# Universality as Presupposed and Recovered Simplicity

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**Abstract**

Critical phenomena are a paradigmatic case of emergence because microscopically different systems display the same macroscopic behavior. However, the universality is not unique to critical phenomena: the ideal gas law also exhibits a form of universality. This paper argues that the key difference lies in how higher-level simplicity is achieved. In the ideal gas law, simplicity is presupposed by strong idealizations built into the lower-level model. In critical phenomena, by contrast, simplicity is recovered through the renormalization group framework. This distinction clarifies why universality alone does not determine whether a case is best understood in terms of emergence or reduction.

## 1 Introduction

Critical phenomena have often been regarded as a paradigmatic case of emergence, largely because of the universality they exhibit. The universality, which means that systems with very different microscopic details display the same macroscopic behavior, has frequently been taken to be a hallmark of emergent phenomena. This universality-based line of argument for emergence has been explored by a number of authors (Crowther 2015; De Haro 2019; Morrison 2012; Morita 2023; Palacios 2019, 2022). The renormalization group (RG) framework has played a central role in these discussions, since it provides the standard explanation of critical phenomena and their universality. The relationship between RG explanations and universality itself is also an important issue (Ardourel and Bangu 2023; Batterman and Rice 2014; Castellani and Margoni 2022; Franklin 2019; Menon and Callender 2013; Rodriguez 2021; Wu 2021).

This paper approaches the issue from a different angle. Rather than asking only how the RG explains universality, this paper asks what universality itself amounts to in the case under considerations. If universality is understood merely as insensitivity to microscopic details together with commonality across macroscopically different systems, then it is by no means unique to critical phenomena. The ideal gas law also, for instance, exhibits a kind of universality, since many physically distinct gases display the same macroscopic relation under appropriate conditions. This raises the following question: what distinguishes RG-based universality in critical phenomena from idealization-based universality in the ideal gas law, and why does this difference matter for the notion of emergence?

My claim is that the difference lies not simply in the presence or absence of universality, but in how higher-level simplicity is achieved. In the case of the ideal gas law, the relevant simplicity is presupposed by the strong idealizations built into the lower-level model from the outset. In the case of critical phenomena, by contrast, the simplicity of the higher-level behavior is not given in advance but is theoretically recovered through the RG framework, which identifies the relevant structure within a heterogeneous microscopic domain. To articulate this contrast, this article employs the notion of effective complexity, originally proposed by Gell-Mann and Lloyd (1996), not as a quantitative measure, but as a conceptual tool for distinguishing between presupposed and recovered simplicity.

The paper proceeds as follows. Section 2 introduces the two cases of universality: critical phenomena and the ideal gas law. Section 3 examines these cases in terms of the distinction between robustness and universality proposed by Gryb et al. (2021) and applied to the case of critical phenomena by Palacios (2022), and argues that this distinction alone does not fully capture the difference between them. Section 4 introduces effective complexity as a conceptual tool and uses it to distinguish between recovered simplicity in critical phenomena and presupposed simplicity in the ideal gas law. Section 5 then considers the implications of this distinction for emergence and reduction.

# 2 Two Cases of Universality

## 2.1 Critical Phenomena and RG

Critical phenomena are phenomena that occur near critical points. A striking feature of these phenomena is that certain macroscopic behaviors are shared by systems with very different microscopic constitutions. For example, ferromagnetic systems near the Curie point and fluids near the liquid-gas critical point exhibit the same patterns of scaling behavior. The relations among critical exponents are common across different kinds of systems. For this reason, critical phenomena are widely regarded as a paradigmatic case of universality.

A sophisticated account of this universality is based on the RG framework. Roughly speaking, the RG framework includes three procedures: the RG transformation, the analysis of RG flows and fixed points, and scaling analysis around the fixed point. The RG transformation $\mathcal{R}$ includes a coarse-graining procedure, through which microscopic details are systematically suppressed. Iterative applications of this transformation generate an RG flow in parameter space and identifies a fixed point $x^*$ satisfying $\mathcal{R}(x^*) = x^*$. Systems that are microscopically different may nevertheless flow toward the same fixed point. Such systems are said to belong to the same universality class. Analyzing the fixed point provides an explanation of critical phenomena.

