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ON THE STRUCTURE AND ACCUMULATION OF REALIST CONTENT

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Ever since the heyday of the Vienna Circle, scientific realists have worked hard to document and clarify the structure and growth of truth content in theoretical descriptions. Today, this trait is particularly intense among "selective realists" – realists focused on theory parts with high empirical corroboration rather than whole theories. From their perspective, theories 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 acknowledge that (a) radical conceptual change is a recurring scientific phenomenon and (b) empirical theories have poor reliability records at the most profound ontological level. At the same time, they point to significant descriptive continuities at intermediate theoretical levels between successful theories and their successors – i.e., a false theory can (and often does) contain parts that succeed as correct descriptions. Selectivists seek to identify those parts. Their approaches limit ontological commitment exclusively to highly confirmed theoretical descriptions; unfortunately, the selection criteria they use seemingly support many regrettable choices. One source of trouble is that extant approaches leave unclear the ontology described by the selected parts. Historical cases and scientific practice gesture toward a functional resolution of this difficulty, but the clues could be more transparent and need elaboration. Otherwise, selectivism has improved in consistency over the last three decades. Current projects emphasize the continuity of well-established scientific content (relating to how entities and processes effectively behave within a specific regime or descriptive level) instead of just the continuity of "structure". This paper provides some clarifications that arguably clear the road for realist commitment toward functional and effective theoretical content. The proposed functional/effective turn is checked against some plausible objections.

Keywords: truth content, scientific realism, functional realism

О СТРУКТУРЕ И НАКОПЛЕНИИ РЕАЛИСТСКОГО СОДЕРЖАНИЯ

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Со времен расцвета Венского кружка научные реалисты усердно работали над документированием и разъяснением структуры и роста содержания истины в теоретических описаниях. Сегодня эта черта особенно выражена среди «избирательных реалистов» – реалистов, сосредоточенных на частях теории с высоким эмпирическим подтверждением, а не на целых теориях. С их точки зрения, теории с постулатами, систематически используемыми в подтвержденных новых предсказаниях, с высокой вероятностью являются описательно истинными или содержат соответствующую часть. В отличие от традиционных реалистов, селективисты признают, что (а) радикальные концептуальные изменения являются повторяющимся научным явлением и (б) эмпирические теории имеют низкую надежность на самом глубоком онтологическом уровне. В то же время они указывают на значительную описательную преемственность на промежуточных теоретических уровнях между успешными теориями и их преемниками, т.е. ложная теория может содержать (и часто содержит) части, которые успешны в качестве правильных описаний. Селективисты стремятся идентифицировать эти части. Их подходы ограничивают онтологическую приверженность исключительно хорошо подтвержденными теоретическими описаниями. К сожалению, критерии отбора, которые они используют, по-видимому, приводят ко многим решениям, достойным сожаления. Одним из источников проблем является то, что существующие подходы оставляют неясной онтологию, описываемую выбранными частями. Исторические случаи и научная практика указывают на функциональное решение этой проблемы, но подсказки могли бы быть более прозрачными и нуждаются в доработке. В остальном за последние три десятилетия селективизм стал более последовательным. Текущие проекты подчеркивают преемственность устоявшегося научного содержания (касающегося того, как сущности и процессы ведут себя в рамках определенного режима или описательного уровня), а не просто непрерывность «структуры». В этой статье представлены некоторые разъяснения, которые, возможно, расчищают путь к реалистическому стремлению к функциональному и эффективному теоретическому содержанию. Предлагаемый функционально-эффективный поворот проверяется на предмет обоснованных возражений.

Ключевые слова: истинное знание, научный реализм, функциональный реализм

1. Introduction

Functional entities are characterized by what they *do* rather than what they *are*. One example is a carburetor, a gadget that takes gas and air as inputs and produces a mixture of the two as output – anything that does that *is* a carburetor, regardless of what it is made of, its origin, or how it develops. Functional entities have their "ultimate" character left opaque, but – realists argue – scientific justification can reach into their "intermediate" nature (contra radical empiricists). These entities contrast with standard realist posits. For instance, the standard realist version of the light waves postulated by Fresnel and Maxwell is ontologically richer than Einstein's realist interpretation. The former, but not the latter, is conceptually embedded in a classical metaphysis that required the existence of a medium for light (the ether luminiferous), which led to protracted conceptual conundrums [Earman, 1998; Cordero, 2011a; Cordero, 2011b].

