Towards a Unified Dispositional Framework for Realizable Entities

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Abstract. Realizable entities are properties that can be realized in processes of specific correlated types in which the bearer participates. It will be valuable to create a systematic classification of realizable entities because they are useful for various modeling purposes in ontologies. In this paper we outline a unifying framework for realizable entities (including dispositions and roles) in the upper ontology Basic Formal Ontology (BFO) that is theoretically underpinned by J. McKitrick's pragmatic approach to dispositions. In particular, we develop a formal ontological account of "extrinsic dispositions" and illustrate its potential applications with clarification of functions and roles in BFO.

Keywords. realizable, disposition, extrinsic disposition, role, Basic Formal Ontology (BFO)

1. Introduction

The world is teeming with realizable entities: properties that can be realized in processes of specific correlated types in which the bearer (e.g., material objects) participates. For example, the fragility of this glass can be realized in a process of the glass breaking. Realizable entities and the realization relation between properties and processes are vital for considering the interplay between two major upper-level ontological categories: continuants (aka endurants), in particular material objects, and occurrents (aka perdurants), in particular processes. For instance, Guarino & Guizzardi [1] propose the view of events as *manifestations* (realizations) of "individual qualities" (property particulars) and Guarino [2] expects that this manifestation account of events will inspire many upper ontologies. More specifically, dispositions (e.g., fragility) among other things have been intensively investigated in formal ontology [3][4][5] and they have been deployed in the building of many domain ontologies (see Toyoshima's [6] general survey). The disposition category is adopted by some upper ontologies that have core features (e.g., the continuant/occurrent distinction) in common, such as Basic Formal Ontology (BFO) [7][8] and the Unified Foundational Ontology (UFO) [9][10]. Accordingly, realizable entities are useful for modeling a wide range of domain-specific entities, such as suicidal tendencies in medical informatics [11]. It nonetheless remains

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largely unexplored how to articulate different realizable entities *systematically*, notwithstanding the line of study started by Röhl & Jansen [12].

In this paper, we will embark upon a systematic study of realizable entities. For this purpose, we examine the category of realizable entity in BFO, especially its prominent direct subtypes: dispositions and roles. As for dispositions, there is long-standing controversy as to their ontological nature. For example, Guarino [2] says: "the difficulty of distinguishing one disposition from another (…) is a good evidence of their problematic ontological status" (p. 14). Barton et al. [5] propose a set of identity criteria for dispositions that can meet this challenge, but a more fundamental question is what it is like for a property to be a disposition. Consider the following alleged "recipe" for identifying dispositions [13]: one can identify a disposition by using an expression of the form "the disposition to bring about *R* if *T* holds" where *R* is a realization (e.g., the glass-breaking) and *T* is a triggering condition (e.g., the glass being forcefully pressed). From an ontological point of view, however, the reliability of this recipe remains unclear. For instance, the recipe could yield the "disposition to get harmed if attacked", but am I really *disposed* to get harmed if attacked? If we are agnostic as to such dispositions, how should we treat this recipe-based identification of dispositions in formal ontology?

The issue of dispositions is further complicated by the BFO characterization of roles as a disjoint subtype of realizable entities. For one thing, this realizable understanding of roles may be sometimes regarded as contentious. Guarino [2] states that it: "reflects a very peculiar understanding of the role notion which, although useful, would require a broader framework" (p. 14) and one reason why he thinks so is the difficulty of figuring out the relationship between dispositions and roles in BFO. (We will discuss his concern in more detail later.) Assuming that being a student consists in studying at school, for instance, exactly how is Mary's role of being a student at school linked with her disposition to study? To borrow Guarino's expression, addressing these questions requires careful consideration of dispositions and roles within "a broader framework", presumably within a systematic framework for realizable entities in general.

The paper explores a systematic perspective on realizable entities by revolving around the BFO framework. Section 2 describes how BFO represents realizable entities, dispositions, and roles. Section 3 develops one way of classifying systematically realizable entities, taking a cue from McKitrick's [14] pragmatically motivated approach to dispositions. Section 4 is devoted to the discussion on the potential application of our proposal. Section 5 concludes the paper. In the text, we will write terms for type-level entities (aka universals, or classes) in italics and terms for token-level entities (aka particulars, instances) and relations in bold, respectively.

In formalization, variables stand only for tokens, predicates (written in bold) stand for types (unary predicates) and relations, and free variables are universally quantified. We will employ conventional logical symbols of first-order logic, including "¬", "→", and "∃". Table 1 lists relational predicates together with their informal explanation and most of them represent binary relations, which can have the practical virtue of enhancing the practical implementation of our proposal in information systems, such as the ones constructed in the Web Ontology Language (OWL).

2. Realizable Entities in Basic Formal Ontology

We begin by adumbrating the basic background of BFO before explaining its category of realizable entity. BFO is an upper ontology that is rooted in the realist methodology

Table 1. A list of relational predicates and their informal explanation. (The references therein mean prior work from which relations are imported, although they may be reinterpreted in our context.)