This framework explains why microscopically diverse systems exhibit the same critical behavior. The point is not merely that many systems happen to resemble one another near the critical point, but that the RG transformation distinguishes between relevant and irrelevant variables. Variables that are irrelevant for critical behavior are progressively suppressed through coarse graining, whereas the relevant structure is retained. As a result, many microscopic differences do not affect the macroscopic behavior that characterizes critical phenomena.

The universality of critical phenomena therefore exhibits a kind of simplicity. The critical behavior can be characterized by a relatively small number of exponents and scaling relations, even though the underlying microscopic systems are highly heterogeneous. Importantly, this simplicity is not secured by simple assumptions or idealizations imposed at the outset. Rather, it is achieved through the RG framework, which dismisses some details of lower-level models and identify the relevant variables. This point will be central to the contrast with the ideal gas law developed below.

## 2.2 Ideal Gas Law

The ideal gas law also captures a physical feature common to different systems. It is expressed as $pV = NT$, where $p$ denotes pressure, $V$ volume, $N$ the number of particles, and $T$ temperature. This equation describes the behavior of an ideal gas, whose molecules are assumed to have negligible volume, no intermolecular interactions, and perfectly elastic collisions. The law therefore depends on strong idealizations. Despite these simplifying assumptions, the ideal gas law captures a relation shared by many different gaseous systems. A wide variety of gases, composed of different kinds of molecules, exhibit approximately the same relation among pressure, volume, particle number, and temperature. In this sense, the ideal gas law represents a form of universality: it identifies a macroscopic regularity common to many physically distinct systems.

This case differs from critical phenomena, however, in how this simple law is secured. As Dizadji-Bahmani et al. (2010) argue, the ideal gas law can be derived from classical mechanics under suitable assumptions[1]. In this derivation, assumptions such as perfectly elastic collisions and the isotropy of space are introduced at the microscopic level. The resulting microscopic model is already highly simplified, and it is from this simplified basis that the macroscopic law is derived. In this respect, the simplicity exhibited by the ideal gas law is not recovered from a heterogeneous microscopic domain through a procedure like such as the RG. Rather, it is built into the model from the outset. The universality of the ideal gas law therefore rests on presupposed simplicity.

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[1] On their interpretation, this derivation can be understood as a Nagelian reduction.

# 3 Robustness and Universality

In order to clarify the difference between these cases, we appeal to the notions of robustness and universality. Palacios (2022) examines critical phenomena in terms of the distinction between robustness and universality proposed by Gryb et al. (2021). Palacios summarizes the distinction as follows:

**Robustness** insensitivity of some behavior to variation in the microphysical details that characterize a particular token.

**Universality** insensitivity of some behavior to variation in the macroscopic details that characterize the type of system considered. (Palacios, 2022, 37)

Roughly speaking, robustness concerns insensitivity to microscopic variation within a system, whereas universality concerns commonality across different types of systems.

Critical phenomena satisfy both conditions as Palacios (2022) points out. The RG framework explains critical behavior by showing how microscopically different systems can flow toward the same fixed point. Since the RG transformation suppresses irrelevant microscopic details, the resulting critical behavior is insensitive to many lower-level differences. In this sense, critical phenomena exhibit robustness. At the same time, systems as different as magnets and fluids display the same scaling behavior near the critical point. This is a case of universality, since the same macroscopic behavior appears across distinct types of systems.

The ideal gas law can also be understood in these terms. Under the relevant idealizing assumptions, microscopically different gaseous systems exhibit the same relation expressed by $pV = NT$. In this sense, the law is robust with respect to variation in lower-level details. It is also universal in Palacios's sense, since the same macroscopic relation holds across many physically distinct gases. Thus, the ideal gas law, no less than critical phenomena, satisfies both robustness and universality.

Although both cases display insensitivity to microscopic and macroscopic variation, the sources of that insensitivity differ. As Oono puts it, critical phenomena are "the outcome of complicated entanglement of numerous degree of freedom," whereas the ideal gas is "the universality emerging in the limit of simplicity" (Oono, 2013, 141). To clarify this contrast, the next section introduces the notion of effective complexity as a conceptual tool. The point is not that one case is universal and the other is not, but that the simplicity involved in the two cases is achieved differently: in one case it is presupposed, whereas in the other it is theoretically recovered. This point is clarified through the notion of effective complexity.

# 4 Presupposed Simplicity and Recovered Simplicity

## 4.1 Effective Complexity as a Conceptual Tool

This subsection introduces the notion of effective complexity as a conceptual tool for clarifying the difference between the two kinds of universality introduced above. In the present context, the point is not to provide a quantitative measure of complexity, but to articulate what the simplicity amounts to and how higher-level regularities are obtained in different cases of universality.

