such as the emergence of a particular replicase-containing protocell —may itself constitute a bottleneck if it marks a constriction in the causal network. Yet bottlenecks need not depend on such singularities. The bottleneck framework thus accommodates singularities as special cases, within a broader causal architecture.

6.3. Origins lacking antecedent causes

A third objection might target the very possibility of origin phenomena that lack any identifiable—or even possible—antecedent causes. In such cases, the concept of a bottleneck might appear inapplicable. The origin of the cosmos is frequently cited as the most salient example. Under some interpretations of general relativity, the Big Bang represents a space-time singularity—an initial condition in which conventional causal and physical laws cease to apply. If time begins with the origin of the universe, there is literally no "before," and thus no causal antecedent network to trace, let alone any bottleneck within it. Recent approaches in quantum cosmology, such as the Hartle-Hawking "no-boundary" proposal, also challenge traditional causal reasoning by positing that the universe arose not from a prior cause, but from a

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

transition out of a quantum state or vacuum fluctuation without prior temporal or causal precursors (Lehners 2023).

These cases pose deep challenges for causal explanation and may lie outside the scope of any account predicated on upstream causal dependency. They even suggest that some origin phenomena might be better understood as points of explanatory breakdown—epistemic or ontological singularities—rather than as the downstream effects of prior causal processes.

I will respond in two ways. First, even in cosmology, some theorists seek to recover explanatory structures that resemble bottlenecks—such as symmetry-breaking events, inflationary regimes, or entropic constraints (e.g., Boyanovsky 2012). While these may not be causes in a strict temporal sense, they nonetheless mark regions of theoretical convergence and explanatory salience. As such, the bottleneck account may retain relevance in a generalized form.

Second, it is important to delimit the intended scope of the bottleneck framework. The account is designed to illuminate origin phenomena that occur within an already constituted ontological and causal backdrop such as the origin of life, institutions, languages, or biological lineages. These are origin phenomena in a practical, reconstructible sense: They occur in contexts in which the identification of upstream causal dependencies is possible, and where bottlenecks can be located within empirical or theoretical models. The origin of the cosmos may represent a distinct kind of explanatory challenge, possibly even unique—one that is not simply difficult to resolve but may lie outside the domain of causal explanation altogether.

7. More on the bottleneck account

Before concluding, let me to elaborate on two interrelated facets of the bottleneck account: the epistemic status of the causal networks invoked, and the structural variability of bottlenecks themselves.

A characteristic feature of many origin phenomena across disciplines is that they lie in the past and are often only accessible through indirect evidence. As a result, origin explanations frequently rely on traces—for example, fossil, chemical, genetic, or behavioral—left by the phenomena in question. However, these traces are often scarce, degraded, or ambiguous, making the reconstruction of causal networks leading up to the phenomena highly partial or even underdetermined (Tucker 1998; Stanford 2001; Turner 2005; Currie 2021; Malaterre 2024). This raises a question about the status of the causal networks invoked in the bottleneck account: Are these networks to be understood as actual historically instantiated structures, or as possible configurations compatible with available evidence?

My view is that the causal networks referenced in the bottleneck account should be construed as idealized representations, shaped by the epistemic constraints and investigative resources of a given context. They represent what one would aim to reconstruct if one had access to an optimal evidential base. In this ideal case (Figure 4A), the upstream portion of the causal network would include all pertinent antecedent conditions, processes, and interactions, while the downstream portion would detail the ramifications and outcomes of the phenomenon. In practice, however, the evidential landscape is rarely, if ever, ideal. Data are often sparse, unevenly distributed, or noisy. The connections among available causal factors may