Functional realists try to improve the epistemic case of theories, which, like that of the ether, are marred by underdetermination and conceptual problems. To that end, they try to thin down theoretical content without eliminating it. Entities and processes found indispensable for the empirical success of a theory gain recognition as approximately accurate and suitable for realist commitment, in the expectation that subsequent research will sharpen their truth content. The theory parts thus selected are "functional" rather than fundamental, emergent within the contingencies of an empirical domain, and the descriptions associated with them are generally "effective" rather than exact. Effective descriptions purport to be correct only within certain margins of relevant representation. For example, in the transition of gravitational theories from Kepler to Einstein, the Keplerian claims we still recognize as accurate are thin in content compared to the versions held by Kepler and later by Newton. The versions presently held come from successive revisions that took long to develop, with much (but not all) of the original content gone. To illustrate, Newton replaced Kepler's directive force with the attractive gravitational force; Einstein eliminated the force and put spacetime curvature as a source of gravity instead. The point is that Kepler's Theory, Newtonian Gravitation, and General Relativity share a core of correct functional assertions – abstract, coarse-grained, and restricted. Crucially, this leaner core is sufficient to derive Kepler's novel predictions. Realists further stress that, as a matter of historical fact, there has been an accumulation of retained content in many scientific disciplines from the 17^{th} century to the present. While giving up part of the content of earlier theories, each successor has both kept past content and contributed new one, some of which remains to this day. However, identifying such contents turns out to be complicated. Influential efforts to address the difficulties found include Anjan Chakravartty's [1998] "Semirealism" (directed at content retained across theory change[1]) and Statis Psillos' emphasis on posits indispensable to the success of theories [1999]. Still, a need for further refinement became apparent in the following decade. Responses followed, as outlined in the next section, but problems remain.

Taking a functional turn improves the project of scientific realism, or so I argue in what follows. My concentration will be on recent efforts to strengthen content-focused approaches, taking hints from history and scientific practice. The truth attributions I propose apply primarily to systems in situations ("regimes") that give rise to a discernible functional ontology O, represented through a set of selected features (Λ), with allowance for coarse-graining (δ), laws and regularities (L) holding over the targeted domain, and domain restriction (Δ), giving the regimes a representation of the form $<O, \Lambda, \delta, \Delta>$; more about this in Section 4.

1 Subsequently developed with a concentration on causal efficacy in [Chakravartty, 2007].

2. Selective Realism

Selectivism forms a variegated family of positions sharing two ideas: (1) empirically successful theories generally get many things wrong about their intended domains, but (2) theories are not something one should accept or reject monolithically – a false theory may still be *approximately true*. A false theory may contain theoretical descriptions (theory parts) that are as putatively true as they get in ordinary life – we just need to identify those parts in some principled way.

Critics complain about this approach, charging that the provided selection criteria project current theories retrospectively and use either flawed distinctions between "working" and "idle" posits or misguided indispensability arguments for theory parts and do so in ways that are self-serving or even incoherent (see, e.g., [Lyons, 2006; Stanford, 2006]).

Over the last decade, selective realists have responded with revisions and clarifications of the strategy. A promising proposal, developed by Juha Saatsi [2005], Peter Vickers [2013], and others, approaches the selection of theory parts in successful theories by subjecting predictions to *inferential analysis*. For a successful prediction P from a theory T, they (i) take a valid derivation and focus on the theory parts leading to P; (ii) identify in the inferential chain the minimal theory parts that seem crucial for deriving P; and (iii) present those parts as the likely epistemic recipients of the theory's success. As will be explained shortly, this "inferential" stratagem tends to select descriptive parts that are abstract relative to their fuller counterparts in the initial or "mother" theory but also descriptively more correct than the latter, hence better candidates for retention in subsequent theories. This approach improves the case of selective realism. However, in a seminal reference, Saatsi &Vickers [2011] highlight Kirchhoff's Theory of Diffraction and other cases as illustrations of significant failure of the approach, leading them to voice fears about the strategy.

Some thinkers find the above fears exaggerated [Cordero, 2016]. Nevertheless, *the selective approach* has significant pending matters. In particular, it needs the following enhancements:

(i) A convincing criterion to identify putatively true and putatively false components in successful theories [Alai, 2017].

(ii) Clarity about the structure and ontology of the parts selected for realist commitment and how they fit in theories underpinned by different conceptual frameworks [Cordero, 2017].

(iii) A compelling account of how (if at all) contemporary science is more amenable to realist interpretation than past science – e.g., why we should expect successful contemporary theories to have fewer stoppers from underdetermination [Wray, 2013].