A familiar notion of complexity is Kolmogorov complexity, which measures the complexity of an object in terms of the length of its shortest description. As Gross (2021) emphasizes, however, this notion is not well suited to many cases in scientific practice. A completely random sequence counts as maximally complex in the Kolmogorov sense because it cannot be compressed, but such randomness is often treated in science not as meaningful complexity but as noise. To address this problem, Gross adopts and develops the notion of effective complexity introduced by Gell-Mann and Lloyd (1996).

The core idea of effective complexity is to focus not on an object taken in isolation, but on the ensemble of which it is treated as a typical member. What matters is the amount of information required to characterize the relevant regularities of that ensemble. Effective complexity is therefore not an intrinsic property of an object. It depends on how the ensemble is specified and on which regularities are taken to matter for explanatory purposes. Effective complexity is useful here because the relevant issue is not the intrinsic complexity of an individual lower-level system, but the regularities of the ensemble in which such systems are treated as explanatorily equivalent.

The following subsections investigate the cases of critical phenomena and the ideal gas law in terms of this conceptual framework. Following Gross's (2021) distinction between the behavior-level and mechanism-level, we examine the microscopic and macroscopic levels of these cases. This perspective helps clarify how the simplicity arises in both cases: whether it is presupposed by idealizing the lower-level description in advance, or theoretically recovered by identifying the relevant structure within a heterogeneous microscopic domain.

## 4.2 Critical Phenomena and Recovered Simplicity

At the macroscopic level, critical phenomena are characterized by relatively simple regularities, such as critical exponents and scaling relations. An ensemble that treats systems exhibiting the same critical behavior as typical members can therefore be described in a concise way. In this sense, the higher-level description is simple: a wide variety of phenomena can be captured by a small number of parameters and functional relations.

The crucial issue, however, concerns the lower level. Before the RG framework is brought to bear on the case, the microscopic systems associated with critical phenomena may appear as a heterogeneous collection lacking any clear common structure. If they are treated simply as members of a broad and weakly structured ensemble, their effective complexity does not yet reflect the explanatory structure relevant to critical behavior. However, once the RG framework identifies which differences are irrelevant and which structural features are retained, these same systems can be understood as members of a universality class. Then, the relevant ensemble is no longer weakly structured. In this sense, the effective complexity of the microscopic level depends on how the ensemble is theoretically articulated.

Here the explanatory role of the RG becomes decisive. The RG provides a principled way of distinguishing relevant from irrelevant variables through coarse graining. This point is important: the RG does not merely discard detail indiscriminately. Rather, it identifies which lower-level differences matter for critical behavior and which do not. By doing so, it shows how microscopically distinct systems can flow to the same fixed point and thereby belong to the same universality class. The universality class is therefore not simply a pre-given collection, but a theoretically articulated ensemble defined by the RG framework. In critical phenomena, the relevant lower-level ensemble is not given in advance but articulated through the RG framework.

This means that the structured lower-level ensemble corresponding to the simple macroscopic behavior is not available from the outset. Prior to the RG analysis, the microscopic domain appears as a heterogeneous set of models and systems without a clear explanatory grouping. The RG reorganizes this diversity by revealing a non-trivial equivalence structure: systems that differ in many microscopic respects are shown to be equivalent with respect to critical behavior. What the RG framework makes available is a structured lower-level ensemble relative to which the macroscopic simplicity becomes intelligible.

From the perspective of effective complexity, the point is therefore not just that the higher-level description is short, but that the relevant lower-level ensemble must first be identified through theoretical work. The simplicity of critical phenomena is not presupposed by starting with a simplified microscopic basis. Rather, it is recovered through a framework that extracts the relevant structured regularity from microscopic heterogeneity and thereby makes the higher-level regularity intelligible.

## 4.3 Ideal Gas Law: Presupposed Simplicity

Let us now consider the case of the ideal gas law. At the lower level, the system is drastically simplified by strong idealizations. Molecules are treated as having negligible volume, intermolecular interactions are ignored, and collisions are assumed to be perfectly elastic. Instead of beginning from a heterogeneous domain whose relevant structure must be discovered, the model begins by imposing conditions under which many complicating factors are excluded from consideration.