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

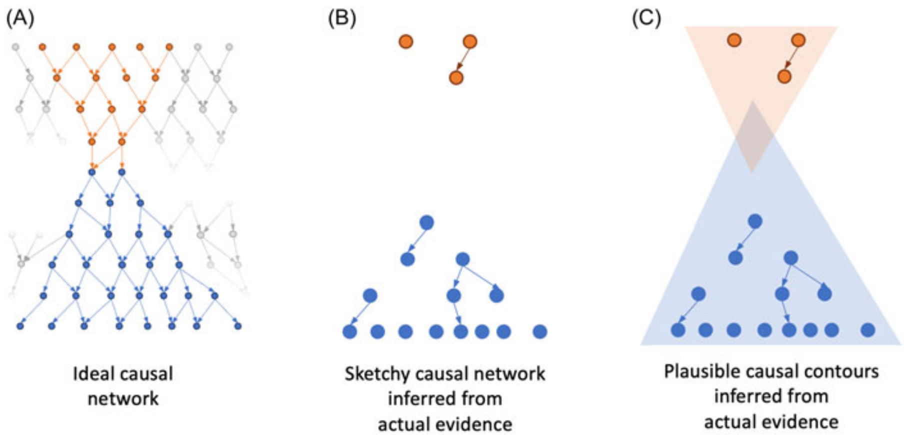

Figure 4. Epistemic status of the causal network in origin explanations. (A) Ideal causal network given a specific epistemic context. (B) Sketchy causal network inferred from available evidence. (C) The same sketchy causal network supplemented by hypothesized supplementary causal factors and relationships, revealing a bottleneck in causal space.

be ambiguous or subject to competing interpretations. Accordingly, the reconstructed causal network will often be highly fragmentary or "sketchy" (Figure 4B). Yet even under such conditions, scientists routinely engage in the task of inferring plausible networks, typically by combining empirical constraints with reasoned hypotheses. This then often results in outlining the broad contours of likely causal networks (Figure 4C).

For example, although bats are strongly suspected to be natural reservoirs of the Ebola virus, the specific mechanisms of viral maintenance and transmission within bat populations remain poorly understood (Plowright et al. 2017; Riesle-Sbarbaro et al. 2024). In many documented Ebola outbreaks, the upstream causal factors—ecological conditions, host behavior, viral shedding—remain elusive, as do the precise circumstances of initial human exposure. This results in a fragmentary network of causal claims and possibilities (hence the presence of question marks in Figure 3). Still, enough evidence exists to posit that a set of converging causal factors—reservoir species, ecological triggers, human encroachment—likely contributed to a transmission bottleneck that enabled viral spillover. The existence of such a bottleneck—however loosely defined—is inferred not from a complete causal map but from a partially reconstructed network in which certain nodes and relationships—despite the gaps—appear pivotal.

The case of the origin of life is also illustrative. No satisfactory explanation yet exists. Even the downstream causal structure—what followed once life emerged—is incompletely understood. While molecular phylogenetics points to a Last Universal Common Ancestor (LUCA), LUCA appears to be far more complex than the first truly living systems, implying that large segments of the early biosphere remain undiscovered or lost (Cornish-Bowden and Cárdenas 2017). Upstream, evidence is even thinner. Geological and planetary data sketch a highly uncertain picture of early

https://doi.org/10.1017/psa.2025.10185 Published online by Cambridge University Press

Earth conditions around 4 billion years ago, while microfossil evidence places the existence of life at least by 3.4 billion years ago, possibly earlier. Experiments in prebiotic chemistry have shown how certain molecular building blocks might form under early Earth-like conditions, and analyses of meteorites have revealed the presence of extraterrestrial organics (Cleaves et al. 2008; Sutherland 2017; Oba et al. 2022). But the pathways from this chemical diversity to something recognizably alive are still missing. Moreover, early prebiotic systems may have left no traces due to subsequent geological processes. In all likelihood, the origin of life will not be discovered in the traditional sense but will have to be reinvented (Eschenmoser 2007). For all these reasons, any explanation of the origin of life will likely consist of how-plausible—or even how-possible—scenarios blending historical constraints, prebiotic experiments and engineered proof-of-concepts syntheses. Even so, many such scenarios converge on a constricted set of transitional conditions—bottlenecks—marking the emergence of life from nonlife.