I have made some suggestions on (i) in Cordero [2011; 2017], but the matter remains controversial. My focus in this paper will be on (ii) and some applications to (iii).

The literature does not sufficiently explore the character of retentions across theory change in successful science. However, it is a topic implicated in the shortcomings perceived in the selective realist strategy. The clarification proposed in this paper suggests a functional interpretation of selective realism that meets some of the existing objections. As already indicated, my arguments draw from historical examples and scientific practice – e.g., the way quantum field theory (QFT) focuses on emergent approximate structures under specified conditions (commonly termed "specific regimes" in physics).

Road Map: The paper deals with how to resolve some problems faced by selective realism without giving up the main realist inference from empirical success to putative truth. The proposed approach takes hints from historical cases and the use of functional and effective entities and structures in physics. Section 2 discusses the challenge of taking a realist stance towards just part of a theory and expecting retention of that part in successor explanations. The topic of content retention presents complications regarding the ontology that the realist accepts when committing to a given "theoretical part." Staple cases like Fresnel's Theory gesture towards a functional explication, but the clues are vague and need elaboration and precision. Section 3 provides terminological clarifications to that end. Section 4 uses the results to argue for shifting the realist emphasis towards functional and effective theoretical content, leading to reforming the selective realist thesis. Finally, Section 5 tests the functional/effective turn proposed against some objections.

3. Theoretical Parts for Realists

Taking a realist stance towards just some portion of a theory T involves the belief that the part in question represents real features of the world at some (not necessarily fundamental) ontological level. The claim is that part of T correctly describes the intended domain, even if the total theory gets many things wrong. But how does this help? Selective realists purge theory parts of dubious content, leaving them with less content than their counterparts in the unpurged theory. Consider Fresnel's description of reflection and diffraction. The original theory, embedded in a framework that required the existence of the ether of light, is now recognized as wrong. Yet, selectivists notice that substantial parts of Fresnel's theoretical claims remain 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."

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."

Selectivists claim that severing the original conceptual links with the ether lets [FC] stand on its own as a prospectively correct theory part: light is electromagnetic radiation whose stuff is left ontologically opaque. I.e., the oscillations it carries could be distortions of a material substratum, or they could be something else. Purged of the ether framework, the description provided by [FC] looks "ghostly" compared to that in the original theory. In exchange, dropping the ether framework makes the light concept abstract enough to make [FC] sound and transferable to successor theories. Like most posits picked by selective realists, [FC] leaves open matters of traditional metaphysical interest – in this case, about the material substratum of the waves. This omission did not gain wide acceptance until at least one decade after Einstein made the ether an optional posit in his Special Theory. [FC] makes no claims about the substratum and admits multiple realizations. *Relative* to the original Fresnel theory, the light waves in [FC] are incomplete entities that merely *function* like Fresnel waves while potentially being entirely different. What subsequent theories retain as "waves" and "FC" from Fresnel's theory are *functional* posits and *effective* representations (as opposed to full posits by the lights of the earlier metaphysics).

A theory thus purged of problematic components has improved chances of being approximately correct. Still, as critics note, even severely purged theories often prove wrong in profound respects. For example, [FC] is not considered a prospectively true posit universally. One reason is that the optical indexes depend on various factors – most dramatically, the intensity of light, non-linear features, and quantum effects (e.g., creation and destruction of photons).

So, the topic of content retention presents complications. Which ontology should the realist commit to in the case of a given "theory part"? Within limited regimes, [FC] (with reduced but still significant physical content) has survived multiple theory changes, remaining *empirically successful and free of specific doubts,* which makes [FC] projectable as a putatively correct posit to this day. I will suggest in Section 4 that [FC] and other exemplary cases gesture towards a functional explication of the realist strategy, but the clues need clarification, elaboration, and precise labeling. That is the subject of the next section.

4. Some Clarifications

The previous considerations contain implicit distinctions that need precision.

