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Middle Size Matters, but it is Lego Bricks all the Way Down

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Abstract
This paper develops *compositional functionalism*, an account of explanation within the primitive ontology framework that reconciles compositional grounding with the autonomy of the special sciences. I argue that functional explanations are appropriate within a given level, while compositional and dynamical explanations account for why those explanations work across levels. In this way, compositionality and functionalism are complementary rather than competing. The view explains why effective ontologies emerge at specific scales, why higher-level laws are stable yet only approximately exceptionless, and why compositional precision matters at microscopic levels but becomes dispensable at macroscopic ones. I further argue that this framework extends to the quantum domain through the pilot-wave theory, which restores a constructive account of matter in spacetime. The world remains "Lego bricks all the way down," but the patterns formed at each level acquire their own explanatory significance.

Keywords Primitive ontology · Reductionism · Functionalism · Explanation

1 Introduction

Understanding how special sciences relate to fundamental physics is a notoriously difficult problem. On the one hand, reductionist approaches emphasize that higher-level phenomena are grounded in the behavior of more fundamental entities. On the other hand, functionalist and emergentist views stress the autonomy of higher-level explanations, arguing that they capture stable and explanatorily relevant patterns that cannot be reduced in any straightforward way to microphysics. These perspectives are often seen as competing: one prioritizes compositional structure, the other functional organization.

In this paper, I argue that this opposition is misguided. I develop an account, namely *compositional functionalism,* according to which compositional and functional explanations play complementary roles. Functional explanations are appropriate within a given level of description, while compositional and dynamical explanations account for why those explanations are successful in the first place. In this sense, higher-level autonomy is not denied but explained.

The proposal is developed within the primitive ontology framework, which provides a clear picture of matter as composed of entities evolving in spacetime according to dynamical laws. I argue that this framework allows us to retain the classical constructive explanatory schema, according to which phenomena are explained in terms of the motion of underlying constituents, while accommodating the insights of contemporary functionalist approaches. The result is a unified account that reconciles reduction, emergence, and explanatory autonomy.

The paper is structured as follows. Section 2 introduces the classical "inverted pyramid" picture of the sciences and the associated reductionist schema. Section 3 examines how this schema has been refined in light of philosophical developments, focusing on the transition from strict Nagelian reduction to more flexible accounts based on approximation and limiting relations. Section 4 presents the functionalist alternative, emphasizing the explanatory autonomy of higher-level patterns. Section 5 discusses the challenges posed by quantum theory and contemporary physics, including nonlocality, contextuality, and the scale-dependent structure of physical theories. Section 6 introduces the primitive ontology framework and the notion of constructive theories, providing the basis for a compositional account of explanation. Section 7 develops compositional functionalism in detail, distinguishing between intra-level functional

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explanation and inter-level compositional and dynamical explanation. Section 8 extends the framework to the quantum domain via the pilot-wave theory. Section 9 highlights the advantages of the view, and Sect. 10 addresses a range of objections. Section 11 concludes.

2 Inter-Theoretic Relations and the Inverted Pyramid View of Theories

The idea that physical theories are more fundamental than the special sciences is often captured by the "inverted pyramid" picture, according to which physics occupies the base as the most general and fundamental level of description (Weinberg 1992). Physics describes entities at the smallest scales in terms of their properties and dynamical laws, while higher levels are associated with special sciences that explain phenomena at larger scales. For instance, zoology explains animal behavior in terms of structures, organization, and ecological roles. These levels form a hierarchy in which higher-level descriptions appear to be built upon lower-level ones.

Each level is characterized by an *effective ontology*: a set of entities that behave as if they were fundamental at that scale. At the lowest level, this includes particles and their laws of motion; at higher levels, it includes entities such as atoms, molecules, or organisms, together with their characteristic properties. These entities exhibit a degree of autonomy within their domain, even if they are not fundamental in an absolute sense.

This picture is naturally associated with reductionism, understood as the view that higher-level phenomena are grounded in, and in principle derivable from, the fundamental level. On this view, dependence runs bottom-up: higher-level facts are determined by lower-level physical facts. This often goes together with the primacy of physics, according to which physics is indispensable, while the special sciences are, at least in principle, reducible.

By contrast, emergentist approaches take the autonomy of the special sciences to indicate that higher-level entities and laws play an irreducible explanatory role. More generally, positions on inter-theoretic relations range from eliminative reductionism, which recognizes only fundamental entities, to strong emergence, which posits genuinely novel properties and laws at higher levels. In scientific practice, however, reduction is often understood more modestly as explaining the behavior of wholes in terms of the behavior of their parts.

Let us call this hierarchical, bottom-up picture the *classical schema of explanation*. Its core ideas are straightforward: sciences are organized in a layered structure; non-fundamental entities are composed of more fundamental ones; and higher-level laws are derived, at least in principle, from underlying dynamics.

3 The Classical Schema of Explanation and its Developments

As we have seen, classical mechanics, understood as a universal theory of particles in motion, is naturally associated with a reductive schema taken to account for phenomena at all scales. This schema involves two distinct but related claims: one concerning the nature of non-fundamental objects, and the other concerning the laws that govern them. In what follows, I consider these two aspects in turn.

3.1 Special Science Ontologies as Composites

At the classical level, it is largely uncontroversial that macroscopic objects, and more generally the entities described by the special sciences, are composed of more fundamental constituents. If one were to express this idea schematically, one might say that, if fundamental objects are taken as the building blocks of reality, then "it is Lego bricks all the way down."

More precisely, each special science employs an effective, non-fundamental ontology in terms of which it describes and explains phenomena at its own scale. In chemistry, for instance, matter is described in terms of atoms, which function as the relevant effective ontology. Within this ontology, entities can be grouped into kinds: entities of the same kind behave similarly under the same conditions, while entities of different kinds behave differently. In chemistry, these kinds correspond to chemical elements, such as oxygen, hydrogen, carbon, or gold, whose atoms share relevant features and exhibit systematic patterns of behavior.