A second key facet of the bottleneck account concerns the form that bottlenecks take or should take to qualify as proper bottlenecks as per the proposed framework. I do not mean the framework to require that origin explanations should all resemble a neatly delineated, hourglass-shaped structure, with upstream factors funneled through a narrow transitional region before symmetrically diverging downstream. In practice, bottlenecks exhibit considerable variability in shape, scope, and structure.

For one thing, the causal networks identified as relevant to origin phenomena do not need to be strictly delineated and separated from the rest of the world's causal structure. Rather, the goal is to extract subsets of causal space in which factors are more densely interconnected with each other than with external variables. This is a qualitative rather than strictly formal criterion: What matters is the relative clustering and salience of causal relationships, not the strict causal isolation as formalized for instance by Markov blankets in probabilistic causal models (Pearl 2009). I propose to adopt a looser approach: identifying a causally salient region embedded within a larger system, given the explanatory aims of a particular epistemic context.

Similarly, the "shape" of the bottleneck is likewise qualitative. Bottlenecks need not be narrow points or symmetric arrangements: They can be regions or constriction patterns with diverse topologies. Still, scientists can often identify a region of transition or compression—a zone through which many causal chains must pass, and whose structure determines the shape of what follows. Just as in real life, not all bottlenecks look alike, but we generally recognize one when we see it.

That said, these qualitative intuitions are not incompatible with quantitative formalization. Network science provides several tools to analyze and detect bottlenecks in complex systems. For instance, the Cheeger constant (Mohar 1989) can measure the extent to which a network contains a sparsely connected partition—an indicator of a potential bottleneck. Other indicators such as betweenness centrality allow one to quantify the structural importance of nodes through which many connecting paths pass (Newman 2018). Thus, the bottleneck account remains compatible with both qualitative intuition and quantitative network analysis.

8. Conclusion

Rather than treating origins merely as the temporal beginning of a phenomenon or as a privileged ontological moment, I have proposed a conceptual framework that characterizes them as epistemically distinctive loci within a broader causal space—points where causal dependencies converge, compress, or become selectively visible as a causal bottleneck. Such bottlenecks do not merely precede the phenomenon they help explain; they structure our ability to render it intelligible considering antecedent conditions. I proceeded in two stages. First, I argued that origin explanations target a specific type of explananda: origin phenomena, which are phenomena characterized by their historical situatedness and the proliferating and enduring causal networks they entail. Second, I suggested that origin explanations derive their explanatory power precisely from pinpointing causal networks that converge to and meet with these origin phenomena. The hallmark of such origin explanations is to thereby reveal bottlenecks in causal space. In this respect, their specificity lies in identifying a distinct topological feature of relevant portions of the world's causal web. Crucially, this framework applies across disciplines and accommodates a wide variety of origin phenomena—from geological and biological origins to cultural and technological ones—highlighting the cross-domain utility of the bottleneck account. While bottlenecks are characteristic of origin phenomena, investigating other salient topological features of causal networks could unveil other specific forms of explanations. For instance, explanations for extinctions—which naturally complement origin explanations—may draw specificity from the relatively abrupt ending of their otherwise proliferating and enduring causal networks. Considering topological features of explanatorily relevant causal networks may thus offer heuristics for delving further into the diverse array of forms of explanation.

Acknowledgments. I am grateful to Benoit Barbeau, Matthew Brewer, Alexandre Champagne-Ruel, Adrian Currie, Corey Dethier, Philippe Nghe, Emily Parke, Denis Réale, and Franziska Reinhard for various inputs and suggestions on origin explanation. The manuscript also benefitted from feedback received at the Origin workshop at UQAM (2022), PSA biennial meeting (2024), Biophysics and Evolution seminar at ESPCI-PSL (2024), and Origins Institute at McMaster (2025). I also thank two anonymous reviewers for valuable comments.

Funding Statement. Funding from the Social Sciences and Humanities Research Council of Canada [Grant 430-2018-00899] and Canada Research Chairs [CRC-950-230795] is gratefully acknowledged.