Relational predicate	Informal explanation
ADP(x,y) [4]	x (realizable entity) is an add-part of y (realizable entity)
HCB(x,y) [3][5]	x (realizable entity) has as categorical basis y (quality)
HTR(x,y) [3][5]	x (realizable entity) has as trigger y (process)
INH(x,y) [7][8]	x (specifically dependent continuant) inheres in y (independent continuant)
REAL(x,y) [3][5]	x (realizable entity) can be realized in y (process)
REON(x,y)	x (extrinsic disposition) relies existentially on y (intrinsic disposition)
SUM(x, y_1, ..., y_{n+1})	x is a mereological sum of y_1, …, y_{n+1}

for ontology development [15]: ontologies should represent entities in actual (scientific) reality. It has the top-level distinction between continuants and occurrents, the former being further divided into independent continuants and dependent continuants. Among dependent continuants are specifically dependent continuants, which depend (existentially) on at least one independent continuant.[2] As for occurrents, we will focus on one of its subcategories, namely processes: occurrents that exist in time by occurring, have temporal parts and depend on at least one independent continuant as participant. Two major subtypes of specifically dependent continuants are realizable entities (which will be detailed below) and qualities: specifically dependent continuants (e.g., color, shape, and mass) that do not require any further process in order to be realized.

A realizable entity is a specifically dependent continuant that inheres in some independent continuant and is of a type some instances of which are realized in processes of a correlated type. BFO identifies two immediate subtypes of realizable entities, namely dispositions and roles. First of all, a role in BFO is: "a realizable entity that (1) exists because the bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be (optionality), and (2) is not such that, if this realizable entity ceases to exist, then the physical make-up of the bearer is thereby changed (external grounding)" ([7], pp. 99-100). Therefore, a role is an optional and externally grounded realizable entity. Suppose for instance that Mary is a student at the XYZ college. Mary has the role of being a student (which may be realized in, e.g., a process of Mary's studying) because she happens to be in some specific institutional circumstances with respect to the XYZ college (optionality) and she does not undergo physical changes just because she ceases to be a student (externally grounded).

By contrast, a disposition in BFO is: "A realizable entity (…) that exists because of certain features of the physical makeup [material basis] of the independent continuant that is its bearer" ([7], p. 178). BFO also describes a disposition as an *internally grounded* realizable entity: if a disposition ceases to exist, then the physical makeup of the bearer is thereby changed. To use a canonical example, the fragility of this glass can be realized in a process (realization) of breaking when it is pressed with force, it is based on some structured molecules (material basis) of the glass, and the glass is physically changed when it is no longer fragile (internally grounded).

Thus, BFO characterizes dispositions as internally grounded realizable entities. BFO employs what may be called the "grounded test" for realizable entities. That is to say, a realizable entity is internally grounded if and only if its bearer needs to be physically changed for it to cease to exist, and it is externally grounded if the realizable can cease

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[2] It is sometimes said that processes can be bearers of properties, such processes of oscillation having waves as property [16]. BFO seems to refrain from this possibility, but we may think that the bearer view of processes could be an auxiliary assumption that would simplify our formalization below.

to exist without its bearer changing physically. Consequently, a realizable entity is a disposition iff it passes the internally grounded test.

In contrast, roles are not only externally grounded but also "optional". The notion of optionality used there may be less clear to comprehend than grounded-ness. As Röhl & Jansen [12] say, one way to clarify it would be to utilize Guarino & Welty's [17] work on the classification of types based on their notion of rigidity. They define rigidity, semi-rigidity, anti-rigidity, and non-rigidity of types as follows:

- A type is *rigid* if it is essential to all its possible instances.
- A type is *semi-rigid* if it is essential to some of its possible instances and not essential to others.
- A type is *anti-rigid* if it is non-essential to all its possible instances.
- A type is *non-rigid* iff it is either semi-rigid or anti-rigid.

We can elucidate optionality (and "non-optionality") in terms of these features, while prescinding from exactly how the notion of rigidity can be integrated into the BFO framework (see Seyed & Shapiro's [18] inquiry into this integration). Assuming that roles are type-level entities, Guarino & Welty [17] think that role types are anti-rigid because: "Roles are properties that characterize the way something participates [in] a *contingent* event or state of affairs" (p. 214). Every instance (e.g., Mary) of *Student* can cease to be such in a suitable situation (e.g., her graduation from the XYZ college), for example. One way to elucidate optionality is thus to construe it as anti-rigidity, and non-optionality as either rigid or semi-rigid. Another way is to understand optionality and non-optionality as non-rigidity and rigidity, respectively, *à la* Röhl & Jansen [12], who highlight a category of externally grounded and non-optional realizable entities that is not presently acknowledged by BFO. In short, rigid and anti-rigid types of externally grounded realizable entities would be safely taken to be non-optional and optional, respectively; whereas, the treatment of their semi-rigid types may be an open question.

Two clarificatory remarks on roles in BFO are in order here. First, the phrase "play a role" has been popular in formal ontology and other domains, but roles in BFO are something to be *had* or *borne*. To see this point, it will be useful to mention Mizoguchi et al.'s [19] claim that the alleged "role-playing" has two components: to *hold* a role and to *perform* a role. To take a variant of their example, Mary is still a student of the XYZ college when she is asleep at home because sleeping Mary can hold a student role (because she has enrolled in this college), but she does not perform it: that is, she does not do anything associated with her being a student. This distinction between holding and performing a role corresponds to having a role and this role being realized within the BFO framework, respectively: when asleep, Mary has a role of being a student and this role remains unrealized.