Within the classical schema, such effective ontologies are explained compositionally. The ontology at a given level is taken to be composed of the ontology at the level below. Thus, atoms are understood as composed of protons, neutrons, and electrons, and chemical elements are distinguished, for instance, by their number of protons. More generally, one can think of a sequence of compositional levels: particles compose atoms, atoms compose molecules, molecules compose more complex structures, and so on up to macroscopic objects. At each stage, higher-level entities are understood as aggregates of more fundamental ones, even if they behave as if they were autonomous at their own scale.

3.2 Special Science Laws as Derivable

While the compositional nature of special science entities is widely accepted, reduction also requires an account of

the relationship between higher-level laws and the laws of fundamental physics. The key question is therefore not only whether higher-level entities are composed of more fundamental ones, but also whether, and in what sense, the laws governing those entities can be derived from the underlying dynamics. This issue has been the subject of extensive debate.

Nagel's (1961) model of inter-theoretic reduction provided an early systematic account, according to which higher-level laws are deduced from lower-level ones via bridge laws connecting the vocabularies of the two theories. However, this model proved too rigid to accommodate actual scientific practice. Schaffner (1976) accordingly proposed a more flexible account, allowing for the modification and approximation of higher-level theories prior to their derivation from more fundamental ones.

Nonetheless, further challenges have been raised. Batterman (2002) argues that many macroscopic phenomena depend on singular limits and idealizations, so that straightforward derivations from the micro-level are not available. In response, reductionists have weakened the notion of reduction by emphasizing limiting relations and idealizations, thereby reconciling reduction with emergence (e.g. Butterfield 2011). On this view, reduction need not take the form of strict deduction, but can instead proceed via approximations. Similarly, others have emphasized that reduction is often statistical rather than deductive: for instance, thermodynamic laws can be explained in terms of microphysics by showing that they hold for the overwhelming majority of microstates (Callender 1999).

A further challenge concerns the autonomy of the special sciences. Higher-level concepts are often multiply realizable (Fodor 1976), explanatorily indispensable (Putnam 1976), and embedded in distinct unificatory frameworks (Kitcher 1984). In addition, it has been argued that large-scale structures may influence local dynamics, raising the possibility of top-down explanation (Ellis 2012; Gillett 2016). These considerations suggest that higher-level explanations cannot simply be replaced by lower-level ones.

Defenders of reduction, such as Weinberg and Kim (1998), respond by maintaining that explanatory primacy ultimately resides at the microphysical level, even if explicit derivations are infeasible in practice. On their view, higher-level descriptions may be indispensable for pragmatic or epistemic reasons, but they do not undermine the underlying dependence on the fundamental level.

Taken together, these developments suggest a refined version of the classical schema. While strict, deductive reduction is often unattainable, a weaker form remains viable: higher-level laws are derivable in principle, though only through approximations, idealizations, and probabilistic reasoning. Emergence, on this view, reflects epistemic and methodological limitations rather than genuine ontological novelty. Call this the *sophisticated classical reductive schema*: everything is still "Lego bricks all the way down," and non-fundamental laws are, in principle, grounded in the motion and interaction of those bricks.

4 Constitutive Functionalism as an Intra-Level Reductive Schema

As we have seen, classical reduction focuses primarily on inter-theoretic relations: it aims to explain how higher-level entities and laws are grounded in, and derived from, a more fundamental level. However, this leaves open a different question, namely in what sense the special sciences are themselves explanatory. Critics of reductionism have argued that even if composition and derivation hold, this does not account for the distinctive features of special sciences, such as their autonomy, stability, and explanatory relevance. In response, attention has shifted from inter-level reduction to intra-level explanation.

One influential response is functionalism, most prominently associated with Dennett (1991) and developed in the philosophy of science by Ladyman and Ross (2007). These approaches adopt a more liberal understanding of reduction and focus on explaining the explanatory success of the special sciences within their own domains. On this view, entities and laws in the special sciences emerge as *real patterns*: they are identified and justified by their role in successful explanation and prediction. The hierarchical "inverted pyramid" is replaced by a layered picture in which each level is characterized by functionally defined patterns, with no need for a deeper compositional grounding.

4.1 Functionalism and Special Sciences

According to this view, explanations in the special sciences are fundamentally functional: what matters is the role that entities play, rather than their underlying composition. For example, in chemistry one explains why sodium chloride dissolves in water by appealing to the dispositions of the relevant chemical kinds: sodium tends to lose an electron, while chlorine tends to gain one, forming ions. This explanation does not invoke the internal composition of these kinds or their relation to more fundamental entities. Chemical properties are thus understood dispositionally: they characterize what a kind does, not what it is.

Functional explanation also accounts for the characteristic features of special science ontologies. These ontologies are stable, opaque, and governed by autonomous and (approximately) exceptionless regularities. In chemistry, for instance, atomic elements function as the effective

ontology: they remain fixed across the domain, their internal structure is largely irrelevant for chemical explanations, and their behavior is determined by systematic regularities, such as the dependence on outer electron configuration. These features make chemical explanations both robust and practically successful, even in the absence of a complete microscopic theory.

At larger scales, the importance of functional explanation becomes even more evident. In biology or zoology, entities such as organisms are defined primarily by their behavior. A tiger, for example, is characterized by its role as a predator, its typical patterns of behavior, rather than by its microphysical composition. Such functional definitions are compatible with multiple realizations and are not strictly exceptionless, but they remain explanatorily effective within their domain. In these contexts, reference to underlying physical structure is not only unnecessary but often unhelpful for explanation.