Competing declarations. None to declare.

References

Adamski, Paul, Marcel Eleveld, Ankush Sood, et al. 2020. "From Self-Replication to Replicator Systems En Route to de Novo Life." *Nature Reviews Chemistry* 4 (8):386–403. https://doi.org/10.1038/s41570-020-0196-x.

Ankersmit, Frank R. 1983. *Narrative Logic: A Semantic Analysis of the Historian's Language.* Vol. 7. Martinus Nijhoff Publishers.

Armstrong, D. M. 1997. *A World of States of Affairs.* Cambridge University Press.

Banerjee, Arinjay, Andrew C. Doxey, Karen Mossman, and Aaron T. Irving. 2021. "Unraveling the Zoonotic Origin and Transmission of SARS-CoV-2." *Trends in Ecology & Evolution* 36 (3):180–84. https://doi.org/10.1016/j.tree.2020.12.002.

Beatty, John. 2006. "Replaying Life's Tape." *The Journal of Philosophy*: 336–62.

Beatty, John. 2017. "Narrative Possibility and Narrative Explanation." *Studies in History and Philosophy of Science Part A* 62 (April):31–41. https://doi.org/10.1016/j.shpsa.2017.03.001.
Beatty, John, and Eric Cyr Desjardins. 2009. "Natural Selection and History." *Biology & Philosophy* 24 (2):231–46. https://doi.org/10.1007/s10539-008-9149-3.
Bechtel, William, and Adele Abrahamsen. 2005. "Explanation: A Mechanist Alternative." *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 36 (2):421–41. https://doi.org/10.1016/j.shpsc.2005.03.010.
Benner, Steven A., Elizabeth A. Bell, Elisa Biondi, et al. 2020. "When Did Life Likely Emerge on Earth in an RNA-First Process?" *ChemSystemsChem* 2 (2). https://doi.org/10.1002/syst.201900035.
Boyanovsky, Daniel. 2012. "Spontaneous Symmetry Breaking in Inflationary Cosmology: On the Fate of Goldstone Bosons." *Physical Review D* 86 (2):023509. https://doi.org/10.1103/PhysRevD.86.023509.
Cauchemez, Simon, Achuyt Bhattarai, Tiffany L. Marchbanks, et al. 2011. "Role of Social Networks in Shaping Disease Transmission during a Community Outbreak of 2009 H1N1 Pandemic Influenza." *Proceedings of the National Academy of Sciences* 108 (7):2825–30. https://doi.org/10.1073/pnas.1008895108.
Cleaves, H. James, John H. Chalmers, Antonio Lazcano, Stanley L. Miller, and Jeffrey L. Bada. 2008. "A Reassessment of Prebiotic Organic Synthesis in Neutral Planetary Atmospheres." *Origins of Life and Evolution of Biospheres* 38 (2):105–15. https://doi.org/10.1007/s11084-007-9120-3.
Cleland, Carol E. 2019. *The Quest for a Universal Theory of Life: Searching for Life As We Don't Know It*. Cambridge University Press. https://doi.org/10.1017/9781139046893.
Cornish-Bowden, Athel, and María Luz Cárdenas. 2017. "Life before LUCA." *Journal of Theoretical Biology* 434:68–74.
Currie, Adrian. 2018. *Rock, Bone and Ruin*. MIT Press.
Currie, Adrian. 2021. "Stepping Forwards by Looking Back: Underdetermination, Epistemic Scarcity and Legacy Data." *Perspectives on Science* 29 (1):104–32. https://doi.org/10.1162/posc_a_00362.