Second, Guarino [2] says that "BFO can only account for a notion that is *related* to the ordinary notion of social role" but not "a social role in the ordinary sense" (p. 14). According to Toyoshima [20], this may be partly due to multiple possible understandings of role terms. Consider the statement: "Mary is a student." For instance, UFO [9][10] takes *Role* to be a subtype of what UFO calls "anti-rigid sortal universal" and Mary to be an instance of *Student* which is a subtype of UFO:*Role*. In this account, one can identify the referent of the English term "student" with an instance of *Student*. On the BFO account, by contrast, a student like Mary is not an instance of *Student role* (which is a subtype of BFO:*Role*), since Mary is not a realizable entity. Rather, Mary *has* (rather than *being*) an instance of BFO:*Role* of being a student. Moreover, the term "student" can be generally defined as a person who has some role of student ([7], p. 100).

3. Towards Systemization of Realizable Entities

3.1. J. McKitrick's Dispositional Pluralism

By and large, philosophical discussions of dispositions focus primarily on physical properties (e.g., electric charges) to articulate the fundamental fabric of the world. In formal ontology, by contrast, domain experts are interested in dispositions as a convenient conceptual tool for representing a broad range of entities, as is well illustrated by the dispositional theory of diseases that is given by the BFO-compliant Ontology for General Medical Science (OGMS) [21] and a dispositional approach to such mental entities as belief, desire, and intention [22]. In other words, formal ontologists need an account of dispositions that is wide enough to characterize multifarious entities.

This practical attitude towards dispositions can be theoretically undergirded by McKitrick's [14] theory of dispositions that is pragmatically motivated by a dispositional analysis of various entities such as character traits and gender [23] (refer to Toyoshima et al. [24] for a formal analysis of her dispositional theory of gender). She argues for what she calls "five marks of dispositionality", according to which a property (instance) is a disposition if it ([14], p. 2):

1. has some characteristic manifestation ["realization" in our terminology] M [type];
2. is such that some circumstance C [type] will trigger manifestation M;
3. can be possessed without manifestation M occurring;
4. is instantiated ["borne"] by things [bearers] of which a conditional of the form "if it were subject to circumstance C, it would exhibit manifestation M" is generally true; and
5. can be accurately characterized with an expression of the form "the disposition to produce manifestation M in circumstance C."

Notice that her five marks can be seen as a more sophisticated version of the "recipe" for identifying dispositions that was alluded to in Section 1.

Based on these five marks, McKitrick endorses what she calls "dispositional pluralism", i.e., the thesis that dispositions are an abundant and diverse group of properties. For instance, it is prevailing orthodoxy that dispositions are intrinsic properties. The distinction between intrinsic and extrinsic properties is notoriously difficult to be defined explicitly, but the basic idea is that a property instance is *intrinsic* if it inheres in its bearer purely in virtue of the way its bearer is and it is *extrinsic* otherwise [25]. The fragility of a certain glass is intrinsic because the glass is fragile under any external circumstances, even when packed in a bubble wrap. In her pluralistic approach, however, McKitrick argues that there are also "extrinsic dispositions" (see Section 3.3), as well as many other non-ordinary kinds of dispositions, such as "ungrounded dispositions" (see Section 3.2).

We hypothesize that McKitrick's dispositional pluralism can be leveraged as one promising systematic approach to realizable entities, including BFO:Disposition. For one thing, this doctrine goes far beyond the BFO category of disposition: for example, McKitrick's extrinsic dispositions are externally grounded: an extrinsic disposition is borne (at least partly) in connection with the world that is external to its bearer, and when the external world changes, it can cease to exist even without the bearer's physical changes, hence the failure to pass the internally grounded test. (Relatedly, intrinsic dispositions are internally grounded.)

Dispositional pluralism can be expected to provide, so to speak, a "dispositional lens" through which to view realizable entities consistently. This dispositional lens will help to analyze more meticulously, for instance, roles and their relationship with dispositions in BFO. To center around dispositions in order to explore realizable entities in general will also enable taking advantage of the fact (mentioned in Section 1) that dispositions are the best-investigated type of realizable entities in formal ontology.

As a preliminary to formalization, we provide the following *is-a* hierarchy of mutually exclusive ontological categories with their corresponding unary predicates (where a type *A* being a subtype of a type *B* implies all instances of *A* being instances of *B*):

> Realizable entity (REA)
> > Intrinsic realizable entity
> > > Intrinsic disposition (IND)
> > > > Ungrounded disposition (UND)
> > Extrinsic realizable entity
> > > Extrinsic disposition (EXD)

Note that realizable entities in our class hierarchy can be identified with realizable entities in the BFO framework. Our classification of realizable entities will thus serve to characterize subtypes of realizable entities in BFO. For instance, intrinsic and extrinsic dispositions (which will be closely scrutinized in Section 3.3) can be located within the BFO hierarchy as follows:

> BFO:Specifically dependent continuant
> > BFO:Quality
> > BFO:Realizable entity
> > > BFO:Disposition ("internally grounded realizable entity")
> > > > Intrinsic disposition
> > > Extrinsic disposition

3.2. The Causal Import of Realizable Entities

We begin with the basic problem of what it means for an entity to be realizable. Assuming that dispositional pluralism is general enough to cover a large number of realizable entities, this would amount to the question of what dispositions in dispositional pluralism can have in common. To address it, we will consider McKitrick's [14] discussion on *causal bases* of dispositions. This notion should not be conflated with material bases of dispositions in BFO (see Section 2), not least because causal bases are properties of the disposition bearer but material bases are its material parts.

