Dispositions and the Infectious Disease Ontology

Albert GOLDFAIN [a,1], Barry SMITH [b] and Lindsay G. COWELL [c]

[a] *Blue Highway, Syracuse, NY, USA*

[b] *University at Buffalo, Buffalo, NY, USA*

[c] *Duke University Medical Center, Durham, NC, USA*

Abstract. This paper addresses the use of dispositions in the Infectious Disease Ontology (IDO). IDO is an ontology constructed according to the principles of the Open Biomedical Ontology (OBO) Foundry and uses the Basic Formal Ontology (BFO) as an upper ontology. After providing a brief introduction to disposition types in BFO and IDO, we discuss three general techniques for representing combinations of dispositions under the headings *blocking dispositions*, *complementary dispositions*, and *collective dispositions*. Motivating examples for each combination of dispositions is given along with a specific use case in IDO. Description logic restrictions are used to formalize statements relating to these combinations.

Keywords. infectious disease ontology, basic formal ontology, dispositions

1. Introduction: IDO, BFO, and OGMS

The Infectious Disease Ontology (IDO) is designed to provide a consistent terminology, taxonomy, and logical representation for the domain of infectious diseases. IDO consists of a core ontology (henceforth "IDO Core") intended to cover terms common to all infectious diseases (e.g., 'host', 'pathogen', 'infection', 'immunity'), and a suite of extension ontologies for specific diseases (e.g., Influenza, HIV, Malaria). The purpose of the IDO Core is to ensure that the extension ontologies created in its terms are interoperable. IDO Core is designed to be disease- and pathogen-neutral and to represent entities and relations across three dimensions: (1) *biological scale*: gene, cell, organ, organism, population (2) *disciplinary perspective*: clinical, biological, epidemiological, (3) *host, pathogen, and vector organism type*: e.g., human, rat, pig, maize, HIV, influenza, mosquito. Both the IDO Core and its extensions will adhere to the guidelines and best practices of the OBO (Open Biomedical Ontology) Foundry ontologies. As such IDO depends on the Basic Formal Ontology[2] (BFO) as its upper ontology.

[1]Corresponding Author: Albert Goldfain, Blue Highway LLC, 2-212 Center for Science & Technology Syracuse, New York 13244-4100; E-mail: agoldfain@blue-highway.com.

[2]`http://www.ifomis.org/bfo`

A key feature of the infectious disease domain that must be captured in IDO is the nature of the ability and tendency for entities to participate in certain kinds of processes. Thus, BFO dispositions are of central importance to IDO. The philosophical literature is rich with analyses of dispositions, elements of which we believe can be fruitfully applied in developing ontologies that capture relations between biological entities which involve an element of ability or tendency.

This paper is a preliminary step in the formalization of dispositions for IDO. In the next two sections, we describe the treatment of dispositions in BFO and IDO and present a simple conditional analysis of dispositions. We spend the remainder of the paper describing and formalizing different types of relations between dispositions.

2. Dispositions in BFO and IDO

BFO embraces a distinction between categorical properties (e.g., triangularity) and dispositional properties (e.g., fragility). BFO makes this distinction by partitioning specifically dependent continuants (i.e., individual entities that depend for their existence on a specific bearer) into qualities (categorical properties) and realizable entities (including dispositional properties and roles). The relevant BFO definitions (from [3]) are:

> **Quality** $=_{def}$ A specifically dependent continuant that is exhibited if it inheres in an entity or entities at all.
>
> **Realizable Entity** $=_{def}$ A specifically dependent continuant that inheres in independent continuant entities and is not exhibited in full at every time in which it inheres in an entity or group of entities.
>
> **Realization** $=_{def}$ A process in which a realizable entity is exhibited or manifested.

For the present paper, the only realizable entities we will concern ourselves with are dispositions[3], defined in BFO as follows:

> **Disposition** $=_{def}$ A disposition is a realizable entity which is such that, if it ceases to exist, then its bearer is physically changed, and whose realization occurs in virtue of the bearer's physical make-up when this bearer is in some special circumstances.

Unlike roles, dispositions are not optional for the entities that bear them. If an entity has a certain structure in the present, then it has a certain disposition, and if it ceases to have that structure in the future, then it loses that disposition. In other words, a disposition is a realizable entity that is a reflection of the in-built or acquired physical make-up of the independent continuant that is its bearer, and it may be lost because the parts of its bearer have changed in some way. A disposition is thus also known as an internally-grounded realizable entity.