4.2 The Universality of Functional Explanation

Some functionalists extend this approach further, arguing that all explanation is ultimately functional or structural. Wallace (2012), for example, contends that classical mechanics should not be understood as a theory of matter in motion, but as a general mathematical framework whose explanatory power depends on how it is applied. On this view, physical theories provide structural tools for modeling systems, rather than descriptions of an underlying ontology. The Hamiltonian formalism, for instance, acquires physical significance only once a specific system is specified.

In this spirit, Wallace argues that Gibbsian statistical mechanics provides the most general framework for physics, while Boltzmannian approaches represent more limited special cases (Wallace 2012). More broadly, this perspective, sometimes labeled *constitutive functionalism* (Knox and Wallace 2025), takes explanation to consist in identifying stable functional patterns across different domains. Special sciences are understood as organizing phenomena in terms of such patterns, which are justified by their explanatory and predictive success.

On this view, compositional structure remains in the background, "Lego bricks all the way down," but is explanatorily irrelevant. What explains phenomena at a given level is not their underlying composition, but their conformity to functional patterns or structural frameworks that capture their behavior.

5 Quantum Challenges and the New Schema

Quantum theory is often taken to challenge the classical reductive schema. In particular, features such as contextuality, non-separability, and nonlocality appear to undermine the idea of a stable, separable microphysical base from which higher-level phenomena can be derived.

5.1 Nonrelativistic Quantum Mechanics

In its standard formulation, quantum mechanics introduces a fundamental tension. The quantum state evolves deterministically according to the Schrödinger equation, yet measurement outcomes are probabilistic and seem to depend on the notion of an observer. This has motivated a range of interpretations that weaken or reject the idea of a fundamental, observer-independent ontology.

A deeper challenge comes from entanglement. In entangled states, such as the singlet state, the properties of the system are not reducible to those of its parts. This violates separability and suggests that the fundamental level is not composed of independent local entities, but instead forms a holistic structure. Together with the experimental violation of Bell inequalities, this also points toward nonlocality, where correlations between distant systems cannot be explained by local interactions.

These considerations appear to undermine the classical picture of reduction, which relies on separability and locality. If the fundamental level is non-separable and nonlocal, then the idea of explaining higher-level phenomena in terms of independently behaving parts becomes problematic.

5.2 Relativistic Theories: Quantum Field Theories and Beyond

Similar challenges arise in quantum field theory. In quantum field theory, particles are not fundamental objects, but excitations of underlying fields, and their existence may depend on the representation used. Moreover, the effective field theory framework of quantum field theories suggests that physics is organized into scale-dependent theories, each valid within a limited domain. These theories are often insensitive to the details of more fundamental descriptions, raising doubts about the existence of a single privileged base.

Dualities further complicate the picture. Different theoretical descriptions can be mathematically equivalent, even when they appear to describe radically different ontologies. This suggests that what counts as "fundamental" may depend on the representation rather than on an underlying reality.

In quantum gravity, these issues become even more pronounced. Many approaches suggest that spacetime itself

is emergent, rather than fundamental. If spacetime is not part of the basic ontology, then the classical compositional picture—based on objects located in spacetime—must be reconsidered.

5.3 Constitutive Functionalism

Taken together, these developments have motivated a shift toward more functional and structural approaches to explanation. On this view, the classical hierarchical picture is replaced by a network of interdependent levels, each characterized by its own effective descriptions. Explanation consists in identifying stable patterns, structures, or constraints that hold at a given scale, rather than reducing phenomena to an underlying base.

This perspective is captured by constitutive functionalism discussed in Sect. 4. Within this framework, higher-level entities are understood as *real patterns* that emerge from the underlying structure but are not explained by it. In the quantum domain, Everettian quantum mechanics (Wallace 2012) provides a natural realization of this idea: macroscopic objects are not explained compositionally, but as stable patterns arising from the universal quantum state.

From this standpoint, the classical reductive schema is replaced by a functionalist one. While composition may still hold in some sense, it is no longer explanatorily central. What explains phenomena is not their underlying constitution, but their role within a larger structural or dynamical framework.

6 The Primitive Ontology Approach and Constructive Explanation

Against the functionalist shift outlined in the previous section, the primitive ontology approach, especially as developed by Allori (2013, 2026 and references therein), aims to preserve the classical explanatory schema in a refined form. On this view, a fundamental physical theory should provide a clear ontology in spacetime together with dynamical laws governing its behavior. The goal is not merely to describe patterns, but to explain them in terms of underlying constituents and their dynamics.

At first sight, the developments discussed in Sect. 5 appear to challenge this program: quantum theory seems to undermine separability, locality, and the very idea of a compositional base. However, Allori argues that these conclusions have been drawn too hastily. Her project is to reassess whether, and at what cost, the classical constructive schema can be extended to the quantum domain. The motivation is not conservatism, but the claim that constructive theories are explanatorily superior to purely functional or structural approaches.

6.1 Fundamental Physical Theories as Constructive Theories

Within this framework, a fundamental theory is ideally a *constructive theory*, inspired by Einstein (1919). Constructive theories aim to "build up" complex phenomena from simpler underlying processes, and genuine understanding is achieved when such a construction is provided. The kinetic theory of gases, for instance, explains thermodynamic behavior by reducing it to molecular motion.

Einstein contrasted constructive theories with *principle theories*, which do not provide a bottom-up account but instead formulate general constraints on possible phenomena. Thermodynamics is the canonical example: it specifies conditions that physical processes must satisfy, but does not explain why they hold. While principle theories are explanatory within their domain, they remain incomplete from a constructive perspective.

Allori's central claim is that a satisfactory fundamental theory should be constructive in this sense: it should specify a spatiotemporal ontology together with a law of motion from which higher-level phenomena can be derived. Classical mechanics provides the paradigm, describing matter in motion and accounting for macroscopic behavior in terms of composition and dynamics.

