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Models and representation in functional realism

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Abstract. Selective realists confine ontological commitment to the scientifically established content of theories, but critics complain that the selection criteria used let in regrettable choices. Part of the trouble is that the selection requirements leave the ontology approved for commitment unclear. This paper provides clarifications that shift the realist stance toward functional and effective theoretical content in successful theories—i.e., content focused on what the entities and processes posited do rather than what they ultimately are. Historical anticipations of the proposed turn are traced, and their contemporary relevance is considered, followed by a discussion of some reservations about approaching scientific realism in functionalist terms.

1 Background

This is how Ernan McMullin saw the link between scientific practice and realism at the start of the current debate between realists antirealists:

> The near-invincible belief of scientists is that we come to discover more and more of the entities of which the world is composed through the constructs around which scientific theory is built. (McMullin, 1984).

He was reacting to antirealist complaints that had gained purchase in philosophy over the previous decades. Critics claimed that science yields exceedingly little (if any) legitimate substantive retention of theoretical description and no referential stability beyond the observable level in theory change. In their view, it is generally false that well-confirmed scientific theories are approximately true—the entities they postulate often turn out to be non-existent, and we lack good reason to believe their central tenets.

By contrast, to scientific realists like McMullin, theories making successful novel predictions do so because what they say about the world is *approximately* true. However, one problem with this thesis is that history suggests that, in the long run, theories generally turn out to be "false" as total constructs—a claim raised influentially by Larry Laudan's skeptical reading of the history of science (1981). According to Laudan, so many past successful scientific theories have turned out to be false that there is no reason to believe that currently successful theories are approximately true, let alone that there is a realist link between success and truth. History, his followers urge, is littered with evidence unfavorable to realism. For

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example, at the peak of its heyday, the ether theory of light was declared to be established beyond a reasonable doubt—such was its perceived success and good sense, as numerous physics reports at the dawn of the 20th century show. Here are two distinguished appraisals:

> [Regarding the ether] its discovery may well be looked upon as the most important feat of our century (Williams 1901/ 2007, p. 230).
>
> [It is] a fact deduced by reasoning from experiment and observation .... There is abundant proof that it is not merely a convenient scientific fiction, but is as much an actuality as ordinary gross, tangible, and ponderable substances. It is, so to speak, matter of a higher order, and occupies a rank in the hierarchy of created things which places it above the materials we can see and touch" (Fleming 1902, p. 192; quoted in Swenson 1972, p. 138).

Only a few years later, however, Einstein regarded the ether of light as an optional posit. As the 20th century advanced, physicists widely agreed that no ether of light had to be postulated. This case suggests a radical failure of reference, reaching into the central terms and fabric of the deposed theory. To critics, the overoptimistic realist interpretation of the pre-Einsteinian optical theory of light proved not just wrong but wrong at the level of its central ontology. Furthermore, the episode is typical of successful science, as attested not only by theories from comparatively underdeveloped sciences like those of phlogiston and caloric but also from discernibly mature disciplines like electromagnetism. One more recent example is the alternative theory presented by Feynman and Wheeler, according to which Maxwell's equations do not describe an undulating, self-subsisting electromagnetic field but describe just how the movements of charges are deterministically coordinated over spacetime. The complaint is that realists assert that there are transversal microscopic undulations where simply nothing might exist. (More about this in Section 5C).

Seminal Selective-realist responses from the late 1980s and 1990s include John Worrall (1989), Philip Kitcher (1993), Jarrett Leplin (1997), and Stathis Psillos (1999). Selectivists see in the history of science a past littered with epistemic failures (as Laudan claims) but also enduring successes, especially from theories that emphasize the epistemological importance of initially implausible novel predictions (a trend that grew strong in the physical sciences in the early 19th century), exemplified by the part of Fresnel's wave that remains accepted to this day. The whole theory got many parts of its intended domain wrong. Notably, Fresnel's original account of reflection and diffraction was embedded in a conceptual framework that metaphysically required the existence of the ether of light. That explanatory part of the theory is now widely recognized as wrong. Yet, selectivists stress that a substantial part of Fresnel's theoretical claims remains hard to question—for instance, that "light is made of microscopic transversal physical waves that (to a very high approximation) obey Fresnel's laws for reflection, refraction, and polarization," without any claims about light's material substratum. Let us call this part "Fresnel's Core" ([FC] for short). It constitutes a nucleus of theoretical descriptions that light phenomena satisfy at a level that, in the non-purged theory, is "non-fundamental." (A "fundamental" physical theory is one expected to provide accurate descriptions without restrictions (i.e., in all regimes). It is an open question whether there "must" be a fundamental theory of physics in that sense).