By making both qualities and dispositions first-class entities, BFO implicitly rejects both categorical monism, the view that all properties are categorical, and dispositional monism, the view that all properties are dispositional. We embrace

---

[3] Dispositions are further subdivided into capabilities and functions in BFO; anything said about dispositions in this paper also applies to the subtypes.

the view that a disposition will only inhere in a bearer at a given time in virtue of the qualities of the bearer at that time: every disposition is in need of some categorical base. Collectively, it is certain qualities inhering in parts the entity has (for example molecular structure) which form the physical basis for each given disposition, and we can say that they confer the disposition on the bearer. Reference to both qualities (such as mass and temperature) and dispositions (such as solubility) has explanatory value in scientific theories, and the conferring qualities are a good way to differentiate dispositions from one another. Thus, a change in qualities (in physical structure) may imply a change in, gain, or loss of a disposition. Also, dispositions may be borne without ever being manifested.

As part of its realist orientation, BFO attempts to avoid treatments of modality (necessity, possibility) in terms of special entities such as possible worlds in favor of a focus on objects existing in the present, actual world. Dispositions provide a formal mechanism for taking account of future manifestations (BFO occurrents) in terms of what is true of the underlying independent continuants in the present; roughly, dispositions say how something *is* in terms of *what it has the built-in potential to do or suffer*.

IDO subscribes to a dispositional characterization of disease provided by the Ontology for General Medical Science[4] (OGMS). In OGMS, every disease is a disposition towards pathological processes whose physical basis is a disorder and whose realization is a disease course. Some but not all manifestations of the disease disposition become clinically significant in the sense that they occur with signs and symptoms accessible to the patient or the clinician[1]. IDO inherits these relationships between entities as illustrated in Figure 1:

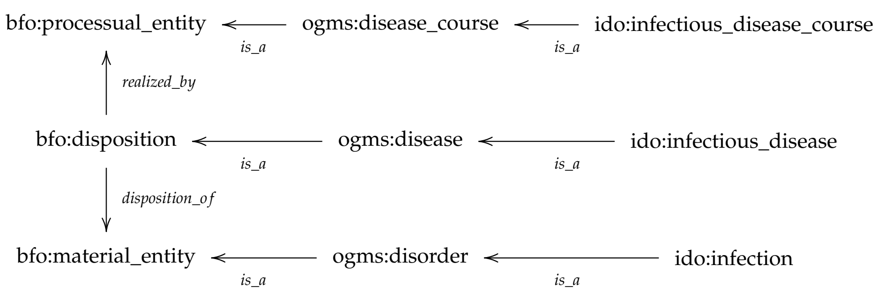

Figure 1. Relations between IDO and OGMS.

The relevant OGMS definitions are as follows:

Disorder $=_{def}$ A disorder is a material entity which is clinically abnormal and part of an extended organism. Disorders are the physical basis of disease.

Disease $=_{def}$ A disposition (i) to undergo pathological processes that (ii) exists in an organism because of one or more disorders in that organism.

Disease Course $=_{def}$ The totality of all processes through which a given disease instance is realized.

[4] http://code.google.com/p/ogms/

And the relevant IDO definitions hanging from these OGMS terms are as follows:

Infection $=_{def}$ A disorder that has as part a clinically abnormal infectious agent colony which causes the elevated risk for pathological processes associated with the disorder.

Infectious Disease $=_{def}$ A disease whose physical basis is an infection.

Infectious Disease Course $=_{def}$ A disease course that is the realization of an infectious disease.

Taking diseases to be dispositions highlights the fact that they can be present without being manifested and that they can be realized in multiple different sorts of manifestations (dependent for example on presence or absence of symptom-suppressant drugs). Resort to dispositions thus allows us to describe what an object *can* do and to have this description still be correct even if relevant realizing processes never take place. This is obviously a great advantage in an area such as immunology, where the object of our study involves structures in the body designed precisely to *prevent* certain categories of processes. Diseases inhere in organisms with disorders, not solely in the disorders, since there may be parts of the organism aside from the disorder that participate in the disease course. For infectious diseases in particular, we do not localize the disease in the disorder since the infection is actually not a part of the diseased organism.

Diseases, like all dispositions, are often detected and understood through the examination of their manifestation. Beyond the infectious disease course, IDO recognizes several subprocesses of host-pathogen interaction, each of which can be seen as the realization of some disposition. A disposition D is only added to IDO Core when D picks out a biologically recognized property and we are able to specify the IDO process type for manifestations of its instances. Even though biological reality may be such as to contain a disposition towards any logical combination of processes, we feel that IDO should only contain those sparse dispositions most relevant to capturing the important dynamics of infectious diseases.