(A) "Emerging" entities, properties, and patterns arise under certain conditions in the world studied by a theory. Items may emerge only approximately, as in the case of light rays. Also, entities and processes may be inferentially derivative from a base theory; their existence does not "necessitate" the latter's ontology (they may exist even if the premises of the derivation are false). In classical optics, light waves are conceptually grounded in the ether, but subsequent theories drop that grounding. Until the early 20th century, the mainstream theory of light was embedded in a metaphysics in which every physical wave conceptually necessitated a material substratum. Einstein turned the received theory into a conjunction of separable parts, dropped the ether component, and kept the remainder as an abstract description of light. The resulting waves function as Fresnel's waves only at relatively coarse descriptive levels that leave their deep ontology opaque. Like Einstein on light waves, selective realists look for an ontology that saves a superseded or dubious theory by dropping some of its content, usually the theory's deepest (fundamental) ontology. The result is a more abstract theory whose parts rest on a leaner ontological framework.

(B) Scientific claims generally hold only with restrictions. Recall Galileo's version of the law of free fall (GL): *"In the absence of air resistance, a body in free fall will during equal increments of time acquire equal increments of speed* [acceleration]*."* Since the acceleration of gravity varies with altitude, GL states a false proposition. So, physicists go for a weaker law that is coarse-grained and domain-restricted but true – something like: "*In the absence of air resistance, bodies in free fall within 5 Km of the Earth's surface will keep the same acceleration (±10-2 m/t^2)"*. This putatively correct statement effectively agrees with GL within the specified coarseness and domain restriction.

(C) In what follows, a "functional" entity or property will be individuated by its causal role. (recall the example of a carburetor in Section 1). The label "functional posit" applies to entities characterized by what they *do* rather than *what they are.* Relative to the base ("fundamental") theory at play, functional entities have their "deep nature" left opaque. However, there is no "structuralist" presumption here, no claim that the world has nothing other than structure or that only structure is knowable.

(D) Galileo's law describes free fall as *effective* rather than exact behavior under the conditions specified in (B). The label "effective" applies to entities and processes which, though drawn from one theory, closely "approximate" the behavior of entities and processes of another theory operating under a particular regime (i.e., the two behaviors closely match in the respects deemed relevant). For example, in the Kinetic Theory of Matter, entities behaving like continuous macroscopic bodies *effectively* emerge in a molecular milieu under specific regimes of energy and scale).

(E) The modal structure of a proposed functional entity is generally partial and weaker than that of its counterpart in the fuller, unrestricted theory. While unrestricted claims embody the complete conceptual and modal structure of the base theory, functional claims embody only part of that structure.

(F) Let's call a theory's literal, undiluted face value ontology its *fundamental* ontology. By contrast, its "functional" ontology is constituted by counterparts derived for some particular regime (as with Galileo's effective law or the smoothing of conceptual tension with relativity theory in QFT). The contrast between literal/functional is relative. The literal ontology of one theory (e.g., continuous matter) can be an available functional ontology of another (e.g., molecular theory).

(G) The term "descriptive level" (DL) generalizes the idea of "descriptive regimes" in physics. A set of "regime parameters" will characterize a DL, for example by listing the following:

- The theory's face value ontology (O).
- Λ: the aspects considered relevant for describing the empirical domain at the chosen level. Let's represent Λ by the set {λi}.
- The level of coarse-graining accepted for λi (represented by the set {δi}).
- The laws and regularities (L) holding over the domain targeted.
- The sub-region Δ of the total Λ-space where the description effectively holds.

Let's spell out each of these regime parameters a bit.

(g1) **O** stands for the regime's (local) face value ontology, which may vary from descriptive level to level. For example, according to practicing physicists, we have access to an effective QFT of protons and neutrons that works well as long as we don't get too close to the level of individual quarks and gluons, in which case the effective theory breaks down.

(g2) **The abstract character of the representation.** This aspect is expressed by the finitude of the list Λ of physical aspects considered relevant at the chosen descriptive level. The features not listed in Λ are generally deemed too small to be noticed or zig-zag around in the intended domain in such a way that their effects cancel out. For example, protons and neutrons consist of quarks held together by gluons (physicists regard them as short-wave field oscillations whizzing inside at high energies). Importantly, protons and neutrons are considered real – regardless of their level of fundamentality.

(g3) **The amount of coarse-graining tolerated (δ).** One can describe and understand a liquid at the gross traditional level without knowing anything about its molecular composition, even though there is a description in terms of particles. In principle, there may be many fine-grained theories of the liquid state incompatible with one another at the literal level.

(g4) **The laws and regularities that hold over the targeted domain.** Typically, laws and regularities over a targeted domain hold true only as coarse-grained relations, their general form being (to first approximation): $L(x_i) = f(x_i) \pm \delta(x_i)$.

g(5) **The domain sub-region (Δ) where the description is expected to hold.** Successful theories typically have limited applicability. The Newtonian theory of fluids does not hold true where the number of molecules in a region is so small that the effects of individual molecules become individually significant. More dramatically, we can imagine packing molecules into a sufficiently small space area and collapsing them into a black hole.