From the selectivist perspective, discarded theories that, like Fresnel's, yield successful predictions contain substantive parts that correctly describe (at the very least) local law-like structures, processes, and entities. On the other hand, identifying those parts has proven difficult, resulting in enduring controversy (for an outline of the disputes, see, e.g., Cordero 2024)

As said, selective realists focus on theory parts that enjoy high empirical corroboration rather than complete theories. From their perspective, theory parts with posits systematically deployed in corroborated novel predictions are, with high probability, descriptively true or contain a proper part that is. Unlike traditional realists, selectivists admit the following claims:

(i) Radical conceptual change is a recurring scientific phenomenon, and

(ii) Empirical theories have poor reliability records at the most profound ontological level.

At the same time, selectivists point out the existence of significant descriptive continuities at *intermediate* theoretical levels between successful theories and their successors, as illustrated by [FC]. If so, a false theory can (and often does) contain parts that succeed as correct descriptions. Selectivists seek to identify those parts, and their approaches confine ontological commitment exclusively to highly confirmed theoretical descriptions. Unfortunately, the selection criteria they use allow for regrettable choices (see, e.g., Saatsi and Vickers 2011). One source of trouble is that selectivists leave the ontology described by the parts picked for commitment unclear. Historical cases and scientific practice gesture toward a functional resolution of this difficulty, but the clues are unclear and need elaboration.

From the selectivist perspective, theories that make corroborated predictions contain correct parts worthy of realist commitment. As noted, Fresnel's Theory Core [FC] is one such component in Fresnel's and Maxwell's theories. [FC] describes a domain of interest at an abstract level that filters out the portion that deals with the material substrate of light (the ether). This abstract core explains how undulations of microscopic wavelengths give rise to light's reflection, refraction, and polarization—phenomena that [FC] inferentially predicts in detail, even though the explanation leaves out the deeper ontological underpinnings.

The debate continues. Criticism has led to changes to the selectivist approach, and some have improved it, but it still faces some problems. In particular, it most acutely needs a non-ad hoc criterion for selecting the correct parts in theories. And selectivists must clarify their ontological commitment to the theory parts thus selected. Advances are on view in both these regards, but controversies remain. Here, I will assume that the noted problems have solutions and explore the character and promise of the project.

(1A) Theory cores

Fresnel's Core is not an isolated case. Comparably substantive theory parts are widespread in contemporary science. One conspicuous example from physics is the Standard Model of Elementary Particles, an abstract framework that harmonizes quantum field theory (QFT) and Special Relativity. Frank Wilczek (2015) calls it the "Core Theory" and presents it as an "intermediary" account that delivers already an accurate representation of physical reality, which any future, hypothetical "real thing" must take into account.

Wilczek hails the Core Theory as one that works "for all practical purposes." Most mainstream physicists agree. Importantly, Wilczek's Core gestures towards *functional explications* of the entities and descriptions involved, as do [FC] and numerous theory hubs of intermediate theoretical content in science. But his proposal contains a whiff of instrumentalism that needs philosophical attention to improve its appeal to realists. I will suggest (Section 3) that, once purged of optional instrumentalist concessions, Wilczek's and numerous other cores in science invite realist interpretation. However, the clues need clarification, elaboration, and precise labeling. But first, a word about giving selective realism a functional turn.

(1B) Focus on what things do

"Functional Realism" is a perspective multiply revived in recent literature; see, e.g., Cordero (2011, 2016, 2017, 2019)), Egg (2017, 2021), and Alai (2017, 2021). Nods toward the perspective are also discernible among some "agnostic sympathizers" (e.g., Saatsi 2019). This approach reacts to the antirealist challenge of successful theories marred by false or dubious content, empirical underdetermination, or conceptual problems. It does so by trying to thin down content without eliminating it (as radical empiricists strive to do). In the functionalist approach, theoretical entities and regularities are identified by *what they do at an abstract level rather than by what they "ultimately are" or are made of.* In Cordero (2017, 2024) the prospectively correct theory parts focus on effective (as opposed to exact) regularities and descriptions and involve functional (instead of "fundamental") entities. In the noted references, the parts selected as prospectively correct:

(a) Show empirical success.

(b) Have remained free of compelling specific doubts.

(c) In addition, many have gained elucidation from sources initially external to them.