Currie, Adrian, and Kim Sterelny. 2017. "In Defence of Story-Telling." *Studies in History and Philosophy of Science Part A* 62 (April): 14–21. https://doi.org/10.1016/j.shpsa.2017.03.003.
Dannenmann, Marie, Fabian Klenner, Janine Bönigk, et al. 2023. "Toward Detecting Biosignatures of DNA, Lipids, and Metabolic Intermediates from Bacteria in Ice Grains Emitted by Enceladus and Europa." *Astrobiology* 23 (1):60–75. https://doi.org/10.1089/ast.2022.0063.
Davies, Paul C. W., and Sara Imari Walker. 2016. "The Hidden Simplicity of Biology." *Reports on Progress in Physics* 79 (10):102601.
Dowe, Phil. 2000. *Physical Causation*. Cambridge University Press.
Dray, W. H. 1977. "Les explications causales en histoire." *Philosophiques* 4 (1):3. https://doi.org/10.7202/203061ar.
Ebersole, Frank B., and Marvin M. Shrewsbury. 1959. "Origin Explanations and the Origin of Life." *The British Journal for the Philosophy of Science* 10 (38):103–19.
Enya, Keigo, Yoshitaka Yoshimura, Kensei Kobayashi, and Akihiko Yamagishi. 2022. "Extraterrestrial Life Signature Detection Microscopy: Search and Analysis of Cells and Organics on Mars and Other Solar System Bodies." *Space Science Reviews* 218 (6):49. https://doi.org/10.1007/s11214-022-00920-4.
Ereshefsky, Marc, and Derek Turner. 2020. "Historicity and Explanation." *Studies in History and Philosophy of Science Part A* 80 (April):47–55. https://doi.org/10.1016/j.shpsa.2019.02.002.
Eschenmoser, Albert. 2007. "The Search for the Chemistry of Life's Origin." *Tetrahedron* 63 (52):12821–44. https://doi.org/10.1016/j.tet.2007.10.012.
Futuyma, Douglas J., and Mark Kirkpatrick. 2017. *Evolution*. 4rth ed. Sinauer Associates, Inc., Publishers.
Gaukroger, Stephen. 1995. *Descartes: An Intellectual Biography*. Clarendon Press.
Gildea, Robert. 2015. *Fighters in the Shadows: A New History of the French Resistance*. Harvard University Press. https://doi.org/10.4159/9780674496132.
Glennan, Stuart S. 1996. "Mechanisms and the Nature of Causation." *Erkenntnis* 44 (1):49–71.
Godfrey-Smith, Peter. 2009. *Darwinian Populations and Natural Selection*. Oxford University Press.
Goldenfeld, Nigel, Tommaso Biancalani, and Farshid Jafarpour. 2017. "Universal Biology and the Statistical Mechanics of Early Life." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 375 (2109):20160341. https://doi.org/10.1098/rsta.2016.0341.
Hampson, Katie, Jonathan Dushoff, John Bingham, Gideon Brückner, Y. H. Ali, and Andy Dobson. 2007. "Synchronous Cycles of Domestic Dog Rabies in Sub-Saharan Africa and the Impact of Control Efforts." *Proceedings of the National Academy of Sciences* 104 (18):7717–22. https://doi.org/10.1073/pnas.0609122104.