The pivotal idea is that the realizability of realizable entities would be construed in terms of their causal relevance to their realizations. For example, what makes the fragility of this glass realizable can be ascribed to an intimate causal connection between this fragility and a process of glass-breaking (in which it can be realized). In discussing the causal import of dispositions in her pluralist theory, McKitrick examines Prior et al.'s [26] two theses about causal bases of dispositions. We formulate them as follows:

- *The causal thesis*: Every disposition has a causal basis.
- *The distinctness thesis*: Every disposition has a distinct causal basis from itself.

McKitrick affirms the causal thesis but denies the distinctness thesis. In her understanding: "A causal basis is a property of an object which is, or would be, causally relevant to the manifestation [realization] of a disposition of that object" ([14], p. 132). Note that a disposition can have multiple causal bases because: "if some property is causally relevant to a manifestation [realization], this does not rule out some other property also being causally relevant to that manifestation. So we should not assume that there is only one causal basis per disposition" (ibid., p. 133). In addition: "Causal bases can be either dispositional or non-dispositional [properties]" (ibid., p. 132). For instance, it may be oftentimes said that the fragility of this glass has as causal basis some molecular structure (which is non-dispositional) of the glass [3][5]. On her view, this fragility has also the *fragility itself* as causal basis because it is causally relevant to its realization, namely the breaking of the glass.

As for the distinctness thesis, its denial by McKitrick is motivated to accommodate what she calls "ungrounded dispositions": (epistemically and metaphysically possible) dispositions of fundamental physical entities (possibly subatomic particles) that have no non-dispositional causal basis. Because even ungrounded dispositions have some causal basis (i.e., themselves), the causal thesis would indicate that all dispositions in dispositional pluralism have in common their specific causal import under the name of their causal bases.

McKitrick's view of causal bases of dispositions is coherent and it would be philosophically tenable, but there may be some concerns as to its direct import to our project to give a unifying perspective on realizable entities in formal ontology. First, her usage of the term "causal basis" could confuse normal ontology developers because a disposition can be its own causal basis. Surely, she says that this claim: "is not to say that a disposition causally explains itself, but only that it causally explains its manifestation [realization]" ([14], p. 133). However, we would have good reason to preserve the term "basis" in its intuitive and narrow sense that excludes something being a basis (whether causal or not) of itself, as is exemplified by the material basis ("disorder") of a disease in the BFO-compliant OGMS dispositional account of diseases [21].

Second, the possibility of ungrounded dispositions would clearly deny the distinctness thesis, but this consequence will be of little usefulness in formal ontology because this field mostly deals with ordinary dispositions (e.g., fragility) that have non-dispositional causal bases. At the same time, the idea of ungrounded dispositions may be of potential practical value. Williams [27] propounds a domain-specific conception of ungrounded dispositions (to wit, of "powers" in his terms): a given (scientific) domain ascribes powers to entities that can be thought to be fundamental to the domain. He is skeptical of the philosophical plausibility of this view, but it can be deployed so that each domain ontology can be equipped with an associated ontology of what we may call "domain-relative ungrounded dispositions": very roughly, dispositions in a given domain whose non-dispositional causal bases would belong to other domains. In this respect, McKitrick's original notion of ungrounded disposition will serve as a starting point for developing its potentially useful domain-relative versions.

All these considerations can lead to the following formal specification of the causal import of realizable entities. This stipulates the generalization of the notion of a *categorical basis* [3][5] of a disposition (not necessarily in McKitrick's pluralist sense of the term), through our reinterpretation, to a categorical basis of a realizable entity: a quality or a sum of qualities of the bearer of a realizable entity such that the quality (sum) makes the realizable entity causally relevant to its realization. Following the Williams[27]-inspired argument that McKitrick's ungrounded dispositions are intrinsic

because their causal import must stem only from their bearers, we can define an ungrounded disposition as an intrinsic disposition that has no categorical basis (d1):

d1 $UND(x) =_{def.} IND(x) \wedge \neg\exists y \, HCB(x,y)$

This will allow us to propose our (albeit weakened) "realizable counterpart" of the aforementioned causal thesis. That is to say, all other realizable entities than ungrounded dispositions have a categorical basis (a1):

a1 $REA(x) \wedge \neg UND(x) \rightarrow \exists y \, HCB(x,y)$

Note that, as with causal bases of dispositions in McKitrick's theory, one realizable entity may have multiple categorical bases.