The basic functional strategy at play has a tradition in modern natural philosophy. It has precedents in, e.g., Galileo's method and Newton's take on incomplete theorizing.

2 A bit of history

Selective and functional modeling has a presence in the transition from holistic categories to mechanistic concepts in the discussion of Copernicus' theory. Among numerous other places, functional explanations show up in Galileo's letter to the Grand Duchess Christina (1615), where he points to a way of separating the wheat from the chaff in successful theories. Only some parts of the biblical story, he argues, should receive literal interpretation—the parts about the Sun moving around the Earth are not crucial to the Bible's intended outcome, which is *salvation*. Natural philosophers after Galileo expanded this strategy, most daringly in Newton's dictum "hypothesis non fingo." Indeed, functional turns appear at many levels in Galileo's and Newton's piecemeal approach to describing natural objects instead of the traditional holistic approach to theorizing (see, e.g., Dudley Shapere 1975, 1984, 1986). In analytic philosophy of science, realist interpretations focused on *what things do rather than by what they "ultimately are" (i.e., functional interpretations)* gained traction in the 1970s as part of the critique of attempts to explain theoretical progress by logical-deductive reduction of discarded theories to their successors. One critical line recognizes the coarse-grained and restricted character of laws and regularities that survive theory change, as emphasized by, e.g., Toraldo di Francia (1975/1981). A complementary reaction focuses on inter-theory relations and accumulation of coarse-grained descriptions across conceptual change in many cases, from planetary orbits in Kepler's and Newton's theories—a topic developed in, e.g., Erhard Scheibe (1983) and others. Recognition of the epistemic import of coarse-grained description has become prominent in recent decades, notably in studies of the emergence of classical behavior in Everettian quantum mechanical worlds (see, e.g., David Wallace 2012).

(2A) Realist-friendly readings of history

Interpretations akin to the suggested functionalist turn have played a role in realist-friendly readings of the history of successful science from the early responses to Kuhnian antirealism (e.g., Mary Hesse 1961, Dudley Shapere 1984, and Ernan McMullin 1984). Regarding the new method by which Galileo rethought the project of natural philosophy, these and other thinkers underline Galileo's appeal to abstraction and his mathematization of scientific description, his piecemeal theorizing, and his defense of experimentation (as opposed to mere observation). Each of those Galilean moves required great imagination to meet challenges from reasonable worries. For example, even in the ideal state of a vacuum, the phenomenon of free fall could depend on an indefinitely large number of factors—the body's composition, shape, temperature, and color(s), to mention some candidates. In a decisive modern turn, Galileo took as relevant factors only time, the uniform acceleration of gravity, and the body's position (its center of mass). To Shapere (1975) and di Francia (1976/1981), Galileo showed how, by filtering out information, one could achieve precision and objectivity. This strategy proved a crucial modern resource.

Newtonian extensions of the approach soon fulfilled Galileo's goals against the expectations of his Aristotelian and Cartesian rivals (who achieved little meanwhile). A central factor here was the role played in the new science by abstraction, mathematical precision, the focus on experimentation, and the piecemeal approach to theoretical description.

Galileo was shunning the traditional holistic project of explaining everything at once. This move involved laying out boundaries of separable areas of investigation, which produced a standard against which theories could be assessed. Whatever else might be required to explain a particular body of information (domain), an explanation could be successful only to the extent that it considers the characteristics of the items of the domain (Shapere 1975). Galileo reasoned that it is possible to develop and test theories by actively interacting with nature (as opposed to passively observing it). *De Motu* (1590) sketches illustrative descriptions of experiments with falling bodies using an inclined plane to slow down the rate of descent.

A significant point in the story is Galileo's (and other early scientists') emphasis on what natural objects do rather than what they ultimately ("fundamentally") are. These scientists investigated natural entities only as far as it was possible to measure their properties rather than with the impossible goal of discovering their ultimate essence (di Francia 1976/1981). For this shift, the approach they developed was snubbed by many as epistemically second class because the resulting findings do not bring us nearer the intimate reason of things.

So, many of their contemporaries accused Newton and Galileo of betraying the enterprise of natural philosophy. Some thinkers still disparage the functionalist twist those early scientists encouraged. Nevertheless, their new modern approach has yielded much knowledge about nature. As di Francia stresses, after Galileo, no sensible person who has taken an unbiased look at the experiments will affirm that (within limits) a freely falling body does not cover distance proportional to the square of time. The same goes for the *theoretical* (not directly observable) content of models that get at least part of their intended domains partially correct.