Hawbaker, Neil A., and Donna G. Blackmond. 2019. “Energy Threshold for Chiral Symmetry Breaking in Molecular Self-Replication.” *Nature Chemistry* 11 (10):957–62. https://doi.org/10.1038/s41557-019-0321-y.

Hempel, Carl G. 1965. *Aspects of Scientific Explanation*. Free Press.

Higgs, Paul G., and Niles Lehman. 2015. “The RNA World: Molecular Cooperation at the Origins of Life.” *Nature Reviews Genetics* 16 (1):7–17.

Hitchcock, Christopher. 2001. “The Intransitivity of Causation Revealed in Equations and Graphs.” *The Journal of Philosophy* 98 (6):273–99.

Horning, David P., and Gerald F. Joyce. 2016. “Amplification of RNA by an RNA Polymerase Ribozyme.” *Proceedings of the National Academy of Sciences* 113 (35):9786–91. https://doi.org/10.1073/pnas.1610103113.

Hull, David L. 1981. “Historical Narratives and Integrating Explanations.” In *Pragmatism and Purpose: Essays Presented to Thomas A. Goudge*, edited by L. W. Sumner and F. Wilson. University of Toronto Press.

Jackson, Julian. 2018. *A Certain Idea of France: The Life of Charles de Gaulle*. Allen Lane.

Jeancolas, Cyrille, Christophe Malaterre, and Philippe Nghe. 2020. “Thresholds in Origin of Life Scenarios.” *iScience* 23 (11):101756. https://doi.org/10.1016/j.isci.2020.101756.

Jones, Andrew, and Nikolay Strigul. 2021. “Is Spread of COVID-19 a Chaotic Epidemic?” *Chaos, Solitons & Fractals* 142:110376.

Joyce, Gerald F., and Jack W. Szostak. 2018. “Protocells and RNA Self-Replication.” *Cold Spring Harbor Perspectives in Biology* 10 (9):a034801. https://doi.org/10.1101/cshperspect.a034801.

Keeling, Matt J, and Ken T.D Eames. 2005. “Networks and Epidemic Models.” *Journal of The Royal Society Interface* 2 (4):295–307. https://doi.org/10.1098/rsif.2005.0051.

Kim, Jaegwon. 1973. “Causation, Nomic Subsumption, and the Concept of Event.” *The Journal of Philosophy* 70 (8):217–36.

Kistler, Max. 2006. *Causation and Laws of Nature*. Routledge.

Kitcher, Philip. 1981. “Explanatory Unification.” *Philosophy of Science* 48:507–31.

Kumar, Nishant, Jimi Oke, and Bat-hen Nahmias-Biran. 2021. “Activity-Based Epidemic Propagation and Contact Network Scaling in Auto-Dependent Metropolitan Areas.” *Scientific Reports* 11 (1):22665. https://doi.org/10.1038/s41598-021-01522-w.

Kuukkanen, Jouni-Matti. 2015. *Postnarrativist Philosophy of Historiography. Palgrave Macmillan UK.* https://doi.org/10.1057/9781137409874.

Lehners, Jean-Luc. 2023. “Review of the No-Boundary Wave Function.” *Physics Reports* 1022:1–82.

Lewis, David. 1973. “Causation.” *The Journal of Philosophy* 70 (17):556–67.

Lewis, David. 1986. “Events.” In *Philosophical Papers II*. Oxford University Press.

Lewis, David. 2000. “Causation as Influence.” *The Journal of Philosophy* 97 (4):182–97. https://doi.org/10.2307/2678389.

Luisi, Pier Luigi. 2006. *The Emergence of Life: From Chemical Origins to Synthetic Biology*. Cambridge University Press.

Lytras, Spyros, Wei Xia, Joseph Hughes, Xiaowei Jiang, and David L. Robertson. 2021. “The Animal Origin of SARS-CoV-2.” *Science* 373 (6558):968–70. https://doi.org/10.1126/science.abh0117.

Machamer, Peter K., Lindley Darden, and Carl F. Craver. 2000. “Thinking about Mechanisms.” *Philosophy of Science* 67 (1):1–25. https://doi.org/10.1086/392759.

Malaterre, Christophe. 2010. *Les origines de la vie: Émergence ou explication réductive*. Hermann.

Malaterre, Christophe. 2024. “Overdetermination, Underdetermination, and Epistemic Granularity in the Historical Sciences.” *European Journal for Philosophy of Science* 14 (2):23. https://doi.org/10.1007/s13194-024-00583-8.

Malaterre, Christophe, Cyrille Jeancolas, and Philippe Nghe. 2022. “The Origin of Life: What Is the Question?” *Astrobiology* 22 (7):851–62. https://doi.org/10.1089/ast.2021.0162.

Malaterre, Christophe, Inge Loes ten Kate, Mickael Baqué, et al. 2023. “Is There Such a Thing as a Biosignature?” *Astrobiology* 23 (11):1213–27. https://doi.org/10.1089/ast.2023.0042.