We thus get for regimes a representation of the form $\langle O,\Lambda,\delta,L,\Delta\rangle$. In scientific practice, regimes usually focus on spatial scale and energy ranges; the generalization proposed above is more inclusive. To the extent that functional behaviors are of the $\langle O,\Lambda,\delta,L,\Delta\rangle$ variety, their descriptions are *partial* relative to the base theory, their applications confined to a specific regime outside which the claim may not hold.

(H) Incompleteness: As theory components of the $\langle O,\Lambda,\delta,L,\Delta\rangle$ variety, functional behaviors may feel "incomplete" relative to their counterparts in the original theory. The following applies to functional entities and processes:

- They are abstract, focused on just some of the aspects Λ covered by the regime.
- They hold with only coarse-grained accuracy (represented by the parameters "δ_i").
- They may arise in just a sub-region Δ of the total logical space spanned by the complete theory.

In what follows, functional-effective versions of a theory T will be represented by putting T in brackets followed by a specification of the characterizing parameters: $[T]_{O,\Lambda,\delta,L,\Delta}$ (the indexes will be generally omitted for easiness).

(I) Pluralist feature: A functional theory or theory part generally comprises existence claims and regularities drawn from the total theory but with their content reduced by abstraction, coarse-graining, and domain restriction. Realism about [T] asserts that the kinds of entities and regularities included in [T] are *real* – they act and are acted upon under a particular regime in the theory's empirical domain. They are natural denizens at play in the specified domain, even if, relative to the base theory, they stand as incompletely formulated and non-fundamental.

(J) When a functional posit is recognized, the cause of its behavior may be left unspecified. Why do functional components behave as they do? The reason is often local cancellations of interactions and analogous contingencies (e.g., in the sense explained in [Bohm, 1957, Chapter 5]).

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

5. Emphasizing Functional/Effective Content

Claims derived from a theory T without restrictions are the stuff of "traditional" realism about T. By contrast, functional claims are the stuff of realism focused on how entities and processes *effectively behave within* some specified regime or descriptive level ("functional" realism). Although unrestricted descriptions can be true in principle, history places them among the least epistemically reliable in science because of their ambitious content. Compared to functional descriptions, unrestricted ones are weakly established and unstable against theory change. Unrestricted assertions routinely give way to functional counterparts under critical pressure, typically leading to a thinning of the initial content through abstraction, coarse-graining, and domain restriction. Functional posits may grow thinner as time goes by, but their level of corroboration is often high, grounding an expectation that they will never shrink into purely empirical regularities. In contemporary empirical science, the most warranted posits are nearly all functional.

The above considerations gesture towards taking a functional/effective turn that both sharpens the notion of realist gain in selective realism and, on the face of it, helps overcome at least some objections to the project. On the envisaged approach, realist commitment goes primarily to "functional" theories or parts thereof. The proposal suggested here centers on the following functional/practical thesis:

Thesis. Theory parts selected by the proposed functionalist approach are approximately true and will gain retention in successor theories as functional (as opposed to fundamental) parts within specifiable descriptive regimes.

Notice that this thesis will fail if, more than rarely, theory parts selected from empirically successful theories fail to gain substantive retention in successor proposals. As with the functional version of Fresnel's Core [FC], in parts selected for realist commitment, the entities and regularities involved (the ontology) are identified by *what they do rather than by what they "ultimately are."* Importantly, the existence and structure of those entities and processes (in the functional/effective version of a theory T) are generally open to independent corroboration over the subdomain specified for [T].

Admittedly, the abstraction level of a theory part in [T] focuses on aspects of the world selected under guidance from specific concerns. However, the entities and processes made salient by the noted abstraction are *objective* – they have ascertainable generative mechanisms and engage in objective interactions with other entities. As such, functional entities are not "useful fictions" but part of mind-independent reality, even though unveiling them may be guided by human interests. An instance in point is the planet Neptune, which remained unnoticed until observed departures of Uranus from its expected orbit prompted astronomers to change their level of abstraction by considering additional celestial objects. Also, in a pluralist fashion, a given object can belong to different functional ontologies over other domains (e.g., a metal rod can be functionally a thermometer or a crosspiece, having the required causal efficacy for both).