Admittedly, the "Galilean" approach's success is a contingent development, not something guaranteed by logical necessity or the "nature of science." Nonetheless, although limited, the achievements of the modern scientific approach are manifestly outstanding in the magnitude, degree of articulation, subtlety, systematic integration, explanatory power, and predictive power of the contemporary disciplines that embrace the approach.

(2B) The contemporary stage

A closer example of functional entities is the light waves in electromagnetic theory after Einstein, free of reference to light's material substratum (like the waves in Fresnel's Core in Section 1. These waves are characterized by what they *do* rather than what they *ultimately are*, their "deep nature" left opaque (but not their "intermediate" nature). Einstein's waves contrast with the waves Fresnel and Maxwell had endorsed, which were conceptually embedded in a metaphysis of modes of being that required the existence of a luminiferous medium (Cordero 2011, 2012).

Like its selective predecessor, functional realism seeks to free successful theories of problematic parts, but now with a functional emphasis on restricted domains (regimes). The purge involved is not directed at "metaphysical" content, only at explicitly problematic posits. Entities and processes accepted as physically real are assessed to be free of specific doubts and indispensable for the theory's empirical success within a "physical regime."

For each empirical phenomenon, natural scientists associate some measurable parameters that determine the "regime" in which the phenomenon occurs. A regime is thus a domain of measurable aspects, entities, regularities, range of application, and degree of descriptive resolution or coarse-graining, marked by the energy, mass, and size of interest. The values of these parameters determine in which physical regime the phenomenon occurs. For example, the mass, size, and velocity of an ordinary apple falling from a tree place it in a physical regime in which classical mechanics provides extremely accurate descriptions.

The theory parts selected for realist commitment are generally "functional" rather than fundamental, emergent within regimes of an empirical domain, and the descriptions associated with them are "effective" rather than exact.

The effective descriptions derived from selected parts purport to be correct only within certain margins of relevant representation.

Truth content may lay at any theoretical level, including levels intermediate between the 'phenomenological' and the 'fundamental (more details in Section 3F).

This selective approach concentrates the realist position on claims established beyond reasonable doubt. Important arrays of such claims occur at intermediate theoretical levels of abstraction, generalization, and domain restriction (of lesser ontological height than the "fundamental" level of description sought by traditional philosophy and early science).

> **Functional-Realist Thesis:** Theory parts selected using the realist criterion for identifying epistemically promising components are either true or contain a sub-part that is. These will generally gain retention *as functional/effective parts* within specifiable descriptive regimes in successor theories.

One advantage of the above thesis is its refutability. It will fail if, more than rarely, theory parts selected from an empirically successful theory fail to gain substantive retention in successor theories. Here is another plus: The proposed approach abandons the emphasis on the fundamental ontological level, which leads standard realism to overlook that theories' most apparent epistemic achievements occur at intermediate theoretical levels.

3 Some needed clarifications

The realist strategy outlined in the previous section contains implicit features and distinctions that need spelling out.

(3A) The task of purging content

As Galileo did with the law of free fall and (at a higher theoretical level) Einstein did with light waves, selective-functional realists analyze successful theories that contain problematic parts. They remove the troublesome parts and then consider the remaining contents, focusing on intermediate theoretical levels with corroborated empirical success. The purge proceeds with the help of three resources:

(i) abstraction

(ii) coarse graining, and

(iii) domain restriction.

(3B) Theoretical representation

Practicing physicists have an established way of describing the regularities found in nature, displayed, for example, by the mature version of the Galilean representation of the law of free fall. It takes the form $\langle \Lambda, O, L, \delta, \Delta \rangle$, where the symbols stand for the following aspects:

The set Λ is the set of aspects/quantities considered relevant, $\Lambda = \{\lambda_i\}$. In the present case, Λ includes time, position, instantaneous velocity, and acceleration of the falling body. The set O consists of entities populating the domain, in this case material bodies. The set L is the set of laws and regularities holding over the targeted domain. Typically, these are justified as coarse-grained regularities rather than exact laws, their general form being (to first approximation):

$$L(x_i) = f(x_i) \pm \delta(x_i).$$

By δ_i, we denote the amount of coarse graining tolerated on values for each of the λ_i quantities listed in Λ, and by Δ, we mean the restricted domain over which the representation is expected to hold.

Consider Fresnel's Core and its revision in the 20th century as a second example. Tellingly, the level of generality it was initially granted contracted in response to subsequent information about the dependence of the optical indices on various factors, most dramatically, light intensity, non-linear features, and quantum effects (e.g., creation and destruction of photons). A theory part's theoretical level typically changes when it lands in a successor theory, usually moving to a lesser relative depth than in the initial theory.