3.3. Extrinsic Dispositions in Dispositional Pluralism

We are exploring realizable entities with recourse to a dispositional lens that is theoretically underpinned by dispositional pluralism. Here we will focus on one non-standard kind of dispositions only, namely on extrinsic dispositions. An extrinsic disposition is a disposition that exists (at least partially) in virtue of the way the world that is external to the bearer is. McKitrick's examples of extrinsic dispositions include vulnerability (the disposition to be harmed if attacked), visibility (the disposition to be seen when someone looks towards it), weight (the disposition to depress a properly constructed scale relative to a local gravitational field, following Yablo [28]), and mass (the disposition to produce a gravitational force which is generated by its immersion in the Higgs field, following Bauer [29]).[3] As we said in Section 3.1, extrinsic dispositions would be externally grounded realizable entities in BFO. At the same time, we leave open whether the BFO internally/externally distinction in groundedness is to be (re)interpreted in terms of the intrinsic/extrinsic property distinction. (UFO [9][10] characterizes dispositions as a subtype of "intrinsic moments", where moments correspond approximately to specifically dependent continuants in BFO.)

We deploy the following exemplar of extrinsic dispositions which can be attributed to Shoemaker's [30] key/door example. Imagine this key (say **key₁**) and this lock (say **lock₂**) such that **key₁** opens **lock₂**. Consider the realizable entity (say **re₁**) of **key₁** to be realized in a process of the type *lock₂-opening-by-key₁* and the realizable entity (say **re₂**) of **lock₂** to be realized in a process of the same type. From a pluralist point of view, **re₁** and **re₂** are extrinsic dispositions because they are borne in virtue of the existence of **lock₂** and **key₁**, respectively, as is indicated by Shoemaker's [30] discussion of the key-door example in terms of Geach's [31] notion of "mere Cambridge change" (which is, roughly, a change that does not involve any intrinsic change).

Extrinsic dispositions constitute a crucial group of externally grounded realizable entities because they are of great value for ontological modeling, above all of entities with environmental and social dimensions. (Note that, relatedly, intrinsic dispositions are equally important, as they are such paradigmatic dispositions as fragility and

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[3] BFO takes mass to be an exemplar of its category of *quality* (see Section 2). This means that dispositional pluralism might possibly cover some kinds of qualities in BFO. To address this issue will require careful consideration of the BFO distinction between qualities and realizable entities, or more generally the general ontological distinction [13] between categorical and dispositional properties.

solubility.) For that matter, some dispositions in preceding formal-ontological work would prove to be extrinsic dispositions (rather than dispositions in BFO or UFO): for instance, Barton et al.'s [32] idea of a disposition with an "existential condition", namely a disposition which depends existentially on something that is external to the bearer.

For a concrete example, McKitrick [23] characterizes a gender as a cluster of behavioral and extrinsic dispositions (see Toyoshima et al.'s [24] work on this line of ontological representation of gender). To take another one, Turvey's [33] dispositional account of Gibson's [34] notion of affordance (roughly, what the environment "offers" agents) entails an ontological commitment to extrinsic dispositions, as is explained by Vetter [35]. To illustrate this, an affordance of this staircase is its disposition to support John as he moves upward (or downward) using the staircase and this affordance is an extrinsic disposition because it exists in virtue of John, who is not part of the bearer of this affordance (namely the staircase). Moreover, Turvey's affordances within the environment are always coupled with associated dispositions (which he calls "effectivities") of agents. Affordances and effectivities are both extrinsic dispositions and they can be indeed formalized by analogy with **re₁** and **re₂** [36].

We will consider two formal ways of explicating extrinsic dispositions. Firstly, they are in nature, in some sense, "derivative" of some intrinsic dispositions. To illustrate this, **re₁** "derives from" the intrinsic disposition (say **Re₁**) of **key₁** to open any instance (e.g., **lock₂**) of the type *Lock₂*, and **re₂** "derives from" the intrinsic disposition (say **Re₂**) of **lock₂** to open any instance (e.g., **key₁**) of the type *Key₁* [36]. Williams [27] contends that an extrinsic disposition *depends* (existentially) on some intrinsic disposition in the sense that without the latter, the former would exist (although, to wit, he uses the term "power"). Because BFO already has several ontological dependence relations, we introduce the "existential reliance" relation (REON for "relies on") between an extrinsic disposition and an intrinsic disposition to forestall terminological confusion: REON(**re₁**, **Re₁**) and REON(**re₂**, **Re₂**) hold. If REON(**d₁**, **d₂**), we call **d₂** an "intrinsic dependee" of **d₁**. Williams's claim can be then formalized as follows (a2):

a2 $EXD(x) \wedge INH(x,y) \rightarrow \exists z \, (IND(z) \wedge INH(z,y) \wedge REON(x,z))$

We do not assume that REON is functional: an extrinsic disposition can have several intrinsic dependees. Suppose for example that **key₁** can open instances of *Lock₂*, as well as instances of *Lock₂'*, where *Lock₂* is different from *Lock₂'* and **lock₂** is an instance of both *Lock₂* and *Lock₂'*. Then, **re₁** relies not only on **Re₁** (the intrinsic disposition to open instances of *Lock₂*), but also on **Re₁'** (the intrinsic disposition to open instances of *Lock₂'*).

The REON relation can be logically constrained by means of disposition-related relations [3][5]. First of all, every realization and trigger of an extrinsic disposition is a realization and trigger of any intrinsic dependee thereof, respectively (a3, a4):

a3 $REON(x,y) \wedge REAL(x,z) \rightarrow REAL(y,z)$
a4 $REON(x,y) \wedge HTR(x,z) \rightarrow HTR(y,z)$

Note that the reciprocal does not hold: some realizations and triggers of an intrinsic dependee of an extrinsic disposition are not realizations and triggers of this extrinsic disposition, respectively. For example, if **lock₂'** is an instance of *Lock2* but different from **lock₂**, then **Re₁** – in contradistinction with **re₁** – can be triggered by **key₁** turning into **lock₂'**, and realized in **key₁** opening **lock₂'**.