In what follows, the use of IDO dispositions is formalized using description logic restrictions. Ultimately, the full IDO suite of ontologies will require a more expressive logic for comprehensive reasoning[5], but we would like to deploy description logic wherever possible since it is the foundation of the decidable reasoning in OWL DL. Wherever possible, relations from the OBO Relation Ontology (RO) or the proposed extension of this ontology[6] (RO-Proposed) are used in order to avoid the proliferation of new relations and to remain compatible with OBO ontologies. Unless otherwise specified, all relations used in this paper relate universals (types).

The syntax and semantics of the description logic expressions we will use for DL concept descriptions C, D (classes in OWL, universals in BFO), DL role R (property in OWL, type-level OBO relation in BFO), interpretation $\mathcal{I}$, and domain of interpretation $\Delta^{\mathcal{I}}$ are as follows:

[5]Most likely, IDO axioms will need a suitable rule language and second-order logic

[6]`http://www.obofoundry.org/ro/`

Name	Syntax	Semantics
Intersection	$C \sqcap D$	$C \cap D$
Union	$C \sqcup D$	$C \cup D$
Existential Quantification	$\exists \mathbf{R}.C$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b.(a,b) \in \mathbf{R}^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}$
Empty Concept	$C = \bot$	$C = \emptyset$
Concept Inclusion	$C \sqsubseteq D$	$C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
Concept Equality	$C \equiv D$	$C^{\mathcal{I}} = D^{\mathcal{I}}$

Table 1. DL syntax and semantics used in this paper.

3. The Conditional Analysis of Dispositions

A starting point for the logical analysis of dispositions is the simple conditional analysis. Such an analysis attempts to logically explicate the causal link between a stimulus and a manifestation via a subjunctive/counterfactual conditional. Bird presents the simple conditional analysis as follows ([5] p. 24): Let '$D_{(S,M)}$' abbreviate 'x is disposed to manifest M in response to stimulus S, and '$\Box\!\!\rightarrow$' symbolize the subjunctive/counterfactual conditional, so that $Sx \Box\!\!\rightarrow Mx$ if x were S then it would be M. The (simple) conditional analysis of dispositions may then be symbolized:

$$D_{(S,M)}x \leftrightarrow Sx \Box\!\!\rightarrow Mx \tag{1}$$

The simple conditional analysis fails in two ways. In the case of what are called *finkish dispositions*[7], the categorical basis for the disposition is removed after the stimulus Sx is applied, but before manifestation Mx can occur, thus violating the counterfactual. Dispositions frequently take time to manifest after the stimulus is applied, so there is a chance that the disposition may be lost during this time. Bird provides a relevant example: "Some food might become infected with the bacterium Clostridium botulinum and thereby become poisonous. It can lose that disposition [to poison] by cooking or irradiation" [4]. The simple conditional analysis also fails in the case of *antidotes* (or *masks*) to a disposition. In this case the disposition is left intact after the stimulus is applied, but the manifestation fails to occur because of external conditions. Bird puts it as follows: "When an antidote is present an object can have a disposition to M when S yet fail to yield M when given stimulus S, because the conditions that, in conjunction with the disposition's causal basis, would normally bring M about, have been interfered with" [4]. For example, a small forest fire that is contained by firefighters still bears the disposition to burn down the entire forest, but it cannot manifest that disposition because it is contained.

In the philosophical literature on dispositions, it is customary to discuss such background conditions, circumstances, contexts, or laws of nature. Mumford makes an important distinction between two types of background conditions:

> *α-conditions*: being *conditions that prevent the manifestation of a disposition though the disposition itself remains*, for example: lack of oxygen prevents a struck match from lighting though it remains flammable; the lack of a mate prevents a man from breeding though he remains fertile; placing a vase in a sturdy glass prevents it from being broken though it remains fragile.

β-conditions: being *conditions that prevent something from having a disposition*, for example: a match being wet stops it being flammable; a zero or low sperm count stops a male from being fertile; a strengthening process stops a vase from being fragile ([9] p. 86).

These conditions correspond nicely to antidotes and finkish dispositions respectively.

While this machinery is often used only to discredit the simple conditional analysis, it can also be used to describe relationships between dispositions. Background conditions, external circumstances, and laws of nature can all be construed in a dispositional way. Sometimes these dispositions block each other, complement each other, or are manifested in a collective way. We will spend the remainder of the paper examining these dispositional relationships.