The reductive schema thus involves two complementary components: an ontological claim, according to which higher-level entities are composed of more fundamental ones, and a dynamical claim, according to which higher-level laws are derived—under suitable approximations—from the underlying dynamics. Reduction is therefore not a matter of strict deduction, but of combining composition with dynamical derivation.

6.2 Special Sciences as Principle Theories

In contrast to fundamental theories, special sciences are best understood as *principle theories*. They are domain-specific and organize phenomena in terms of general constraints and regularities rather than deriving them from underlying dynamics.

Thermodynamics provides the clearest example: it formulates principles such as the impossibility of perpetual motion or the increase of entropy, which constrain the behavior of macroscopic systems without explaining their microscopic origin. However, the same structure appears more broadly across the special sciences.

In chemistry, explanations proceed in terms of principles of bonding, valency, and reactivity. The periodic table, for

instance, encodes regularities that determine how elements combine and interact. While these patterns can ultimately be related to microphysics, they are not derived within chemical practice from underlying dynamics, but are treated as constraints governing chemical behavior.

Similarly, in continuum mechanics, matter is modeled as a continuous medium governed by phenomenological principles such as elasticity or viscosity. These principles determine how materials deform and flow without reference to their atomic composition. Fluid dynamics provides another example, where equations such as the Navier–Stokes equations constrain macroscopic motion independently of the underlying molecular details.

At larger scales, the same explanatory structure appears in biology and zoology. Here, explanations are given in terms of functional and organizational principles. A predator, for example, is not defined by its microphysical composition, but by its role within a system; organisms are characterized by their capacities for survival, reproduction, and interaction. These principles constrain behavior within the domain, even though they do not specify the underlying mechanisms.

In all these cases, special sciences provide *intra-level explanations*: they explain what happens at a given scale and what is possible within that domain by identifying stable patterns and regularities. These explanations are often functional, in that they characterize entities by what they do rather than by what they are made of.

For this reason, special sciences can be understood as principle theories in an extended sense. Like Einstein's original notion, they impose constraints on phenomena and organize them into systematic patterns without providing a constructive account of their origin. Their explanatory power lies in identifying what must happen, given the principles that define the domain.

From the perspective of compositional functionalism, however, this leaves an important question unanswered: why do these principles hold at all? Answering this question requires moving beyond intra-level explanation to a constructive, inter-level account grounded in the underlying ontology and its dynamics.

6.3 The Explanatory Role of Constructive Theories

Constructive theories address precisely this gap by explaining why the principles identified at higher levels hold, grounding them in the dynamics of more fundamental constituents. Rather than merely describing regularities, they account for them by showing how they arise from underlying processes, thereby realizing Einstein's idea that genuine understanding requires building up complex phenomena from simpler elements.

This is most clearly illustrated by the relationship between thermodynamics and statistical mechanics. Thermodynamic laws function as general constraints at the macroscopic level, while statistical mechanics explains how these regularities arise from the collective behavior of large numbers of particles. In doing so, it clarifies why these laws are stable under perturbations and why apparent violations are extremely rare.

More generally, constructive theories exhibit an explanatory depth that principle theories lack. They account not only for the existence of higher-level regularities, but also for their characteristic features: their stability across a wide range of conditions, their approximate exceptionlessness, and the possibility of deviations. At the same time, they clarify why specific effective ontologies emerge at given scales and why certain patterns become explanatorily relevant.

A further advantage of constructive explanation is that it clarifies the scale-dependence of compositional reasoning. At small scales, precise composition is crucial: even minimal changes in the number or arrangement of constituents can produce qualitatively different entities. At larger scales, by contrast, systems involve enormous numbers of constituents, and macroscopic behavior depends on collective organization rather than exact composition. Constructive theories explain this transition by showing how higher-level regularities arise from underlying dynamics and why functional descriptions become both appropriate and unavoidable at larger scales.

Constructive theories therefore do not replace principle theories, but complement them. Principle theories capture the regularities that govern phenomena at a given level, while constructive theories explain why those regularities hold, what their limits are, and how they emerge from more fundamental processes. It is this explanatory role that underlies the compositional functionalist framework developed in the next section.

7 Compositional Functionalism as the Best of Both Worlds

At this point, it is useful to distinguish clearly between two kinds of explanation. On the one hand, *intra-level explanations* account for phenomena using the entities and laws operative at a given level, as is typical in the special sciences. On the other hand, *inter-level explanations* account for why those entities and laws arise at that level in the first place.

Functionalist approaches have rightly emphasized that classical reduction, understood purely in compositional terms, does not explain the autonomy and explanatory success of the special sciences. However, this criticism targets

the wrong aspect of the classical schema. As discussed in Sect. 6, reduction is primarily concerned with inter-level relations, whereas functional explanations operate within a level. I agree with functionalists that intra-level explanations are typically functional: for instance, explaining why salt dissolves in water appeals to chemical kinds and their properties, not to their particle composition. However, such explanations are not exhaustive. Rather, they can be grounded in a compositional and dynamical account at a more fundamental level.

Recognizing that constructive theories operate across levels while principle theories operate within a level, I develop an account, *compositional functionalism*, that integrates their complementary roles. This framework combines inter-level compositional reduction with intra-level functional explanation. In doing so, it explains both the autonomy of the special sciences and the origin of their effective ontologies and laws, thereby preserving the strengths of both reductionist and functionalist approaches.

7.1 Intra-Level Functionalism

Compositional functionalism fully endorses the functionalist insight that special science kinds are defined by their roles. Across both living and non-living systems, higher-level entities are most naturally characterized in terms of what they do rather than what they are made of.

In chemistry, molecules are understood in terms of their dispositions to interact, catalyze reactions, or exhibit properties such as chirality. Proteins are defined by their ability to fold into specific structures, to act as enzymes, or to regulate biochemical processes, and these roles are multiply realizable across different molecular structures. Similarly, genes are characterized by their role in encoding functional products or regulating expression, and DNA by its role as a stable information-storage system. These functional roles can be realized by different physical substrates, as in the case of RNA-based systems in certain viruses.