(3C) Focus on functional entities and effective descriptions

As used here, the label "functional posit" applies to entities characterized by what they *do* rather than what they *are* according to the theory's fundamental level. A "functional" entity or property is individuated by its effective causal role in the intended domain. Like Einstein's light waves, functional entities have their *"deep nature" left opaque.* Contemporary science has a mainstream approach to conjecturing effective theories and functional ontologies. QFT is a choice example, as mentioned before.

"Effective" descriptions are expected to apply only within certain precision margins. Still, effective descriptions and functional entities have more than mere instrumental interest. In scientific usage, the term "effective" often refers not only to theories that agree with data but to physical interactions and entities that emerge under the conditions of a domain. The resulting descriptions are usually partial and incomplete compared to those provided by the base (fundamental) theory. *They are intended to represent behaviors within a specific regime, outside which the functional/effective theory may not apply.* Common examples include continuous matter, "classical" systems, and [FC].

(3D) Face-value ontology

A theory's "face value ontology" (FVO) is its literal, undiluted ontology. For example, Newtonian gravitational theory's FVO includes massive objects existing in space and time (bodies), their position and momentum, and forces acting at a distance. In Maxwell's theory, FVO includes light waves with ether as the medium for transmission.

By contrast, a "functional" ontology typically has restricted universality and limited Λ (applying to a particular physical regime of the theory). The FVO of one theory (e.g., continuous matter) can have functional status in another (e.g., molecular theory).

(3E) Modal statements

Claims about what is possible, impossible, essential, necessary, and contingent have nuances in functional realism:

(A) The modal structure of a proposed functional entity will be generally more modest (thinner) than that of its counterpart in a fundamental (base) theory.

(B) Multiple realizations: At some more profound ontological level, an entity might differ from what a scientifically well-established functional theory proposes at face value.

(C) The existence of more profound descriptions does not render incorrect functional-effective descriptions within the intended regime, which are more abstract (shallower).

(D) Correct description is possible without reference to any "fundamental ontological level." The classical mechanical description of an ordinary falling apple is correct to a high degree of approximation within the standards of the ordinary regime.

Items (A) to (D) above add precision to the suggested ideas of selective-functional purge, functional entities and effective descriptions, multiple realizations, and the non-fundamentality of face-value ontology. Functional realism concentrates on theories at intermediate levels between the 'phenomenological' and the 'fundamental.'

Next on the list is the topic of levels of description, closely related to the idea of "regime".

(3F) Descriptive levels

The term "descriptive level" (DL) generalizes the idea of "regimes" in physics, as summarized in Section 1. Taking guidance from the analysis of Galileo's Law in (3B), a set of five "regime parameters" will characterize a DL in what follows, presented in a structure $\langle \Lambda, O, L, \delta, \Delta \rangle$ where the abstract level of the representation is specified by the list Λ of physical aspects considered relevant; by O, we denote for the level's face value ontology; by L, we denote the set of laws and regularities over the targeted domain. Typically, these are asserted only as coarse-grained relations, their general form given (to a first approximation) by $L(x_i) = f(x_i) \pm \delta(x_i)$. The parameters ($\delta$) specify the amount of coarse-graining tolerated and Δ gives the domain where the descriptions are expected to hold effectively.

For example, the ontology of classical thermodynamics comprises entities that have thermodynamical properties, conspicuously (1) rate properties (e.g., energy flow rate, entropy flow rate); (2) state properties (e.g., energy amount, entropy amount); and (3) constitutive properties (e.g., thermal capacity, thermal conductivity).

Some clarification comments are helpful here:

1. Crucially, in functional realism, the features listed in Λ are considered as real as any other considered "real."

2. Descriptive levels can have considerable autonomy. For instance, within a given regime, we can describe and understand something as a liquid without knowing about its molecular composition, even if a description of microscopic components is available.

3. The parameter Δ registers that empirically successful theories typically have a limited scope of accurate applicability.

4. The above focus on DLs discloses the pluralist character of the proposed selective realism.

(3G) Incompleteness and opacity

Functional entities and accurate descriptions under a regime $\langle \Lambda, O, L, \delta, \Delta \rangle$ are typically "incompletely" specified *relative to counterparts in fuller theories or more profound levels of description.* In what follows, functional-effective versions of a theory T will be represented by putting T in brackets followed by the corresponding parameters: $[T]_{\Lambda,O,L,\delta,\Delta}$ (the indexes will be generally omitted for easiness, and the functional version of T will be written $[T]$).