4. Blocking Dispositions

Special emphasis must be placed on the fact that what is often preventing the manifestation of a disposition is the manifestation of another disposition. We will call the latter a *blocking disposition*. For example, a particular carnivorous predator with a disposition to eat a particular prey animal blocks predators of the same type from manifesting the same type of disposition (assuming that the particular prey animal is the only one readily available). In general, if D_1 is a disposition and D_2 is a blocking disposition for D_1, then it must be the case that the manifestation of D_2 prevents the manifestation of D_1. A blocking disposition might be understood in different ways:

1. **Incompatible occurrents**: The manifestation of D_1 and the manifestation of D_2 are somehow incompatible occurrents, meaning either that they cannot co-occur or that one negatively regulates[7] the other.
2. **Incompatible qualities**: The manifestation of D_2 results in a continuant's acquring a quality that is incompatible with some quality that the same continuant would have acquired through the manifestation of D_1. That is, we have two qualities that cannot be simultaneously exhibited (e.g., a square circular object).

We utilize reference to blocking dispositions in IDO as a means to describe the general phenomena of protective resistance. By giving resistance a positive characterization, in which we describe what dispositions are actively manifested, descriptions of resistance can play a more explanatory role in explanations and query answering. The current IDO Core definition of protective resistance is as follows:

Protective Resistance$=_{def}$ is a disposition that inheres in a material entity (x) by virtue of the fact that the entity has a part (e.g. a gene product), which itself has a disposition (1) to ensure a physiologic response of a certain degree to an entity of type Y with the capability to damage x, or (2) to prevent the completion of some process caused by an entity of type Y with the capability to damage x. The realization of the

[7]The RO Proposed relation P_1**negatively_regulates**P_2 holds between processes P_1 and P_2 when the unfolding of P_1 decreases the frequency, rate, or extent of P_2.

disposition protects x from or mitigates the damaging effects of Y. The protective resistance disposition is realized in a biological process.

By convention, lowercase variables range over instances and uppercase variables range over types. The prevented process referred to in clause (2) must be critical to how the damaging entity would damage x. For example, there may be several processes caused by an infectious organism that are prevented by the host, but this prevention does not result in resistance because the completion of these processes is not necessary. It is only certain critical processes whose prevention results in resistance.

An example of protective resistance is the resistance of MRSa to the antibiotic methicillin. Without blocking dispositions, we can describe this resistance by noting the lack of affinity to methicillin (a disposition) in the penicillin-binding protein of MRSa (PBP2a): MRSa is resistant to methicillin because one of its parts lacks an affinity for it. As an explanation of *why* MRSa is resistant, however, invoking the lack of affinity to methicillin seems to be begging the question. The same situation can be described in a positive (active) way by considering the disposition of PBP2a to synthesize peptidoglycan (an essential component of the bacterial cell wall) as a blocking disposition for the disposition of methicillin to bind to penicillin-binding proteins.[8] In this way, protective resistance is seen as an active response to methicillin. We discuss at length the benefits of representing such dispositions using an active and positive characterization in [6].

In this situation, we can argue for incompatible occurrents: the process of cell wall construction (as a manifestation of the typical disposition of PBP) is incompatible with the process of methicillin binding (which is the manifestation of affinity to methicillin that PBP2a lacks). We could also argue for incompatible qualities: for a particular peptidoglycan molecule, being part of a lattice is incompatible with being bound by methicillin.[9] As a result, the molecular structure of a well-formed bacterial cell wall (i.e., a peptidoglycan lattice) is incompatible with the molecular structure of a compound bound to methicillin.

Cell wall construction is something a bacteria will participate in when no methicillin is present. In order to see this typical cellular process as an active response, we need the machinery of blocking dispositions. Protective resistance to methicillin is exhibited by MRSa in the process of cell wall construction by blocking the disposition of methicillin to bind to PBP.

It is easiest to formulate blocking dispositions in a description logic schema with variables D_1 and D_2 and the RO_Proposed relation **negatively_regulates**

$$D_2\_blocking\_disposition\_of\_D_1 \equiv \exists \mathbf{realized\_by}.(\exists \mathbf{negatively\_regulates}.\exists \mathbf{realizes}.D_1 \sqcap \exists \mathbf{realizes}.D_2) \tag{2}$$

But we may also describe the inability for D_1 and D_2 to co-occur at time T using:

$$\exists \mathbf{realizes}.D_1 \sqcap \exists \mathbf{realizes}.D_2 \sqcap \exists \mathbf{occurs\_at}.T = \bot \tag{3}$$

[8]Note that since we are dealing with the impossibility of co-occurrence, we could also take the disposition to bind PBP as a blocking disposition for the disposition to synthesize peptidoglycan.