At larger biological scales, the same pattern holds. Cells are defined by their capacities for metabolism, regulation, and reproduction, while organisms are characterized by their ability to integrate these processes to ensure survival and reproduction. A predator, for instance, is defined by its role within an ecological system rather than by its precise physical composition. These functional definitions are compatible with multiple realizability and need not be exceptionless, yet they remain explanatorily effective.

Non-living systems exhibit similar features. Gases, liquids, and solids are defined by their characteristic dispositions, such as expansion, flow, or rigidity, and these macroscopic roles can be realized by very different microstructures. In all these cases, what is explanatorily central is not precise composition, but stable patterns of behavior.

Functional descriptions thus account for the characteristic features of the special sciences: stability, opacity, autonomy, and robustness. However, as emphasized in Sect. 6, they do not explain why these particular ontologies and laws arise at these scales. Addressing this question requires moving beyond intra-level explanation.

7.2 Inter-Level Composition

Compositional functionalism addresses this question through inter-level explanation. The central claim is that functional explanations are valid within a level, but their success is explained compositionally and dynamically by appeal to a more fundamental level.

This involves answering two related questions: why a given effective ontology emerges at a certain scale, and why the corresponding laws hold. The answer proceeds by examining the structure and interactions at a more fine-grained level. For instance, atoms behave as if they were fundamental in chemistry because chemical interactions involve outer electrons and are governed by electromagnetic forces at that scale, while nuclear forces become relevant only at smaller scales. Thus, the autonomy of chemistry is explained by the structure of interactions at the level below.

More generally, explanation proceeds through a chain of levels connecting higher-level phenomena to fundamental physics. The gap between macroscopic and microscopic scales is too large to be bridged in a single step; instead, explanation advances through intermediate levels, each grounded in the one below. From a bottom-up perspective, this compositional structure becomes explicit: particles form atoms, atoms form molecules, and so on, with each level exhibiting its own effective ontology.

In this way, effective ontologies are not fundamental but arise from the compositional organization of lower-level entities. While special sciences provide autonomous explanations at their own level, compositional explanation accounts for why their ontologies and laws hold at all.

7.3 Dynamical Derivation

A central component of this picture is the dynamical derivation of higher-level laws. As discussed in Sect. 6, constructive theories explain why higher-level regularities hold by grounding them in underlying dynamics. Here, this idea is developed in more detail.

In its simplest form, dynamical derivation consists in showing how macroscopic laws arise from the dynamics of an underlying microscopic ontology. In practice, however,

such derivations are not exact or purely deductive. They rely on approximations, idealizations, and limiting procedures, such as coarse-graining, large-number limits, and probabilistic reasoning.

Despite this, dynamical derivation plays a crucial explanatory role. It explains not merely that macroscopic laws hold, but why they exhibit their characteristic features. In statistical mechanics, for example, thermodynamic behavior is explained in terms of the collective dynamics of large numbers of particles, showing why equilibration occurs and why violations of the second law are extremely rare. Similarly, hydrodynamic equations arise from underlying molecular interactions and explain why macroscopic variables provide stable and autonomous descriptions.

A key concept in these explanations is *typicality*: macroscopic behavior is what occurs for the overwhelming majority of microstates (Goldstein 2001; Wilhelm 2022; Lazarovici and Reichert 2015; Lazarovici 2023). This accounts for multiple realizability without invoking a separate metaphysics of realization. As the number of constituents grows, atypical behavior becomes negligible, and macroscopic laws appear effectively deterministic.

Dynamical derivation thus provides inter-level explanation: it explains not only what happens, but why certain descriptions and laws are appropriate at a given scale. Functional explanations suffice within a level, but they do not explain their own success. Compositional explanation fills this gap by grounding higher-level regularities in underlying dynamics.

7.4 Composition, Functionalism, and Scales

Finally, compositional functionalism explains the shift from compositional to functional explanation across scales. At small scales, composition is precise and crucial: small changes in the number or arrangement of constituents can produce qualitatively different entities. At larger scales, however, systems involve enormous numbers of constituents, and macroscopic behavior depends on collective organization rather than exact composition.

This explains why functional descriptions become appropriate at higher levels. Macroscopic systems are robust under small variations, and their behavior is best captured in terms of stable patterns rather than precise composition. Compositional functionalism thus accounts for both the importance of composition at lower scales and its diminishing relevance at higher ones.

Compositional functionalism therefore provides a coherent account of how functional and compositional explanations relate across levels: functional descriptions capture the behavior of systems within a level, while compositional and dynamical explanations account for why those descriptions are successful. In this sense, functionalism explains patterns, while compositional functionalism explains why those patterns exist, persist, and have the features they do. The classical reductive schema is not abandoned, but refined into a non-deductive and scale-sensitive framework.

The crucial question, however, is whether this picture can be sustained in the quantum domain, where phenomena such as nonlocality, contextuality, and non-separability appear to undermine the very assumptions on which the classical schema relies. The next section argues that, contrary to common assumptions, a constructive quantum theory can preserve this explanatory structure.

8 A Universal Quantum Constructive Theory

The developments discussed in Sect. 5 suggest that quantum theory challenges the classical reductive schema by undermining separability, locality, and the idea of a stable compositional base. However, if the framework developed in Sects. 6 and 7 is correct, these challenges do not require abandoning constructive explanation altogether. Rather, they call for a reformulation of the classical schema within the quantum domain.

According to Allori, the guiding idea remains that fundamental physical theories should be constructive. Classical mechanics exemplifies this ideal: it provides a spatiotemporal ontology together with dynamical laws from which higher-level phenomena can be explained. With the advent of quantum theory, however, this explanatory model appeared to break down. Standard formulations, such as the axiomatic framework introduced by von Neumann, as well as more recent approaches like Everettian quantum mechanics (Wallace 2012), are best understood as *principle theories*: they impose constraints on possible phenomena without providing a constructive account of their underlying dynamics.