As noted, claims deemed correct are so at their intended descriptive level (Λ,δ,Δ). The "ordinary" description of an apple differs markedly from its molecular-level description ("Eddington's apple"). Yet there is agreement that the two descriptions are correct, each over the regime of size and energy on which it focuses. Both tell precise enough (and putatively true) stories about the modal structure of an apple within the intended contexts. So, importantly, functional/effective models can have epistemic autonomy. Just as people didn't need to know about molecules to learn much about apples, physicists didn't need to know anything about quarks or gluons when they developed the first theoretical descriptions of protons and neutrons.

At this point, a traditional realist may wish to deny that functional entities and structures are either "real" or "as real" as non-functional ones. This objection today requires an argument that seems unlikely to be achieved. Traditional realists may also insist that, from a theory's perspective, the only existing objects are the ones the theory presents as "fundamental" or "central" – all other objects should ultimately be either reduced to the fundamental objects or recognized as just convenient constructs. The reductionist claim adduced here is arbitrary, however. It overlooks that we have two notions of what makes X physically real: (a) X's most profound ("fundamental") material basis and (b) X's structures and dynamical patterns of interaction with other systems, such as they emerge under various regimes. On the second notion, favored by the suggested functional realist (and the practice of physics), to "exist" is to have causal efficacy. In this sense, in the case of light, functional undulations exist physically (whatever their ontological underpinnings). The proposed selective realist commitment regarding light waves is to the existence of *functional* microscopic transversal undulations – not "fundamental" Maxwell undulations.

It is in this way that functional/effective realism seeks to clarify commitment to *theoretical* content in individual theories (content like the light waves described by [FC], with their wavelengths of about 10^{-7} m and interactions with electrically charged material systems). Selective realism is thus about tying the empirical success of theories to scientifically reliable ampliative inference, particularly regarding explanatory entities and processes beyond the reach of ordinary human perception. It is also about reaffirming the idea of growth of theoretical knowledge.

Functional-selectivist proposals focused on the success of individual theories seemingly overcome significant historical challenges to realist proposals raised since the 1980s. As admitted, however, the selection criterion for theory parts remains controversial. Nevertheless, there is growing agreement for settling the criterion around some pragmatist choices. Here is one possible option [Cordero, 2017]: Pick only theory parts that

(a) have novel predictive success attributable to them,

(b) are free of *specific* (as opposed to global or metaphysical) doubts, and

(c) have gained elucidation from some successful theory initially external to it.

The population of functional entities, processes, and explanations extractable from successful theory parts that satisfy the above criterion has grown exponentially since the time of Newton. The parts in question provide a highly textured array of behaviors about the world beyond the reach of unaided perception – ranging from detailed cosmological histories from more than 13,000 million years ago to the present to ontic behaviors at various levels of generality regarding the composition, structure, and interactions of matter, to organic life, its diversity and history, to the rise of humans (even human nature), and more. The outcome is not a haphazard quilt of dubious significance but a corpus of abstract, finite-range, coarse-grained (but still nontrivially accurate) assertions that, nevertheless, display astonishing (and growing) levels of integration into a detailed and textured picture of the world. Most effective theory parts may be thin in content by traditional standards. Still, they display (or, in the case of new posits compellingly promise) strong resistance to theory change.

As a further bonus, the realist import of the suggested functional/effective claims seems immune to arguments from unconceived alternatives. Suppose an available core [T] merits selective realist commitment. Alternative theories will not compromise [T]'s realist status, provided those alternatives contain some significant part of the core. The leading ontic theories of quantum mechanics illustrate the dreaded underdetermination, with a diversity of incompatible views on the nature of physical systems. The most compelling proposals show practical empirical equivalence, reviving old antirealist fears about quantum physics. Still, the found underdetermination arguably compromises the realist interpretation of only parts of quantum physics [Cordero, 2001; Cordero, 2021]. The same goes for other proposed examples of radical underdetermination in current science. So, for empirically successful theories, it is incumbent upon the skeptic to provide examples of scientifically admissible (as opposed to global, "Cartesian") alternatives that fail to contain functional-effective theory parts that merit realist selection by the suggested criterion (in quantum mechanics, such parts include, e.g., the linear dynamical law, energy levels, spatial molecular structures, and much more).

A key question, of course, is how much (if at all) the suggested functional/effective turn helps the selective project. The proof of the pudding is in the eating, so let's conclude the paper by checking the proposal against some thought-provoking objections.