[9]This could also be framed as an incompatibility of spatial co-location.

Description logic does not provide schema variables, so each such disposition must be fleshed out in concrete terms by the relevant IDO extension ontologies. In the case of MRSa, for example, the disposition of PBP2a to construct a cell wall is a **blocking_disposition_of** the disposition to bind to methicillin, because constructing a cell wall negatively regulates binding to methicillin in the case of PBP2a. In the case of MSSa (Methicillin-*susceptible* Staph aureus), the disposition of PBP to bind to methicillin is a **blocking_disposition_of** the disposition to construct a cell wall, because binding to methicillin negatively regulates cell wall construction.

Such an analysis is not without its problems. One minor concern is that calling something a blocking disposition may be considered too perspectival, biasing the ontological term towards D_1 being blocked by rather than blocking D_2. A more serious problem is how can we empirically distinguish between something not happening to a specific continuant as the result of (1) an external blocking disposition or (2) as the result of its own internal makeup.

A further worry involves the identity criteria for blocking dispositions. *Storm*-resistant walls on a particular house are most likely also *lemonade*-resistant, but in virtue of the same underlying structure (i.e., categorical properties). So is the particular lemonade resistance inhering in those walls identical to the particular water resistance inhering in those walls? It seems counterintuitive to say so, but if we say these are not identical we open the door to a combinatorial explosion of resistance dispositions. Similarly, penicillin binding protein has an affinity to penicillin (as its name suggests) which is conferred by the same qualities that yield methicillin resistance, but we do not want to say that these forms of resistance are identical because some staph aureus may be susceptible to methicillin but resistant to penicillin. The standard answer to such worries from the realist ontology camp is that terms are included in an ontology in reflection not of what is combinatorially possible but rather of the actual needs of biologists who are describing real biological phenomena. Whether dispositions referred to by such terms are or are not identical will need to be decided on a case-by-case basis, but such a decision is then not in principle more problematic for dispositions than for entities of other sorts.

5. Complementary Dispositions

In addition to blocking each other, dispositions can also manifest in complementary ways. This is most evident with those dispositions that happen to be functions. Man-made tools have certain functions because they were designed for complementary manifestation with the functions of other tools (e.g., the functions of hammers and nails, locks and keys). Biological functions, like artifactual functions, evolve in complementary dependence upon each other (e.g., the functions of sperm and egg cells).

A certain key K has a disposition D_K to unlock a certain lock L, while the lock L has a disposition D_L to be unlocked by K. Both D_K and D_L are manifested in the same process, namely, K's unlocking of L. What underlies these complementary dispositions is the key's disposition to transmit torque when rotated, the lock's disposition to release when unlatched, and a relation between the qualities (i.e., shapes) of the lock and key that confers these dispositions (i.e., the key's fitting the lock). In order to see that D_K and D_L are not the same disposition, we can consider the different ways in which the unlocking process might fail. The key's shape may erode and no longer fit the lock, in which case D_K is lost, but D_L remains. The lock may rust to such a degree that D_L is lost, but D_K remains.

Martin uses the phrase 'reciprocal disposition partners for mutual manifestation' to describe such paired dispositions and advocates the use of such pairs to replace cause and effect in scientific explanation [2]. Bird suggests that dispositions might always come in reciprocal pairs [5]. Under these analyses, there are two distinct dispositions in our example, one inhering in the key and the other inhering in the lock, but they are both manifested in the same process (instance). However, other analyses are possible:

1. **Whole with a Single Disposition**: A mereological whole W which has parts K and L has a single disposition D. For example, if $W = K + L$ (where '+' denotes mereological sum) then we can say W has the disposition to undergo an unlocking process (in virtue of an *intrinsic* quality of W (i.e., the relative shapes of its parts K and L). We do not prefer this analysis because there may be many key copies (and indeed many lock copies) made such that all keys fit all locks. We then would have a generic dependence involving a relative shape quality whose bearer would be very difficult to specify.
2. **Whole with a Collective Disposition**: A mereological whole $W = K + L$ in which K has disposition D_K and L has disposition D_L and the whole has disposition $D = D_K +_d D_L$. Of course, such an account would need to define a mereological sum '$+_d$'for dispositions since parthood between dispositions is less clearly defined than parthood between independent continuants and parthood between occurrents. We will discuss something similar in the next section, but we can think of this account treating D as the total manifestation of D_K and D_L.