As a result, the lower-level ensemble is simple from the outset. The microscopic basis is already simplified in a way that makes a compact macroscopic description possible. This point is closely related to the derivability of the law.

As noted above, the ideal gas law can be derived from classical mechanics under suitable assumptions. What makes this derivation possible is precisely that the lower-level description has already been idealized so as to remove many sources of microscopic variation. The higher-level regularity is thus obtained from a lower-level basis that is simple by construction. In the ideal gas law, the relevant lower-level ensemble is already constrained into a relatively simple form by idealization.

The same point applies at the macroscopic level. The behavior of the system is characterized by a single simple relation among thermodynamic variables, $pV = NT$. The ensemble of systems counted as ideal gases is defined precisely by conformity to this equation. Since the relevant regularity is exhausted by this compact law, the higher-level description is also simple. There is no need, in this case, for a theoretical procedure analogous to the RG in order to identify which microscopic differences may be neglected. Those differences have already been excluded by the idealization.

From the perspective of effective complexity, both the lower-level and higher-level descriptions are comparatively simple in the case of the ideal gas law. What is philosophically significant is that this higher-level simplicity is not recovered from microscopic heterogeneity. Rather, it is secured by beginning with an already idealized lower-level description. The universality of the ideal gas law therefore rests on presupposed simplicity: the model yields a common higher-level regularity because simplicity has been built into its basis from the outset.

# 5 Consequences for Emergence and Reduction

## 5.1 Emergence

The distinction between recovered simplicity and presupposed simplicity helps clarify why universality does not bear a uniform philosophical relation to either emergence or reduction. What matters is not merely that the same higher-level behavior is insensitive to certain lower-level differences. The more important issue is how that higher-level simplicity is established, and what kind of lower-level basis supports it.

In the present context, emergence is at issue when a higher-level order becomes available only through an explanatory framework that cannot be reduced to a straightforward reading-off from lower-level descriptions. Put differently, a phenomenon may be called emergent, in the relevant sense, when the lower-level descriptions do not by themselves make the higher-level regularity intelligible, and when a further theoretical framework is required to identify the structure that matters for explanation (De Haro 2019).

This point becomes clearer when we reconsider the status of critical phenomena. Critical behavior, taken by itself, need not always count as emergence. One may, for example, approximately describe critical phenomena within a framework such as the van der Waals equation of state. The explanation relies on a strongly idealized microscopic picture, and the resulting account is structurally closer to the case of the ideal gas law. The simplification is built into the microscopic model from the outset, and the macroscopic regularity is obtained from this already simplified lower-level basis. In such a case, the macroscopic regularity can be derived from an already simplified lower-level model, and in that sense the case does not count as emergence.

The distinctive significance of critical phenomena appears more clearly only in the RG framework. The importance of the RG is not merely that it reproduces the fact of macroscopic insensitivity more accurately or more generally. Rather, the RG distinguishes relevant from irrelevant variables, shows which microscopic differences may be neglected under coarse graining, and identifies the systems that flow into the same fixed point as members of a single universality class. In doing so, it provides not simply a more precise description of an already available order, but a theoretical articulation of the lower-level basis in terms that make the higher-level regularity intelligible.

This point is expressed more sharply by comparing the situation before and after the introduction of the RG framework. Prior to the RG analysis, the systems that later turn out to belong to the same universality class appear only as a heterogeneous collection of models and physical systems with no obvious explanatory grouping. Their microscopic constitutions differ in many respects, and nothing in the mere aggregation of those lower-level descriptions straightforwardly reveals why they should exhibit the same critical behavior. The RG changes this situation fundamentally. By identifying which lower-level differences are irrelevant and which structural features remain significant, it reorganizes a heterogeneous domain into a structured ensemble. The universality class is therefore not simply found as a ready-made category within the microscopic description; it is theoretically articulated through RG analysis.

From this perspective, the critical phenomena in the RG explanation is a case of emergence. The higher-level description captures critical behavior, but the lower-level descriptions, without RG analysis, do not by themselves reveal the behavior, even when the systems belong to the same universality class. In this sense, the RG-based account fits the idea of emergence developed by De Haro (2019) and Morita (2023). Critical phenomena alone do not imply emergence, but the RG framework shows how they can be understood as emergent.