6. Three Tempting Objections

Objection 1: Some may complain that the proposed functionalist turn is just the sort of realism "for all practical purposes" (FAPP) John Bell admonished. The natural philosopher's duty, he urged, is to understand the world, not "to neglect, or to take only a schematic (FAPP) account of [say] the interaction across the split" between pre-and post-measurement situations in quantum mechanics[2].

A Response. The functional turn proposed in this paper welcomes the pursuit of explanatory accounts beyond the restricted domains/ regimes under consideration. It does not ignore (let alone abandon) the possible existence of entities and interactions underpinning functional accounts. It certainly discourages "bad" FAPP. The proposed turn points to models correctly describing the *local ontology and nomology at work under each regime without prejudice against further ontological inquiry*. Thus, in the functional terms of ordinary discourse, a billiard ball is a system of continuous matter within the appropriate energy regime, spatial coarse-graining (e.g., 10^{-5} m), etc. Outside this regime, the system may be radically different. Here is another example, this time involving bad FAPP. 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." Leading proponents declared the ontological issue "solved." But, as Bell stressed, after decoherence, the initial quantum superposition continues "alive" indefinitely along multiple wavefronts. Hence, the proposed FAPP solution gave up the realist interpretation of the state halfway through. It wasn't good FAPP. By contrast, the functional turn suggested in this paper follows scientific-realist lines. Classical entities exist and are natural systems that objectively emerge *within* the confines of specific regimes; they are not presumed to be *fundamentally classical* but *functionally* classical. "Ultimately," they may be quantum many-worlds systems, Bohmian systems, spontaneous collapse systems, or something else[3] (we cannot presently tell).

2 "To restrict quantum mechanics to be exclusively about piddling laboratory operations is to betray the great enterprise" [Bell, 1990].

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 perceptive work on the coherence of the idea of an emerging multiverse entirely within the framework of quantum mechanics (2014), a topic independent of the credibility of the resulting many worlds proposal.

Objection 2: Some critics reject the realist optimism of this paper. One common complaint is that, like today's scientists, past scientists too thought highly of their epistemic success, inferring wrongly that their leading theories were correct [Wray, 2013]. In Wray's view, the case for today's mature science is no better, so he challenges realists to specify why their optimism about current theories is more reliable than in the past.

A Response. Several seemingly relevant differences between past and present theorizing come to mind, particularly regarding:

(a) Scientific methodology.

(b) The character of theories in basic science today.

(c) The realist stances that are available now.

(a) The methodology used in successful, rigorous disciplines is much more challenging now. Past scientists did not emphasize corroborated novel predictions nearly as strongly as they do today. Nor did they admit fallibilism at all levels of theorizing as present scientists do.

(b) The character of theorizing has changed substantially. In particular, most branches of today's physics lean toward functional/effective theories, which are significantly more resistant to theory change than their counterparts in the base theory. This change is illustrated, for example, in the way QFT smooths out conceptual tension between ordinary quantum mechanics and relativity theory regarding separability and locality. The smoothing at play resorts explicitly to abstraction, coarse-graining, and domain restriction. It results in "effective theories" – i.e., emergent coarse-grained natural orders that bring the relevant particles and fields in various regimes to the fore.

(c1) The character of scientific realism, too, has changed. During most of the modern period, scientific theories were embedded in metaphysical conceptual networks that entangled theory parts, which rendered attempts to break them into parts incoherent. As late as 1905, for example, there was a near consensus that '*being a wave*' conceptually necessitated a substratum (the ether) whose propagating deformation the wave *was*. Having the two posits (let us represent them as A and B) "entangled" meant that deletions of the ether posit from the theory could proceed only cosmetically. Breaking the entangled cluster required turning (A-B) into a conjunctive cluster (A●B). Traditionally, the concepts of '*being a wave*' (concept A) and '*having a material substratum*' (concept B) were "metaphysically entangled": waves (thought of as propagations of physical perturbations) "had to be" perturbations of something (e.g., the "ether of light"). We can represent the conceptually entangled case by "(A-B)" and the disentangled case by the conjunction "(A●B)." When Einstein declared the ether an optional posit in electromagnetic theory, the physics establishment resented his ploy and rejected it initially (see, e.g., [Cordero, 2011a]). Einstein's proposed reform advanced gradually in physics (initially with help from positivist ideas). Since then, ontological frameworks in the natural sciences have dropped constraints with a priori pretenses.