The terminology of complementary dispositions is useful in representing symbiotic relationships between organisms. It is used by IDO to describe the properties of interacting hosts and infectious organisms. 'Host', 'pathogen', 'infectious agent[10]', 'mutualist', and 'commensal' are all BFO roles in IDO.

The dispositional relationship between a host and an infectious agent works very much like a lock and key in that the success of a host-pathogen interaction process (e.g., transmission, symbiosis, or colonization) depends on the possession and manifestation of certain dispositions. Two such dispositions are the 'infectious disposition' and the 'capability to play the host role'. The relevant IDO definitions are as follows:

Pathogenic Disposition$=_{def}$ The disposition to initiate processes that result in a disorder.

[10] There are subtle distinctions between the pathogen role and the infectious agent role, but since our primary concern here is dispositions, we will ignore these distinctions for simplicity.

Infectious Disposition $=_{def}$ A pathogenic disposition to be transmitted from one organism to another and to establish a clinically abnormal colony in the second organism.

Capability to Play the Host Role $=_{def}$ A disposition to participate in symbiosis as host with another organism of a certain type.

Infectious Organism Role $=_{def}$ A parasite role borne by an organism in virtue of the fact that it has the infectious disposition towards its partner in symbiosis.

Host Role $=_{def}$ A symbiont role borne by an organism in virtue of the fact that it provides an environment supportive for the survival and reproduction of its partner in symbiosis.

The infectious disposition and the capability to play the host role are complementary dispositions realized during symbiosis. Like the unlocking process above, a symbiosis process may fail if, for example, the host cannot provide enough nutrients for the infectious organism to ensure its survival or because the host is immune.

Description logic does not permit a perspicuous representation of complementary dispositions in terms of the dispositions themselves. In order to capture two dispositions oriented "towards" each other with a potential for mutual manifestation, we must place restrictions on the continuants and occurrents involved. We represent complementary dispositions inhering in continuants C_1 and C_2 whose mutual manifestation process is P using the following restriction on P:

$$P \equiv \exists \mathbf{realizes}.\exists \mathbf{disposition\_of}.C_1 \sqcap \exists \mathbf{realizes}.\exists \mathbf{disposition\_of}.C_2 \tag{4}$$

P is equivalent to the type of process that is the realization of dispositions of both C_1 and C_2. In IDO, this establishes a network-of-restrictions representation for complementary dispositions. For example, a process in which an infectious agent colonizes its host is a realization of complementary dispositions of both the infectious agent and host, such processes are captured in DL for IDO as follows:

$$\begin{aligned} &\mathit{Colonization\_of\_Organism\_Process} \sqsubseteq \\ &\quad \exists \mathbf{realizes}.\exists \mathbf{disposition\_of}.\exists \mathbf{has\_role}.\mathit{Infectious\_Organism} \sqcap \\ &\quad\quad \exists \mathbf{realizes}.\exists \mathbf{disposition\_of}.\exists \mathbf{has\_role}.\mathit{Host} \end{aligned} \tag{5}$$

Both (4) and (5) express necessary, but not sufficient descriptions of complementary dispositions.

It may be asked whether there is a complementary disposition for *every* disposition in an ontology, since every process involving the interaction of two continuants might be viewed from the perspective of either participant. Certainly it seems possible to model any interaction in this way, but for practical reasons, we do not add such an axiom in IDO. Whether we add a complementary disposition in specific cases depends on user needs – if scientists using IDO find it necessary to use a complementary disposition term for annotation, then this term will be added to IDO.

6. Collective Dispositions

A natural generalization of the ideas developed above is to move from a focus on two dispositions towards a consideration of processes involving the collective manifestation of arbitrarily large aggregates of dispositions. Collectives acquire dispositions not possessed by their individual constituents. This is most clearly seen when we consider dispositions as capabilities. A crowd has the collective capability to do the wave in virtue of each individual crowd member's capability to stand at the appropriate time. Two people have the collective capability to lift a w pound weight in virtue of the first person's capability to lift w_1 pounds and the second person's capability to lift w_2 pounds, where $w = w_1 + w_2$. Sometimes collectives are identified by their capabilities. For example, a mob of people is identified by a collective ability (and intent) to do damage. Such collective phenomena involve dispositions inhering in an aggregate of material entities.