If this diagnosis is correct, then the standard framework does not supply a universal constructive theory of the quantum domain. Given the explanatory advantages of constructive theories, it is therefore natural to ask whether such a theory can be found. While quantum features such as contextuality, non-separability, and nonlocality are often taken to rule out this possibility, Allori argues that this conclusion is premature. A constructive quantum theory already exists in the form of the de Broglie–Bohm pilot-wave theory, which describes matter as point particles evolving in time according to a well-defined dynamical law (Allori 2026). Other constructive approaches, such as GRW-type theories with matter density or flash ontologies (GRWm, GRWf), are also available; however, the pilot-wave theory provides the most straightforward realization of a universal constructive

framework, making the compositional structure particularly transparent.

If such a theory is available, then the classical explanatory schema can be preserved in a refined form. Macroscopic phenomena can still be understood as arising from the composition and dynamics of more fundamental entities, even if the derivation is non-deductive and approximation-laden. In this sense, the "Lego-brick" picture of reality remains intact: higher-level behavior is grounded in the motion of underlying constituents, even when this grounding is indirect.

8.1 The Core of the Pilot-Wave Theory

The pilot-wave theory (de Broglie 1924; Bohm 1952) is a deterministic theory of particles moving in spacetime, much like classical mechanics. However, its dynamics differ in an important respect: particle motion is governed by a velocity-dependent guiding equation rather than by forces producing acceleration.

In classical mechanics, interactions are mediated by fields that propagate locally in spacetime. In the pilot-wave theory, by contrast, particles are guided by a wavefunction defined on configuration space. Because the wavefunction depends on the instantaneous configuration of all particles, the motion of any given particle depends on the positions of all others, regardless of distance. In this sense, the theory is fundamentally nonlocal.

While this nonlocality is often taken to be problematic, within the present framework it is better understood as a feature of the nomic structure. The wavefunction does not mediate interactions in spacetime; rather, it is part of the law governing the system as a whole (Allori 2021, 2025; Goldstein and Zanghì 2013). The apparent "interaction" thus reflects the global structure of the law, rather than the transmission of signals between particles.

8.2 Separability, Macroscopic Locality, and Context Dependence

Despite its nonlocal dynamics, the pilot-wave theory preserves a clear ontological picture: matter consists of particles with definite positions. In this sense, separability holds at the level of ontology, even though interactions are nonlocal.

At the same time, nonlocal effects are effectively suppressed at higher scales. Due to decoherence, interference becomes negligible, and macroscopic systems can be described in approximately local and separable terms. This illustrates a central idea of compositional functionalism: while the fundamental level may exhibit nonlocal features, higher-level descriptions can remain local because of the way collective behavior emerges.

The apparent tension between fundamental nonlocality and macroscopic locality is therefore not a contradiction, but a case of inter-level explanation. As argued in Sect. 7, compositional and dynamical considerations explain why certain effective descriptions are appropriate at a given scale. In this case, they explain why local descriptions emerge from nonlocal dynamics.

A related point concerns contextuality. In the pilot-wave theory, operators do not represent intrinsic properties but measurement procedures (Daumer et al. 1996; Bricmont 2016). Measurement outcomes depend both on the system's configuration and on the experimental context. Properties such as spin are therefore not pre-existing attributes, but arise from system–apparatus interactions.

From the perspective of compositional functionalism, this supports the idea that higher-level properties are best understood functionally rather than intrinsically. At the same time, the underlying ontology, particles evolving under a law, remains well-defined and non-contextual. Contextuality thus clarifies how effective properties emerge, rather than undermining the compositional picture.

8.3 Quantum Chemistry

The pilot-wave theory also provides a promising framework for addressing a well-known difficulty: the derivation of chemical laws from quantum mechanics. It has often been argued that central chemical concepts, such as molecular structure, bonding, and reactivity, are not straightforwardly derivable from the Schrödinger equation. As emphasized by Scerri (2007), chemical explanation relies on concepts such as orbitals, chemical kinds, and molecular structure, which depend on approximations like the Born–Oppenheimer scheme and do not directly follow from the fundamental formalism.

From the perspective developed here, this difficulty does not undermine compositional explanation, but reflects the limitations of the standard formulation of quantum theory. The reliance on approximations and effective concepts indicates that the connection between levels is indirect and mediated, not that it is absent. As argued in Sect. 7, compositional functionalism predicts precisely this: higher-level descriptions are functionally autonomous, yet grounded in an underlying ontology through non-deductive dynamical relations.

In this respect, the pilot-wave theory provides a decisive advantage. As a constructive theory, it restores a framework in which molecular structure and chemical behavior can be derived from underlying dynamics in a way that is unavailable in standard formulations. While chemical explanations remain functional at their own level, their success can now be understood as grounded in a compositional account (for

approaches to quantum chemistry along these lines, see, notably, Wyatt 2005; Benseny et al. 2014; Oriols and Mompart 2019; Fortin and Lombardi 2025).

9 Advantages of Compositional Functionalism

Compositional functionalism offers a unified account that preserves the explanatory strengths of both reductionist and functionalist approaches while avoiding their respective limitations. It does not merely describe higher-level patterns, but explains why they arise and why they are successful. The main advantages of this framework can be articulated as follows.

9.1 Explanatory Power and Ontological Grounding

A first advantage concerns its explanatory depth. Compositional functionalism is more explanatory than classical reductionism, as it accounts for why effective ontologies are stable, autonomous, and robust, rather than simply assuming these features. These properties arise from the compositional organization of the underlying ontology. In this sense, higher-level descriptions are autonomous in practice, yet grounded in a deeper level of explanation.