We can also think that every categorical basis of an intrinsic dependee of an extrinsic disposition is a categorical basis of the extrinsic disposition (a5):

a5 $REON(x,y) \land HCB(y,z) \rightarrow HCB(x,z)$

Note that the reciprocal does not hold: a categorical basis of an extrinsic disposition is not a categorical basis of an intrinsic dependee of it. For example, re_1 has as categorical basis some features of $lock_2$, whereas Re_1 does not (all its categorical bases are features of key_1).

One may think that an extrinsic disposition has also as its categorical basis something that is external to the bearer, as is illustrated by Barton et al.'s [32] idea of an "external base" of extrinsic dispositions. For instance, re_1 and re_2 may seem to have as their categorical bases some geometric structure of $lock_2$ and key_1, respectively. According to Contessa [37], however, extrinsic dispositions are a counterexample to the Intrinsic Dispositions Thesis ("All dispositions are intrinsic"), but its falsity does not entail the Intrinsic Bases Thesis ("The causal (categorical) bases of all dispositions are intrinsic"). We leave this issue open for future investigations.

Secondly, extrinsic dispositions may be further elucidated by dint of what may be called their "systemic view". The pivotal idea is that an extrinsic disposition exists within a system that is composed of its bearer and other objects. This systemic account of extrinsic dispositions may not be espoused by McKitrick [14] herself, but it seems to be propounded by Turvey's [33] dispositional approach to affordances (see Toyoshima & Barton's [36] detailed analysis). Vetter [38] provides its explicit formulation in terms of the notion of *potentiality*. Although she distinguishes potentialities from dispositions, McKitrick points out that dispositional pluralism can understand potentialities as a subtype of dispositions. We will below present a dispositional reinterpretation of Vetter's systemic approach to extrinsic dispositions.

The thrust of Vetter's [38] argument about extrinsic dispositions (or "extrinsic potentialities", in her terms) is that the possession of an extrinsic disposition by an object is both necessary and sufficient for the possession of a *joint disposition* ("joint potentiality" in her terms) by a system composed of this object and others. (Note that a joint disposition would be an intrinsic disposition that is borne by multiple objects "together".) In more detail: whenever an object bears an extrinsic disposition, this disposition is "fully grounded" (in her terms) in a joint disposition which is borne by a system composed of this object and others; and whenever a system composed of a number of objects bears a joint disposition, each of the objects thereby bear an extrinsic disposition which is fully grounded in that joint disposition. For instance, key_1 and $lock_2$ have extrinsic dispositions re_1 and re_2, respectively, in virtue of the fact that the "key_1 & $lock_2$ system" bears some joint disposition (say re_3) that fully grounds re_1 and re_2, and *vice versa* (see also Toyoshima & Barton's [36] similar discussion in examining Turvey's [33] dispositional account of affordances and effectivities). Like re_1 and re_2, re_3 can be realized by a process of the kind *$lock_2$-opening-by-key_1*.

To formalize this Vetter-style systemic account of extrinsic dispositions will require specifying the relationship between an extrinsic disposition and a joint disposition. Taking a cue from Toyoshima & Barton [36], we will employ the "add-part_of relation" (ADP) [4]. This add-parthood relation represents the *add*itive character of dispositions: for example, the solubility of this whole tablet has two add-parts, namely the solubility of the left half of the tablet and the solubility of the right half. Given the simplifying assumption that a system is a mereological sum of objects (refer to Röhl [39] for more

thoughts), an extrinsic disposition can be seen as an add-part of a *joint* disposition, as re_1 and re_3 (or re_2 and re_3) satisfy the three axioms [4] characterizing add-parthood:

- The bearers of re_1 and re_2 (i.e., key_1 and $lock_2$) are (proper) parts of the bearer of re_3 (i.e., the sum of key_1 and $lock_2$).
- If re_3 is realized in a process of key_1 opening $lock_2$, then both re_1 and re_2 are realized in a part of this process (i.e., this very process).
- If re_3 is triggered by a process of key_1 pivoting in $lock_2$, then both re_1 and re_2 are triggered by a part of this process (i.e., this very process).

A central tenet of a systemic theory of extrinsic dispositions is that for every extrinsic disposition x that is borne by an object y, there exist a joint disposition z that is borne by a system composed of x and other objects (w_1, …, w_n) that each bear an extrinsic disposition (v_1, …, v_n), such that x, v_1, …, v_n are all add-parts of z (z is a joint disposition for x, for v_1, …, for v_n). Let SUM be a (n+2)-ary relation such that SUM(x, y_1, …, y_{n+1}) means (where n stands for a natural number that is at least 1): "x is a mereological sum of y_1, …, y_{n+1}". This claim can be formalized as follows (a6), although it may be undefinable in first-order logic owing to the arbitrary length of sequences:

a6 $EXD(x) \land INH(x,y) \rightarrow \exists z,u\ IND(z) \land ADP(x,z) \land INH(z,u) \land$
$$\exists v_1,...,v_n, w_1,...,w_n\ SUM(u, y, w_1, ..., w_n) \land$$
$$\land_{1 \leq i \leq n} (EXD(v_i) \land INH(v_i, w_i) \land ADP(v_i, z))$$