BFO makes a three way distinction between material entities: 'fiat object part', 'object', and 'object aggregate', and utilizes the theory of granular partitions to handle issues of truth and reference at different granularities. What counts as an 'object' for a particular investigation is a matter of scale and is usually determined by the perspective of the investigator:

> For a partition to do its work, it needs to have cells large enough to contain the objects that are of interest in the portion of reality which concerns the judging subject, but at the same time these cells must somehow serve to factor out the details which are of no concern. [11] (p. 27)

The same material entity may be considered as an object or an aggregation of (potentially heterogeneous) parts. To reason correctly in a certain context, it is often essential to commit to one or the other perspective. This is evident with the infectious disease domain, where, for example, an infection can be thought of as a unified object in a clinical context, or as a collection of microorganisms in a microbiological context.

To support broad reasoning at different granularities, we either need an ontology of collectives (cf. [12]) or a formulation of which granular partitions are in use. We do not claim that there are a fixed level of granularities or a fixed number of granular partitions:

> Sperm and eggs are both cells, but much of what we have to say about eggs pertains to individual eggs, whereas much more that we have to convey about sperm concern the collective, although we need a mechanism to cross levels of collectivity to speak of a single sperm fertilizing a single egg. Indeed, one of the issues in fertility research is to determine which factors depend on the collective of sperm and the fluids in which they are swimming, and which depend on the individual sperm cells themselves. Hence, we explicitly reject any notion of a fixed set of levels of granularity[10], (p. 336).

Here we will only focus on the differences between dispositions inhering in objects of a certain type and those inhering in aggregates of those types of objects, and the impact of these differences on reasoning. The RO does not have a specific relation for membership in an aggregation, which is a very specific mereological relation, so we will recruit the **proper_part_of** relation for our purposes. The mereology of independent continuants and occurrents is more developed than that of dependent continuants. We hold the view that any parthood relation between dispositions (dependent continuants) must be couched in parthood relations of their bearers (independent continuants) or in parthood relations of their manifestations (occurrents). Each independent continuant may serve a different role in the collective (e.g., a CEO and an assembly line worker are both part of the same collective in different roles), but in IDO we are primarily interested in organism populations of the same type of organism.

The realization of a collective disposition need not involve the realization of the individual dispositions in unison, rather, complex behaviors may be described in terms of complex patterns of realization. Also, we cannot assume that transitivity of parthood implies a compositionality of dispositional properties. A certain population may have a certain collective disposition but may lose that disposition with the addition or removal of members (of the same type) to that population. With these issues in mind, we formulate a definition of collective disposition as follows:

> **Collective Disposition** $=_{def}$ A disposition inhering in an object aggregate *OA* in virtue of the individual dispositions of the constituents of *OA* and that does not itself inhere in any part of *OA* or in any larger aggregate in which *OA* is a part.

The definition purposefully underspecifies the relationship between the individual dispositions. The individual dispositions do not have to complement one another (indeed, they may even block each other) in order for a collective disposition to inhere in the aggregate.

An example of the use of collective dispositions in IDO is the definition of the term 'herd immunity':

> **Herd Immunity** $=_{def}$ A collective disposition that inheres in an organism population by virtue of the fact that a sufficient number of members of the population have immunity to an infectious agent thereby reducing transmission and protecting non-immune members from the infectious agent population.

The organism population in which an instance of herd immunity inheres is determined by its spatiotemporal arrangement. This population is composed of members that are organisms of the same type, X, have the capability to play the host of infectious agent role in symbiosis with an organism that has the infectious disposition relative to X, and are frequent participants in processes that would transmit the infectious agent between members of the population. Herd immunity is an example of a collective disposition that may be lost if more members are added to the population (in roughly the same spatiotemporal region), specifically if non-immune members are added.

In order to represent collective dispositions in description logic, we first need to consider whether a single disposition can cross scales of aggregates. More formally, we need to consider the range of the **disposition_of** relation and the domain of its inverse relation **has_disposition**. Given *X* **has_disposition** *D* we need to decide whether any of *X*'s parts or anything in which *X* is a part can have the same disposition type *D*. Formally,

$$\exists\textbf{has\_disposition}.D \sqcap (\exists\textbf{proper\_part\_of}.X \sqcup \exists\textbf{has\_proper\_part}.X) \stackrel{?}{=} \bot \qquad (6)$$

We favor a view in which the same disposition type can inhere at different levels of granularity, but the same disposition instance cannot. Under this view, no subpopulation S of an organism population P with herd immunity has the *same* herd immunity, and no larger population L in which P is a subpopulation has the *same* herd immunity.