Functional accounts can describe these features as well, but they do not explain why they arise or why they are successful. Compositional functionalism, by contrast, provides a grounding for these patterns, thereby explaining their persistence and reliability.

9.2 Composition, Vagueness, and Scale

A second advantage concerns the relation between composition and vagueness across scales. At microscopic levels, compositional structure is precise and explanatorily indispensable: small changes in the number or arrangement of constituents can produce qualitatively different entities. At macroscopic levels, by contrast, systems involve enormous numbers of constituents, and their behavior depends on collective organization rather than exact composition.

As a result, functional descriptions become both appropriate and sufficient. Compositional functionalism explains this transition by showing why compositional precision is essential at lower levels and why it becomes dispensable at higher ones. Purely functional accounts can describe this shift, but they do not explain its origin.

9.3 The Status of Non-Fundamental Laws

Another advantage concerns the status of non-fundamental laws. At the fundamental level, laws are typically exact and exceptionless, whereas at higher levels they are approximate and may admit exceptions. Thermodynamic laws, for example, once taken to be strict, are now understood as probabilistic, allowing for rare deviations.

As discussed in Sects. 6 and 7, compositional functionalism explains this difference by grounding higher-level regularities in underlying dynamics. In doing so, it accounts both for their stability and for their limits. Functionalist approaches, by contrast, tend to leave the probabilistic character of such laws unexplained.

9.4 The Quantum Case and Chemical Reduction

A further advantage emerges in the quantum domain, particularly in connection with quantum chemistry. As discussed in Sect. 8.3, it has often been argued that chemical laws are not derivable from quantum mechanics, since chemical concepts rely on approximations and effective descriptions.

Compositional functionalism provides a different diagnosis: the difficulty lies not in the absence of a compositional connection, but in the lack of a clear ontology in standard formulations of quantum theory. By supplying such an ontology, the pilot-wave theory restores the possibility of a constructive derivation of chemical structure and behavior. In this way, it shows that the apparent gap between levels is methodological rather than ontological.

Taken together, these points illustrate the central advantage of compositional functionalism. While functional explanations can be given at every level, they do not explain why they work. Compositional functionalism fills this gap by showing how stable, autonomous, and robust higher-level patterns arise from the dynamics of more fundamental constituents. In doing so, it preserves the autonomy of the special sciences while grounding their success in a unified explanatory framework.

10 Objections to Compositional Functionalism

Compositional functionalism aims to reconcile compositional grounding with the explanatory autonomy of the special sciences. While it preserves key insights from both reductionist and functionalist traditions, it faces a number of important objections. In this section, I consider the most significant challenges and outline how the proposed framework can respond to them.

10.1 Functional Definitions and Macroscopic Ontology

A first set of challenges comes from Albert (2015, 2023), who argues that primitive ontology approaches cannot adequately account for functionally defined macroscopic objects. In particular, he criticizes views that attempt to recover macroscopic entities by "coarse-graining" or "squinting" at the microscopic level, noting that many macroscopic concepts, such as heat, are defined in terms of functional roles rather than composition.

This objection can be resisted. Compositional functionalism does not deny functional definitions; rather, it locates them at the level of effective ontologies. Macroscopic entities are not fundamental, but emerge as functionally defined structures grounded in a compositional base. Functional description and compositional ontology therefore play distinct but compatible explanatory roles: the former captures behavior at a given level, while the latter explains why such behavior is possible.

10.2 Causation, Laws, and the Role of the Wavefunction

Albert also raises a second concern, namely that matter in primitive ontology approaches appears inert, being merely "pushed around" by the wavefunction without exerting causal influence. This worry presupposes a causal conception of explanation that is not adopted here.

On the present view, explanation is primarily nomological: the wavefunction is best understood as part of the law governing particle motion (Goldstein and Zanghì 2013; Allori 2021), and there is no expectation that matter should act back on the law. The apparent asymmetry is therefore not a defect, but a feature of the explanatory framework.

At the same time, it is worth noting that the primitive ontology approach can also be developed in alternative, non-nomological terms, most notably in terms of causal powers. Within this broader landscape, Simpson's hylomorphic primitive ontology is especially relevant (Simpson 2026). On Simpson's account, macroscopic objects are not recovered merely by coarse-graining the primitive ontology; rather, they are hylomorphic composites of primitive matter and form. That is, they are composites of matter and form, where "form" is an objective organizational structure that makes a collection of matter count as a unified object of a certain kind. In other words, "form" plays an objective role in individuating macroscopic objects and grounding their causal powers. This proposal is compatible with compositional functionalism, but it should be distinguished from it. Compositional functionalism is not itself a hylomorphic ontology. It is primarily an account of explanation: functional descriptions identify the roles played by macroscopic objects within a level, while compositional and dynamical explanations account for why such roles are stably realized. Simpson's view may be understood as one possible metaphysical implementation of this explanatory structure, insofar as it makes the organization at the macroscopic level an objective feature of the primitive ontology. However, compositional functionalism does not require that this organization be encoded as a distinct formal ontology. Rather, it requires only that functional macroscopic patterns be grounded in, and dynamically explained by, the underlying ontology. Thus, the two views are consistent but not equivalent: Simpson offers a hylomorphic solution to the individuation of macroscopic objects, while compositional functionalism offers a more general account of how functional explanations at the macroscopic level can be compositionally grounded.

10.3 Plurality of Explanatory Relations

A further objection concerns the plurality of explanatory relations emphasized by McKenzie (2022), who distinguishes between compositional, nomological, and explanatory forms of priority. Related ideas appear both in philosophy of physics, where A. Wilson (2020) emphasizes the reality of higher-level structures, and in metaphysics, where J. Wilson (2013, 2014) argues for a plurality of irreducible grounding relations.