(3H) Ontological significance

Taking a realist stance towards a selected $[T]$ amounts to asserting that the kinds of entities and regularities explicit in it are *real.* So, the claim is that those entities and regularities are physically at play (i.e., act and react) in the intended domain, even if they stand as incompletely described non-fundamental beings relative to a base theory in the background.

As in the days of Galileo and Newton, the above suggestions offend those who think that a physical theory is not scientific if it is not fundamental and exact. Today, functional realists accept substantive theories of "intermediate" fundamentality, about which—they argue—we can adopt a realist stance. These theories include some with outstanding scope and fecundity. For example, the functional interpretation of QFT as an effective theory has proven admirably reliable in low-energy interactions.

The following section uses the above precisions to argue for shifting the realist emphasis toward functional and effective theoretical content.

4 Functional/effective content

"Standard" realism concentrates on unrestricted theories and theoretical claims. Although, in principle, unrestricted theoretical descriptions may be true, history places them among the least epistemically reliable in science due to the poor record of their ambitious content. On the other hand, functional realism focuses on epistemically more secure claims—e.g., limited claims about functional entities. Functional attention focuses on how entities and processes behave effectively within a particular descriptive regime of interest.

We thus reach the following suggestion: Taking an explicitly functional turn clarifies the notion of realist gain in selective realism and helps overcome some objections to the project. Accordingly, a deflationary approach is proposed here, in which realist commitment goes primarily to entities and processes corroborated as objectively active in the domain in question (as described by the relevant "functional" theories or parts of them).

In the functional realist approach proposed, the criterion for realist commitment focuses on theory parts free from specific doubts, backed by corroborated novel predictions, even better if they also have external support (Cordero 2019). Admittedly, the selection criterion of the theoretical parts remains controversial. Suppose, however, the sought criterion will settle around the choice just suggested.

Which theories satisfy the realist test? There is a vast and robust population of functional entities, processes, and accounts that satisfy the conditions of being free from specific doubts, backed by corroborated novel predictions, and having some external support. It comprises *a highly textured tapestry of clustered behaviors beyond the reach of unaided perception.* The resulting picture is not a haphazard quilt of dubious significance but a corpus of abstract, finite-range, coarse-grained assertions that, nevertheless, display astonishing (and growing) levels of integration into a detailed and textured picture of the world.

As a further bonus, the noted functional-effective theories are immune to arguments from unconceived alternatives in the following sense. Suppose a functional core $[T]$ merits selective realist commitment. In that case, the existence of alternative theories will not compromise its realist status if those alternatives contain $[T]$, as they must on pain of empirical inadequacy. An illustration of the latter feature is provided by the plurality of ontic theories of quantum mechanics—ontic in that they interpret the quantum state as a physically real thing (Cordero, 2001, 2024). The case involves three leading offers, which provide different ontologies with different laws of nature. Bohmian Mechanics postulates an ontology of particle(s) whose motion follows a new equation hooked up to a wave equation—a guidance law. Everettian "many worlds" theories present decohered superposition as indicators of effective ontological multiplicity in physical reality. Collapse theorists modify the linear dynamical evolution of the wavefunction, changing the state equation to produce a unified story of the macro and micro realms. These ontic approaches portray radically different worlds from top to bottom but make no diverging predictions accessible by present technology. They are effectively empirically equivalent, agreeing on little more than what is observable. It is thus hard to find a theoretical core shared by the above proposals such that we can regard them all as different interpretations of that core. Hard—but not impossible. Cordero (2001, 2024) points to two complementary statements selective realists can make in the case at hand:

(a) Disagreement between the three noted camps is confined to certain parts of the theories—parts that, being empirically underdetermined, realists cannot take as veridical.

(b) On the other hand, realists can point to substantive theoretical content shared by the competing proposals. If this is correct, the key claim is that we can trust theory parts that are empirically successful, free of specific doubts, and shared by all three theories (i.e., not marred by underdetermination).

Which parts are thus shared by the three competing theories? In all three, the quantum state expresses the system's ability to exert causal influence (cause something) at spatial locations where it is non-zero. A system's ability to produce effects—its efficacy in doing something over a spatiotemporal region—is structured by its quantum state.