Mariscal, Carlos, and Leonore Fleming. 2018. “Why We Should Care About Universal Biology.” *Biological Theory* 13 (2):121–30. https://doi.org/10.1007/s13752-017-0280-8.

Mayr, Ernst. 1963. *Animal Species and Evolution*. Belknap Press of Harvard University Press.

McMahon, Sean, and Charles Cockell. 2024. “Astrobiology: Life Detection and the Abiotic Baseline.” *Astronomy & Geophysics* 65 (1): 1.23–1.27. https://doi.org/10.1093/astrogeo/atae011.

Mellor, D. H. 1995. *The Facts of Causation*. Routledge Press.

Mohar, Bojan. 1989. "Isoperimetric Numbers of Graphs." *Journal of Combinatorial Theory, Series B* 47 (3):274–91. https://doi.org/10.1016/0095-8956(89)90029-4.
Nei, Masatoshi, Takeo Maruyama, and Ranajit Chakraborty. 1975. "The Bottleneck Effect and Genetic Variability in Populations." *Evolution*:1–10.
Newman, Mark. 2018. *Networks.* Oxford University Press.
Nghe, Philippe. 2025. "A Stepwise Emergence of Evolution in the RNA World." *FEBS Letters, ahead of print.* https://doi.org/10.1002/1873-3468.70065.
Oba, Yasuhiro, Yoshinori Takano, Yoshihiro Furukawa, et al. 2022. "Identifying the Wide Diversity of Extraterrestrial Purine and Pyrimidine Nucleobases in Carbonaceous Meteorites." *Nature Communications* 13 (1):2008. https://doi.org/10.1038/s41467-022-29612-x.
Pearl, Judea. 2000. *Models, Reasoning and Inference*. Cambridge University Press.
Pearl, Judea. 2009. *Causality*. Cambridge University Press.
Pedroso, Makmiller. 2018. "The Impact of Population Bottlenecks on the Social Lives of Microbes." *Biological Theory* 13 (3):190–98. https://doi.org/10.1007/s13752-018-0298-6.
Plowright, Raina K., Colin R. Parrish, Hamish McCallum, et al. 2017. "Pathways to Zoonotic Spillover." *Nature Reviews Microbiology* 15 (8):502–10. https://doi.org/10.1038/nrmicro.2017.45.
Potochnik, Angela. 2017. *Idealization and the Aims of Science.* University of Chicago Press.
Riesle-Sbarbaro, S. A., G. Wibbelt, A. Düx, et al. 2024. "Selective Replication and Vertical Transmission of Ebola Virus in Experimentally Infected Angolan Free-Tailed Bats." *Nature Communications* 15 (1):925. https://doi.org/10.1038/s41467-024-45231-0.
Roth, Paul A. 1988. "Narrative Explanations: The Case of History." *History and Theory* 27 (1):1. https://doi.org/10.2307/2504958.
Roth, Paul A. 2008. "Varieties and Vagaries of Historical Explanation." *Journal of the Philosophy of History* 2 (2):214–26. https://doi.org/10.1163/187226308X315040.
Roth, Paul A. 2017. "Essentially Narrative Explanations." *Studies in History and Philosophy of Science Part A* 62 (April):42–50. https://doi.org/10.1016/j.shpsa.2017.03.008.
Ruan, Yongsen, Haijun Wen, Xionglei He, and Chung-I Wu. 2021. "A Theoretical Exploration of the Origin and Early Evolution of a Pandemic." *Science Bulletin* 66 (10):1022–29. https://doi.org/10.1016/j.scib.2020.12.020.
Rupprecht, Charles E., Cathleen A. Hanlon, and Thiravat Hemachudha. 2002. "Rabies Re-Examined." *The Lancet Infectious Diseases* 2 (6):327–43. https://doi.org/10.1016/S1473-3099(02)00287-6.
Salmon, Wesley C. 1998. *Causality and Explanation.* Oxford University Press.
Schwieterman, Edward W., Nancy Y. Kiang, Mary N. Parenteau, et al. 2018. "Exoplanet Biosignatures: A Review of Remotely Detectable Signs of Life." *Astrobiology* 18 (6):663–708. https://doi.org/10.1089/ast.2017.1729.
Seager, Sara, Luis Welbanks, Lucas Ellerbroek, William Bains, and Janusz J. Petkowski. 2025. "Prospects for Detecting Signs of Life on Exoplanets in the JWST Era." arXiv:2504.12946. Preprint, arXiv, April 20. https://doi.org/10.48550/arXiv.2504.12946.
Smith, Eric, and Harold J. Morowitz. 2016. *The Origin and Nature of Life on Earth.* Cambridge University Press.
Spirtes, Peter, Clark N. Glymour, and Richard Scheines. 2000. *Causation, Prediction, and Search*. MIT Press.
Stanford, P. Kyle. 2001. "Refusing the Devil's Bargain: What Kind of Underdetermination Should We Take Seriously?" *Philosophy of Science* 68 (S3):S1–12. https://doi.org/10.1086/392893.
Sterelny, Kim. 1997. "Universal Biology." *The British Journal for the Philosophy of Science* 48 (4):587–601. https://doi.org/10.1093/bjps/48.4.587.
Strevens, Michael. 2008. *Depth: An Account of Scientific Explanation.* Harvard University Press.
Strogatz, Steven H. 2019. *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*, *Second Edition*. CRC Press.
Sutherland, John D. 2017. "Studies on the Origin of Life — the End of the Beginning." *Nature Reviews Chemistry* 1 (2):0012. https://doi.org/10.1038/s41570-016-0012.
Szostak, Jack W. 2017. "The Narrow Road to the Deep Past: In Search of the Chemistry of the Origin of Life." *Angewandte Chemie International Edition* 56 (37):11037–43. https://doi.org/10.1002/anie.201704048.
Tucker, Aviezer. 1998. "Unique Events: The Underdetermination of Explanation." *Erkenntnis* 48:59–80. https://doi.org/10.1023/A:1005315532171.