(c2) Unlike traditional realists, functional realists are not troubled by the historical suggestion that empirical theories (including future ones) are generally false as full constructs. The dispute is not about that. It is about whether successful theories *contain* cores with content that – by stringent methodological standards – is very likely true and will generally gain retention in successor theories.

Objection 3. Critics worry that realists following the proposed functional approach will miss underdetermination problems and over-commit. For example, in the case of [FC], they would do so in at least the following two ways[4]:

(O3a) One charge is that functionalists accept too quickly the existence of transversal microscopic undulations in places where possibly *nothing exists* (in a way analogous to someone who commits to there being something in the center of a donut). To appreciate the complaint, consider the Feynman-Wheeler alternative view of electromagnetism (FW), 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.

(O3b) According to the envisaged realist, the undulating field exists in an effective/functional way, akin to Eddington's macroscopic table[5]. But, in the FW account, the electromagnetic field amounts to a mere law quantifying the motion of charges, suggesting an ontological *elimination*. So – the objection goes – the functionalist account has an inconsistency in the descriptions of the world (in terms of an actual undulating field that exists everywhere between the charges and there *not* being any such field connecting the charges but only the charges themselves in motion).

A Response. It is false that *nothing* exists where the transversal undulations associated with light play out.

(3a): To repeat, to "exist physically" is to have causal efficacy in agreement with the local physics principles. Claiming functional reality for microscopic undulations does not amount to maintaining that continuous undulations are present at all descriptive levels – just like asserting the reality of a macroscopic table is not asserting that the table is continuous at all descriptive levels (but only at macroscopic ones). Likewise, the proposed realist commitment is to the existence of *functional* transversal microscopic undulations under a particular regime – not fundamental Maxwell undulations. As for the suggestion regarding the donut, its center of mass 'functions' as a particle only in respects that are insufficient for attributing physical existence. The center of mass – a geometric point – doesn't withstand electromagnetic interactions or local actions and reactions.

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4 This prospective objection was kindly suggested to me by Juha Saatsi and Matthias Egg (private communications). My thanks to both.

5 I.e., as an effectively solid object, despite having nothing but particles at the more fundamental level.

(3b): This objection conditions "real existence" to not having "contradictory" multiple physical realizations. But full-Maxwell and full-SW are proposed only as *possible* realizations, not actual ones. Must one give up realism about the entire content of a theory part just because speculative interpretations of it contradict (as, e.g., with Bohmian and Many Worlds ontologies)? In the case of Maxwell versus FW, the functional field has sufficient causal efficacy for granting its physical existence. The microscopic undulations (whatever their ultimate nature) act and react with screens and materials according to the laws governing the regimes in place. The (geometric) center of a donut is not like this. Admittedly, the waves prospectively inferred to exist in Maxwell's Theory are not part of FW's fundamental theoretical level. However, FW retains light waves as functional/effective entities with objective causal efficacy displayed in their contacts with matter. If so, even on FW, what exists is not just "only the charges themselves in motion" but the charges in motion *and* a constraint (some law-like structure) that both restrict those motions and give rise to undulations that effectively function as physical entities. The functional realist claims are thus consistent: "There is something real *functionally* connecting the charges," *and* "There is no full-theoretical-Maxwell field connecting the charges." The relevant point is that we lack a reason to limit the label "real" to base-level, "fundamental" entities/processes. Physically real denizens may emerge at any non-basic theoretical descriptive level. The epistemological import of unveiling a multiplicity of possible "natures" for physical light calls for a suspension of realism only regarding the *most profound nature* of light. In Maxwell versus FW, the opposing descriptions are each coherent and truthful, provided the realist versions of 'field,' 'undulation,' etc., are *described sufficiently carefully* in suitable functional/effective terms that restrict descriptions to the relevant regime $\langle O,\Lambda,\delta,L,\Delta\rangle$. Incoherence only comes from ignoring the regime in place.

7. Concluding Remarks

This paper's functional/effective version of selective realism shifts realist commitment. It drops the traditional emphasis (centered on fundamental theoretical entities and behaviors invoked by unrestricted, complete theories). Instead, the proposed realist turn focuses on functional/effective counterparts (centered on functional theoretical descriptions and existence claims focused on causal efficacy at any ontological level). The proposed reformulation helps the selective realist project in two ways. First, it clarifies the structure and content of taking a realist stance towards just part of a theory, suitably indexed to a regime and expecting substantive retention in successor explanations. Secondly, it spells out some relevant differences between the realist stance favored during most modern science and the more modest, pluralist – and plausible – selective approach practiced in the sciences today.

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