Nevertheless, some thinkers claim that the quantum state is just a tool for making predictions, not something representing a physical entity. In response, realists like Harvey Brown (2019) explain how the quantum state contains enough information about physical systems to satisfy realist selection criteria like the one outlined earlier. Quantum state-based information about physical systems that meets the selection criterion includes, for example, details of their energy structure, energy exchange channels between its parts and other systems, quantum amplitudes and probabilities, interference between material systems, entanglement, and quantum nonlocality, quantum limits to the principle of energy conservation, intrinsic quantum spin and spin-based interactions; the stability of matter, its scope and limits; the effective dynamics of quantum-probabilities (at all levels). In more concrete situations, the quantum state consistently accounts for numerous properties of material systems. Examples include the color of things, the detailed geometric structure and effective properties of molecules, the probabilistic structure of superconductivity, electrons in molecular bonds (wavefunction shapes and their effects, e.g., in graphene and diamond); it even grounds the notion of "world."

A crucial question is whether the suggested functional/effective turn helps the selectivist project, and if so, how much. The last section explores some plausible suspicions invited by the proposed approach.

5 Some concerns

(5A)

Some traditional realists deny that functional entities and structures are either "real"—or "as real"—as "full theoretical" ones.

Turning this concern into an objection requires argumentation that is seemingly impossible to provide without begging the question. We have at play at least two different notions of what makes something physically real:

Notion (a): The "physically real" is just the most fundamental material basis of the physical world.

Notion (b): The physically "real" are the entities and dynamical patterns that effectively emerge at various physical regimes and function accordingly. On this second notion (favored by the functional-realist stance), to "exist" physically is to have causal efficacy in agreement with the physical laws within the regime at hand.

Traditional realists may also insist that, from a theory's perspective, the only existing objects are the ones the theory includes in its central principles. I.e., all others should either be reduced to the central objects or recognized as convenient constructs. However, while objects placed at the most central theoretical level are of great interest, the functional-realist concern is what shows activity (exists) in the intended part of the world. Antirealist skeptical inductions are correct about the epistemic weakness of the highest theoretical levels but err about the epistemic stability of intermediate theoretical contents. The reductionist objection (5A) lacks warrant.

(5B)

Many critics reject the realist optimism of the previous sections. One source of suspicion is skeptical inductions of the following sort: Like today's scientists, past ones, too, thought highly of their epistemic success, inferring wrongly that their leading theories were highly correct. (e.g., Brad Wray 2013). In Wray's view, the case for today's theories is no better.

Several relevant differences between past and present theories come to mind, particularly regarding: (a) scientific methodology; (b) The character of theories in basic science today; (c) the realist stances available now; (d) while full theories are epistemically unstable, theory cores ($[T]$) are generally robust.

(a) Scientific methodology has become more demanding in the last two centuries. Past scientists did not emphasize successful *novel prediction* as we do now. Today's scientists are more open to revising their theories at the deepest conceptual levels.

(b) The *character* of theorizing has changed, too. There is now a better appreciation of the robustness of explanations at intermediate levels (between phenomenological and fundamental description).

(c, d) Also, the notion of *realism* has changed. Two developments are worth stressing. First, there is a greater metaphysical modesty. Scientific theories were embedded in conceptual networks that entangled theory parts in ways that blocked attempts to break many of them into separate components. An example of conceptual entanglement is that of 'being a wave' (W) and 'having a material substratum' (S) in classical electromagnetism (Cordero 2011). To 'emancipate' concept (W) one had to cut the metaphysically tied (entangled) cluster [W-S] by turning it into a conjunctive (separable) one [W·S], as it is now. Secondly, being approximately correct does not require being error-free. Unlike traditional realists, selectivists are not troubled by the suggestion that scientific proposals are generally false as *complete, unrestricted theories.* Nobody claims that successful theories (past or present) are true as whole proposals in the current dispute. The issue is whether successful theories *have identifiable functional/effective cores with substantive positive truth content* that will generally gain retention in successor theories.

(5C)

Worries about ending up committed to physically non-existent posits: According to some critics[1], if selective realists followed the characterization of Fresnel's Core proposed in Section 1, they would over-commit ontologically. Specifically, they would *end up accepting that there is something where nothing exists.* This worry is fuelled, for example, by the Feynman-Wheeler alternative view of electromagnetism (FW). According to FW, Maxwell's equations do not describe an undulating self-subsisting electromagnetic field but how the movements of charges are deterministically coordinated over spacetime. The objection is thus that selectivists conclude that there are transversal microscopic undulations where simply nothing exists (in a way

[1] I thank Juha Saatsi for pressing this objection on me.

analogous to someone who commits to there being something in the center of a donut).