We can illustrate (a6) with a puzzle made of three pieces (say p_1, p_2, and p_3). p_1 has the extrinsic disposition re_{p1} to be joined with p_2 and p_3. By (a6), there is a joint disposition $d_{p1\text{-}3}$ that has re_{p1} as add-part and whose bearer is the sum of p_1, p_2, and p_3. Then, p_2 (or p_3, respectively) has an extrinsic disposition re_{p2} (or re_{p3}, respectively) to be joined with p_1 and p_3 (or p_1 and p_2, respectively) such that re_{p2} and re_{p3} are also add-parts of $d_{p1\text{-}3}$.

To recapitulate briefly, an extrinsic disposition (borne by, say, **b**) has one or more intrinsic dependees (which are intrinsic dispositions of **b**), and is an add-part of a joint disposition, which is intrinsic and inheres in a system that has **b** as part.

4. Discussion: Applying our Dispositional Lens for Realizable Entities

4.1. Functions in BFO

At present, BFO characterizes functions as dispositions of bearers with a specific kind of historical development [40], although controversy exists as to the validity of the dispositional identification of functions [12][41]. In more details, a function is a disposition that its bearer possesses in virtue of its having a certain physical makeup because of how it came into being, either through evolution (when the bearer is a natural biological entity) or intentional design (when the bearer is an artifact).

Our dispositional framework for realizable entities can help to discern two kinds of dispositions that can be intuitively understood as functions, such as:

- the function (disposition) f_1 of this heart to provide blood for human bodies in general, to wit, for any instance of the type *Human body*;
- the function (disposition) f_2 of this heart to provide blood for this particular human body (say, Nancy's body).

Note that f_1 is intrinsic but f_2 is extrinsic because it exists in virtue of Nancy's body; in other words, f_2 exists only with respect to her bodily system. Given our hypothesis that extrinsic dispositions would be outside the BFO category of disposition, the BFO theory of functions can account for f_1, but not for f_2. One possible interpretation is that, because f_2 relies on f_1, functions in BFO can be elucidated as functions that are intrinsic dependees (e.g., f_1) of the kind of realizable entities (e.g., f_2) that might also count informally as functions but that would not be classified as functions by the current version of BFO.

In this way, extrinsic dispositions can be expected to shed light on a general ontology of functions. For example, it will be interesting to use extrinsic dispositions (as they consist in being within some system having their bearers as component) to analyze so-called "causally contribution theories" of functions [42]: roughly, a function is the associated causal role within a system that has the function bearer as component.

4.2. Roles in BFO

We will finally consider roles in BFO, partly because they remain currently largely unexplored, partly because their study will make a practical contribution e.g., to an enhanced representation of social roles in the BFO-compliant Ontology of Medically Related Social Entities (OMRSE) [43]. To expand our dispositional approach to roles, it will be necessary to show how role terms can be well specified in terms of dispositions. Examples of canonical role terms include "student", "president", and "money". Among other things, students are frequently discussed in prior work, as Boella et al. [44] say that they are a "rather simple" example of roles. On closer examination, however, students turn out to be ontologically multifaceted [20]. For one thing, a student is a paradigmatic example of "social roles" [45] and, as Loebe [46] says, their full-fledged analysis will demand a solid theory of social ontology [47], which has been actively researched in formal ontology [48] and lies outside the scope of this paper (see Toyoshima's [20] discussion on deontic and normative aspects of social roles).

Accordingly, we will begin with some non-social role. As a matter of fact, BFO recognizes non-social examples of roles such as "the role of a stone in marking a boundary" ([7], p. 100). In particular, we will focus on the role term "catalyst" in the sense of being a substance that makes a chemical reaction happen faster without being changed itself. One might wonder whether a catalyst should be analyzed as a role in BFO, but it will be illuminating to consider from our dispositional viewpoint why catalysts are a somewhat controversial example of roles.[4] Suppose that this amount of manganese (say m_1) significantly speeds up the process of this amount of hydrogen peroxide (H_2O_2), say hp_2, turning into water (H_2O) and oxygen (O_2). We can also say, based on BFO, that m_1 has a role (say $role_{m1}$) of being a catalyst to be realized in the decomposition of hp_2.

Let us consider $role_{m1}$ from our dispositional point of view. First of all, it will be a natural starting point to ask whether at least some (if not) roles in BFO can be seen as extrinsic dispositions, since roles and extrinsic dispositions are both a subtype of externally grounded realizable entities. An affirmative answer to this question may be supported by preceding work on roles. As Boella et al. [44] say, for instance, Baldoni et al. [49] espouse the view that a role (in its general sense) can be understood in terms of

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[4] One consideration in favor of a role view of catalysts could be provided by Chemical Entities of Biological Interest (ChEBI), a database and ontology of molecular entities focusing on "small" chemical compounds. ChEBI says that a catalyst is a "chemical role": "A role played by the molecular entity or part thereof within a chemical context" (https://www.ebi.ac.uk/chebi/chebiOntology.do?chebiId=CHEBI:35223; last accessed on July 19, 2021).

an aggregate of affordances. To borrow their example, Jack's role of being a user of a printer can be represented with what this printer affords Jack, such as printed text on paper. When combined with Turvey's [33] dispositional account of affordances (see Section 3.3), this affordance-based theory of roles would favor the conception of roles as a subtype of extrinsic dispositions [50]: Jack's user role under discussion would be his effectivity of printer-user that is inextricably linked with the affordance of the printer.