Turner, Derek D. 2005. "Local Underdetermination in Historical Science." *Philosophy of Science* 72 (1):209–30. https://doi.org/10.1086/426851.

Valler, Nicholas C., B. Aditya Prakash, Hanghang Tong, Michalis Faloutsos, and Christos Faloutsos. 2011. "Epidemic Spread in Mobile Ad Hoc Networks: Determining the Tipping Point." In *Networking 2011*, edited by Jordi Domingo-Pascual, Pietro Manzoni, Sergio Palazzo, Ana Pont, and Caterina Scoglio. Lecture Notes in Computer Science, vol. 6640. Springer. https://doi.org/10.1007/978-3-642-20757-0_21.

Van Fraassen, Bas C. 1980. *The Scientific Image*. Oxford University Press.

Velleman, J. David. 2003. "Narrative Explanation." *The Philosophical Review* 112 (1):1–25.

White, Hayden V. 1973. *Metahistory: The Historical Imagination in Nineteenth-Century Europe*. Johns Hopkins Univ. Press.

Wieviorka, Olivier. 2016. *The French Resistance*. Harvard University Press.

Wong, Michael L., Stuart Bartlett, Sihe Chen, and Louisa Tierney. 2022. "Searching for Life, Mindful of Lyfe's Possibilities." *Life* 12 (6):6. https://doi.org/10.3390/life12060783.

Woodward, James. 2003. *Making Things Happen: A Theory of Causal Explanation*. Oxford University Press.

Ye, Zi-Wei, Shuofeng Yuan, Kit-San Yuen, Sin-Yee Fung, Chi-Ping Chan, and Dong-Yan Jin. 2020. "Zoonotic Origins of Human Coronaviruses." *International Journal of Biological Sciences* 16 (10): 1686–97. https://doi.org/10.7150/ijbs.45472.

Cite this article: Malaterre, Christophe. 2025. "Origin Explanation." *Philosophy of Science*. https://doi.org/10.1017/psa.2025.10185