I suggest it is false that, on FW, *nothing* exists where the transversal undulations associated with light play out. As noted, something "exists physically" if it has causal efficacy in agreement with the physics principles for the regime at hand. One example is the local interaction between electromagnetic waves and charges. The waves do not exist because they figure at the fundamental level of a successful theory (say, post-electromagnetism after Einstein). They are granted existence because of their multiply attested independent interactions with numerous physical systems. The functional reality of microscopic undulations does not amount to their being classical undulations in a fundamental sense—just like the reality of a macroscopic table does not amount to its being continuous at all descriptive levels; they are continuous only at macroscopic levels.

(5D)

A FAPP Approach? In several of his last papers and presentations, John Bell admonished against solving interpretative problems in ways that work merely "for all practical purposes" (FAPP). He was reacting against the way theorists responded to the measurement problem in quantum mechanics by claiming that, as the reduced density matrix arising from decoherence cannot be locally distinguished from that of an ensemble, that solves the issue for all practical purposes. In Bell's view, the natural philosopher's duty is to understand the quantum world, not to ignore aspects of it or to take only a schematic (FAPP) account of (say) the interaction across the split between pre- and post-measurement situations in quantum mechanics (see, e.g., Bell 1990). Some critics might worry that the functionalist realist turn proposed in this paper works merely "for all practical purposes"[2].

The functional-realist turn advocated in this paper admits that content not selected for realist commitment may correctly represent reality. Commitment goes to a thinned-down (but still theoretical) version of the best current theories. The parts selected for realist interpretation may come from any theory level if they show predictive power and are free from specific doubts (especially if, in addition, they enjoy independent attestation). The proposed turn acknowledges the possible existence of entities and interactions underpinning the relatively abstract functional accounts selected, and in this way, it agrees with Bell's demand. The approach welcomes pursuing explanatory accounts beyond the restricted domains/regimes under consideration. Whether the ensuing explorations result in new theory parts worthy of realist interpretation depends on how things play out in each case. It discourages

[2] I thank Dennis Dieks for raising this point and making many other valuable suggestions.

"bad" FAPP. Its goal is to identify models that correctly describe the *local ontology and nomology at work under each regime without prejudice against further ontological inquiry.*

For example, in the functional terms of ordinary discourse, a billiard ball is a system of continuous matter within the appropriate energy regime and spatial coarse-graining of (e.g.) 10^{-5} m). Outside this regime, the system diverges radically from the ordinary description. Here is another example that is closer to Bell's worries. As noted in Section 4, in the 1980s, several approaches to the measurement problem in quantum mechanics identified the onset of decoherence in linear evolution with the "collapse of the wave function." Some leading theorists declared the ontological issue "solved." But, as Bell objected, after decoherence, in the standard theory, the initial quantum superpositions remain "alive" indefinitely along multiple wavefronts. Their relative phases become blurred, rendering the fronts "effectively independent," but the superposed components continue. So, we have a FAPP resolution of the measurement problem that gives up the realist interpretation of the quantum state. That is antirealist FAPP. By contrast, the functional turn suggested in this paper follows scientific-realist lines all the way through. From its perspective, the emergence of classical entities does not make quantum entities disappear. Nor does the deeper fundamentality of quantum mechanics deny classical entities' existence. Classical entities exist as natural systems that objectively arise in a quantum mechanical world *within* the confines of specific regimes. Classical entities are not presumed to be *fundamentally classical*—they are *functionally* classical. "Ultimately," they may be quantum many-worlds systems, Bohmian systems, spontaneous collapse systems, or something else[3]—we cannot tell yet.

6 Concluding remarks

This paper's functional/effective version of selective realism shifts realist commitment. In particular, it drops the traditional emphasis on fundamental theoretical entities and focuses instead on causal efficacy at specific descriptive levels. The realism proposed is deflationist and pluralist. The proposed reformulation helps the project of selective realism in two ways. First, it clarifies the structure and character of a realist stance toward just part of a theory. Secondly, it highlights relevant differences with the standard realist stance, particularly regarding the accumulation of scientific knowledge across theory change.

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[3]Approaching quantum physics in functional terms has gained welcome elucidation in recent years thanks to the second generation of theorists of Everett's many worlds, notably David Wallace's work on the coherence of the idea of an emerging multiverse entirely within the framework of quantum mechanics (2014), a topic of philosophical interest independently of the credibility of the many worlds proposal.

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