## 5.2 Reduction

The same comparison also clarifies the relation between universality and reduction. The ideal gas law provides a clear example of a universal regularity that is compatible with reduction. As argued above, the ideal gas law exhibits universality because microscopically different gaseous systems display the same macroscopic relation under appropriate conditions. At the same time, this relation can be derived from classical mechanics once a suitably idealized microscopic description is given (Dizadji-Bahmani et al. 2010). The lower-level basis is already constrained in such a way that the relevant macroscopic behavior follows from it. In this sense, the universality of the ideal gas law is compatible with a reductive understanding. This case therefore shows that universality does not by itself imply anti-reductionism, as Franklin (2019, 2021) emphasizes.

Critical phenomena in the RG framework, however, differ in an important respect. Their universality still depends on lower-level constitution, since only certain microscopic systems exhibit the relevant critical behavior, namely those that belong to the same universality class. In this respect, Franklin (2019) is right to insist that the explanation of critical phenomena is not independent of microscopic structure. Yet this lower-level dependence does not straightforwardly support a reductive understanding, because the relevant lower-level basis is not simply given independently of the RG procedure. What counts as explanatorily relevant at the microscopic level is itself determined through RG analysis, which distinguishes relevant from irrelevant variables and shows which details can be ignored through coarse graining. The lower-level basis relevant to critical phenomena is therefore not merely identified but theoretically articulated.

This is where Batterman's (2021) point becomes decisive. Even if critical behavior can in some sense be traced back to the microscopic level, the RG explanation has a non-reductive feature. Its explanatory force lies instead in a many-to-one mapping: microscopically heterogeneous systems are shown to flow to the same fixed point. This feature is crucial, because it means that the explanation does not preserve microscopic detail in a way that would support a straightforward derivational picture. Especially in the real-space RG picture, the explanatory achievement essentially depends on the elimination of detail. Universality is explained not by retaining the full lower-level description, but by showing why much of it is irrelevant to the phenomenon in question. Coarse graining is therefore not a dispensable approximation, but a constitutive part of the explanatory framework itself.

The contrast with the ideal gas law can now be stated more precisely. In the case of the ideal gas law, a suitably idealized lower-level description is already in place, and the higher-level law is obtained from that simplified basis. The simplicity of the macroscopic law is therefore presupposed by the structure of the model. In the case of critical phenomena, by contrast, the lower-level basis is not explanatorily usable in that form. It must first be reorganized through the RG framework before the relevant higher-level regularity can be understood. The simplicity of the macroscopic behavior is therefore not presupposed, but recovered.

Taken together, these two cases show that universality implies neither emergence nor reduction in any simple or uniform way. The ideal gas law shows that a universal higher-level regularity can be compatible with reduction when it is grounded in a lower-level description that has already been idealized and simplified. Critical phenomena, by contrast, involve a higher-level regularity whose lower-level basis becomes significant only through a framework that ignores detail and reorganizes microscopic diversity into a structured universality class. For this reason, the universality of critical phenomena is not reducible in the same sense as the universality of the ideal gas law, even though it remains connected to the lower level.

## 6 Conclusion

This paper has argued that universality is not a unitary phenomenon. Both critical phenomena and the ideal gas law exhibit a form of universality, and both exhibit robustness in Palacios's (2022) sense. However, this shared insensitivity to microscopic and macroscopic variation does not by itself capture the difference between them. This paper distinguishes these cases in terms of the notion of effective complexity. The crucial difference lies in how higher-level simplicity is achieved. In the case of the ideal gas law, simplicity is presupposed by the strong idealizations built into the lower-level description. The macroscopic law is obtained from a microscopic basis that has already been simplified. In the case of critical phenomena, by contrast, the lower-level domain is microscopically heterogeneous, and the relevant higher-level regularity is not simply given from the start. Rather, it is theoretically recovered through the RG framework, which identifies the relevant structure by distinguishing relevant from irrelevant variables and reorganizing microscopic diversity into a universality class.

This distinction also clarifies why universality bears no simple or uniform relation to emergence or reduction. The ideal gas law shows that a universal higher-level regularity can be understood in a reductive manner, because it is grounded in an already idealized lower-level basis. Critical phenomena, by contrast, show that universality may support emergence when the higher-level order becomes intelligible only through a framework that reorganizes microscopic heterogeneity rather than merely reading off a result from a pre-given lower-level description. At the same time, the RG explanation retains an important connection to the lower level, since it depends on a particular class of lower-level systems. What matters, therefore, is not universality alone, but how that universality is achieved.

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