Compositional functionalism is broadly sympathetic to the idea that there are multiple explanatory relations and that higher-level descriptions are legitimate and autonomous within their domains. However, it rejects the conclusion that this plurality requires ontological fragmentation. Instead, these relations are interpreted as grounded in a single underlying ontology governed by a nomic structure. The plurality is therefore explanatory rather than ontological: it reflects different ways of describing and organizing the same underlying physical structure, rather than indicating a multiplicity of independent domains.

A further point of comparison is provided by Super-Humeanism (Esfeld and Deckert 2018), which takes a minimalist stance and holds that only the primitive ontology, typically particles and their spatial relations, is fundamental, while laws, dispositions, and other higher-level structures supervene on this base. While this view shares with compositional functionalism the aim of ontological parsimony and the rejection of fundamental properties, it differs in its treatment of the nomic structure.

Compositional functionalism does not reduce laws to descriptive summaries of the underlying distribution, but treats the nomic structure as an essential component of the explanatory framework. In this sense, it occupies an

intermediate position: like Super-Humeanism, it avoids inflating the ontology with additional categories, but unlike it, it preserves the explanatory role of laws as part of the fundamental structure rather than as mere bookkeeping devices.

10.4 Mechanistic Explanation and Level Autonomy

A related challenge comes from the so-called New Mechanism (Bechtel and Richardson 1993; Machamer et al. 2000). On this view, explanation proceeds by identifying the mechanisms that produce a phenomenon, focusing on the organized spatiotemporal interactions of concrete components rather than on universal laws. Instead of a strictly hierarchical reduction, the special sciences are understood as describing partially autonomous but interconnected levels, forming a mosaic of mechanisms.

While the framework proposed here does not deny that systems are ultimately composed of more fundamental entities, "Lego bricks all the way down," it treats this compositional fact as explanatorily secondary: what matters, at each level, is the mechanism responsible for the phenomenon. From the perspective of compositional functionalism, this insight is partly correct but incomplete. Mechanistic explanations capture how phenomena are produced at a given level, but they do not explain why those mechanisms exist, nor why they exhibit the stability and robustness characteristic of special science explanations. Compositional explanation complements mechanistic accounts by grounding them in the underlying ontology and dynamics, thereby explaining not only how systems behave, but why the relevant mechanisms arise and persist.

10.5 Challenges from Contemporary Physics

Further challenges arise from contemporary physics. In quantum field theory, particles are often understood as emergent excitations, effective field theories describe scale-dependent regimes, and dualities suggest that multiple, apparently incompatible descriptions may correspond to the same underlying reality. In quantum gravity, spacetime itself is frequently taken to be emergent. These developments are sometimes interpreted as undermining the idea of a single fundamental ontology.

From the present perspective, however, they reflect limitations of our current theoretical descriptions rather than the absence of an underlying structure. The multiplicity of models and representations is compatible with a single compositional ontology, even if that ontology is not directly accessible in present theories.

10.6 Top-Down Constraints and Emergence

Finally, examples from condensed matter physics are often taken to support forms of top-down explanation. Phenomena such as universality and phase transitions suggest that macroscopic behavior is largely insensitive to micro-level details, and that large-scale organization constrains local dynamics (Anderson 1972).

However, these cases do not undermine compositional explanation. Rather, they show that the behavior of components depends on the global configuration of the system. The apparent "top-down" effects are better understood as constraints imposed by the whole, rather than as independent causal powers. In this way, compositional functionalism can accommodate both the robustness of higher-level phenomena and their grounding in underlying dynamics.

Taken together, these objections do not refute compositional functionalism, but clarify its proper interpretation. The view should be understood as a sophisticated, non-deductive form of reduction: it does not claim that higher-level phenomena can be straightforwardly derived from micro-laws, but that their stability, autonomy, and explanatory success can be accounted for in terms of the compositional organization of an underlying ontology governed by a nomic structure. In this sense, it preserves the core insight of reductionism while accommodating the complexity and plurality of scientific explanation.

11 Conclusion

In this paper, I have developed and defended compositional functionalism, an account of explanation within the primitive ontology framework that reconciles compositional grounding with the explanatory autonomy of the special sciences. The central claim is that functional and compositional explanations are not competing strategies, but complementary ones: functional explanations account for phenomena within a given level, while compositional and dynamical explanations account for why those explanations are successful.

This perspective preserves the classical constructive ideal of explanation while accommodating the insights of contemporary functionalist approaches. Special sciences can be understood as principle theories that organize phenomena through stable, domain-specific constraints, while a fundamental theory provides a constructive account of the underlying ontology and its dynamics. The resulting picture is one in which explanatory autonomy is real but not primitive: it is grounded in the compositional organization of the underlying physical world.

The same framework extends to the quantum domain. While standard formulations of quantum mechanics appear to undermine the classical reductive schema, the pilot-wave theory provides a constructive alternative that preserves a clear ontology of matter in spacetime. In this way, it allows us to retain the "Lego-brick" picture of reality, even in the presence of nonlocality, contextuality, and non-separability. These features do not refute compositional explanation, but instead illustrate how it must be refined in a non-classical setting.

A key advantage of compositional functionalism is that it explains what purely functional accounts leave unexplained. In particular, it accounts for why effective ontologies emerge at specific scales, why higher-level laws are stable yet only approximately exceptionless, and why compositional precision matters at lower levels but becomes dispensable at higher ones. It thus provides not only a description of higher-level phenomena, but an explanation of their origin, scope, and limits.

More generally, the view developed here reconciles three ideas often thought to be in tension: reduction, emergence, and explanatory autonomy. Reduction is preserved in a non-deductive form, emergence is understood as the result of scale-dependent organization, and autonomy is explained rather than taken as primitive. The resulting picture is one in which the world remains "Lego bricks all the way down," but the patterns formed at each level acquire their own stability and explanatory significance in functional terms.

If this is correct, then the autonomy of the special sciences is not a limit of reduction, but its most visible success.

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Declarations

Competing Interests The author declares that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

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