In this direction, we can think of $\mathbf{role_{m1}}$ as an extrinsic disposition to accelerate the decomposition of $\mathbf{hp_2}$ when $\mathbf{m_1}$ meets $\mathbf{hp_2}$. For that matter, Vetter [38] cites this catalyst example in discussing joint dispositions ("joint potentialities" in her terms). Since an extrinsic disposition has some intrinsic dependee (see Section 3.3), it is reasonable to consider the intrinsic disposition (say $\mathbf{d_{m1}}$) of $\mathbf{m_1}$ to catalyze hydrogen peroxide in general, to wit, any instance of the type *Hydrogen Peroxide*. This analysis of $\mathbf{role_{m1}}$ will highlight the importance of the disambiguation of the term "catalyst", for $\mathbf{d_{m1}}$ may well be described as $\mathbf{m_1}$'s realizable entity of being a catalyst for the decomposition of hydrogen peroxide, just as $\mathbf{role_{m1}}$ may be described as $\mathbf{m_1}$'s realizable entity of being a catalyst for $\mathbf{hp_2}$. To put it precisely, our claim is that a catalyst role would be an extrinsic disposition.

We contend that this dispositional understanding of non-social roles (including catalysts) could be generalized to social roles, together with some auxiliary theories (e.g., social ontology). To provide a pointer to future inquiry, consider Alice's social role (say $\mathbf{doctor_A}$) of being a doctor. First of all, assuming that being able to treat a person is a minimal element of being a doctor, Alice would cease to be a doctor when she is entirely incapable of treating a person. This claim can be captured when $\mathbf{doctor_A}$ is analyzed in terms of Alice's intrinsic disposition to treat a person.

Moreover, the current dispositional view of social roles may have the potential to tackle the issue of contexts for social roles. The notion of context is generally reckoned to be germane to roles in the sense that roles would cease to exist when their contexts do [19][20][45]. In particular, as Loebe [46] says, the challenge of considering social roles is partly due to the intricacy of their contexts (e.g., schools for student roles). One possible hypothesis is that, provided that social roles can be dispositionally approached, their contexts would be systems with respect to which associated extrinsic dispositions exist. To illustrate this, consider Alice's role (say $\mathbf{treater_A^B}$) of treating Bob, as it is closely linked with $\mathbf{doctor_A}$. A context for $\mathbf{treater_A^B}$ would be the "Alice & Bob system" which is composed of Alice, Bob, a joint disposition which fully grounds $\mathbf{treater_A^B}$ and also Bob's role (say $\mathbf{treatee_B^A}$) of being a person of Alice's treatment (note the complex ontological nature of a system [39], which is composed, in a sense that we do not analyze here, of independent continuants and realizable entities).

To be sure, there is a non-trivial difference between the Alice & Bob system (which is a context for $\mathbf{treater_A^B}$) and a context for $\mathbf{doctor_A}$, possibly the hospital to which Alice belongs. To fill this gap will require scrutiny of many social roles that are intimately connected with $\mathbf{doctor_A}$: e.g., others doctors, patients, and nurses in Alice's hospitals. It will be also necessary to take into account extrinsic dispositions that shape the social import of $\mathbf{doctor_A}$, such as the disposition (*à la* Donohue [51]) of the hospital committee to sanction Alice when she fails to follow a designated guideline for treatment. In this way, our dispositional framework for realizable entities would form the basis for a full ontological analysis of social roles and their contexts.

Finally, we emphasize the importance of the disambiguation of the term "role" and social role terms (e.g., "student") because, when they are rather difficult to analyze in our dispositional approach to roles in BFO, they may be better interpreted in terms of

other BFO categories than realizable entities. In effect, Arp et al. [7] state: "The term 'role' can (…) be used in a different sense in contexts such as Jane's being the seventh person to fill the role of director of this institute (…). 'Role' in this sense is being used to designate what BFO calls a *generically dependent continuant*" (ibid., pp. 100-101). It is worth registering a possible linkage between roles that are a subtype of generically dependent continuants and Brochhausen et al.'s [52] idea of "socio-legal, generically dependent continuants" which come into existence through declarations and which are concretized in roles in the BFO sense of the term.

5. Conclusion

The principal goal of this paper was to launch a systematic investigation into realizable entities, as they figure in a large variety of domains. To achieve it, we adopted a disposition-centered methodology for considering realizable entities in the BFO upper ontology that is theoretically underwritten by McKitrick's [14] dispositional pluralism. In particular, we examined extrinsic dispositions because they may encompass a wide range of entities, including gender [23][24]. We also discussed functions and roles in BFO through our "dispositional lens" for realizable entities. Those first important steps towards a systemization of realizable entities will need to be completed by future works. For example, further investigation is warranted into our systemic account of extrinsic dispositions, especially into Vetter's [38] "full grounding" relation between dispositions.

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