An object aggregate C has collective disposition D if, assuming for all $1 \leq i \leq n$, P_i is part of the process aggregate that realizes D

$$P_i \in \exists \textbf{proper\_part\_of}.\exists \textbf{realizes}.D \tag{7}$$

and there is a member of C with a disposition to manifest each P_i

$$\exists \textbf{proper\_part\_of}.C \sqcap \exists \textbf{has\_disposition}.\exists \textbf{realized\_by}.P_i \neq \bot \tag{8}$$

If both conditions are satisfied then we can describe the constituents of C by:

$$\begin{aligned} \exists \textbf{proper\_part\_of}.C \sqcap (&\exists \textbf{has\_disposition}.\exists \textbf{realized\_by}.P_1 \sqcup \\ &\exists \textbf{has\_disposition}.\exists \textbf{realized\_by}.P_2 \sqcup \\ &\vdots \\ &\sqcup \exists \textbf{has\_disposition}.\exists \textbf{realized\_by}.P_n) \end{aligned} \tag{9}$$

This restriction lets us reason over the parts of the aggregate that bears the collective disposition.

7. Conclusion

We have discussed the various ways in which individual dispositions interact in their mutual realization and provided examples of how this characterization is used within IDO. Any ontology of infectious diseases must provide the basis for data integration and reasoning across organism types, disciplines, and scales, and these three dimensions play a central role in our characterization of dispositions. In particular, blocking dispositions and complementary dispositions are used to represent the relationships between the organisms bearing the roles (e.g. host, pathogen, vector) needed to perpetuate a chain of infection. Collective dispositions are used to relate dispositions and their realizations observed at the level of populations to dispositions and their realizations observed at the level of individuals, something of importance in the clinical and biological domains, but of particular importance for connecting entities in these domains to epidemiological entities.

Independent continuants may appear not to interact at all (or only to interact to a small degree) because their constituent parts are in a state of dynamic equilibrium. Dynamic equilibria are pervasive in biomedicine and involve many pairwise blocking and pairwise complementary dispositions being realized simultaneously at a smaller scale than the scale of observation. The disposition relationships presented in this paper may be used to further study dynamic equilibria from an ontological perspective.

While the present work is an initial step in formalizing dispositional interactions for IDO, it is still somewhat fragmented. At present, OWL-DL restrictions are being constructed for the textual definitions presented in this paper. Further work is required to express all such restrictions and axioms in a single representational framework. We believe such a framework must include expressive higher-order logics to enable sufficiently powerful reasoning in the infectious disease domain.

Acknowledgements

This work was funded by the National Institutes of Health through Grant R01 AI 77706-01. Smith's contributions were also funded through the NIH Roadmap for Medical Research, Grant 1 U 54 HG004028 (National Center for Biomedical Ontology). Cowell's contributions were also funded by a Burroughs Wellcome Fund Career Award at the Scientific Interface. We would like to acknowledge the useful feedback from three anonymous reviewers.

References

[1] R. Scheuermann, W. Ceusters, and B. Smith, Toward an Ontological Treatment of Disease and Diagnosis, *Proceedings of the 2009 AMIA Summit on Translational Bioinformatics* (2009), 116–120.

[2] D. Armstrong, C. Martin, and U. Place, *Dispositions: A Debate*, Routledge, London 1995.

[3] R. Arp and B. Smith, Function, Role, and Disposition in Basic Formal Ontology, *Proceedings of Bio-Ontologies Workshop (ISMB2008)*, 45–48.

[4] A. Bird, Antidotes All the Way Down?, *Theoria* **19** (2004), 259–269.

[5] A. Bird, *Nature's Metaphysics: Laws and Properties*, Clarendon Press, Oxford, 2007.

[6] A. Goldfain, L. Cowell, and B. Smith, Towards and Ontological Representation of Resistance: The Case of MRSa, *Proceedings of the First International Conference on Biomedical Ontology* (2009), 61–64.

[7] C. B. Martin, Dispositions and Conditionals, *The Philosophical Quarterly* **44**(1994), 1–8.

[8] G. Molnar, *Powers: A Study in Metaphysics*, Oxford University Press, Oxford, 2003.

[9] S. Mumford, *Dispositions*, Oxford University Press, Oxford, 1998.

[10] A. Rector, J. Rogers, and T. Bittner, Granularity, Scale, and Collectivity: When Size Does and Does Not Matter, *Journal of Biomedical Informatics* **39** (2006), 333–349.

[11] B. Smith and B. Brogaard, A Unified Theory of Truth and Reference, *Logique et Analyse* **43** (2003), 49–93.

[12] Z. Wood and A. Galton, A New Classification of Collectives, *Formal Ontology in Information Systems: Proceedings of the Fifth International Conference* (2008).