Semantics Matters: A New Light on Ontological Commitments of Logics

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Abstract

It is a central foundational theme to specify ontological commitments that are implicitly embedded in formal logic. In this paper, we address a largely unexplored topic of ontological commitments of the semantics of logic. In particular, we focus on the idea of "modal logic without possible worlds" in contradistinction with the widespread usage of the possible-world semantics in formal ontology. More concretely, we present B. Vetter's potentiality-based theory of possibility and discuss how to develop a modal semantics that would accord with the modal primacy of dispositions in the upper ontology Basic Formal Ontology (BFO).

Keywords

semantics, ontological commitment, modal logic, possible-world semantics, potentiality, disposition, Basic Formal Ontology (BFO)

1. Introduction

Logical representation languages are of paramount importance for formal ontologies. Gruber [1] famously defines an ontology in computer science as "an explicit specification of [a shared] conceptualization". Being inspired by this definition, Guarino [2] propounds the view (which is formally furthered later [3]) that an ontology is a "logical theory accounting for the intended meaning of a formal vocabulary". Ontologies are so inextricably linked with logics that, according to Garbacz & Trupuz [4], language description can count as a desideratum for the identity of ontologies. By this criterion, for instance, the first-order logical version of the upper ontology Basic Formal Ontology (BFO) [5, 6] is *different* from the Web Ontology Language (OWL) version of BFO, although they may be intuitively said to be "(conceptually) the same".

Relatedly, it has been a prevailing orthodoxy, notably since Guarino [2], that the design and usage of a given logic for ontologies requires an accurate understanding of "ontological commitments" [7] of the logic (roughly, what exists according to the logical system), as they are often implicitly embedded in the logic [3, 8]. To take one example, Smith [9] argues against what he calls 'fantology': the kind of ontologies that reflect naively the syntactic surface of first-order (predicate) logic which is paradigmatically expressed by the formula 'Fa'. He finds problematic the fantologist's excessively reductive ontological commitment

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solely to (universal-level) properties ('F') and so-called "bare particulars" ('a'), as they function merely as predications and names, respectively. Smith instead proposes a neo-Aristotelian "six-category ontology" which is characterized by the dichotomy between universals and particulars as well as the trichotomy among substantials (objects), qualities (properties in their general sense), and processes (occurrents, perdurants). This proposal can be seen as an extension of Löwe's [10] "four-category ontology" consisting of the universal/particular dichotomy and the substantial/quality dichotomy. As Guarino [11] and Borgo & Hitzler [12] observe, many existing upper ontologies (such as BFO) are more or less built upon this four-category framework, or even presumably upon the six-category one.

The subject of ontological commitments of logics nonetheless remains relatively uninvestigated (see Borgo & Hitzler's [12] general overview). For instance, first-order logic is usually taken to be a default option for formalizing ontologies, as is indicated by the fact that it is embraced by (formalization of) the Guarino-style logical conception of ontologies [2, 3]. Far from being problematic, the usage of first-order logic is indeed useful for articulating the kind of ontological commitments that would otherwise go unnoticed e.g. in the OWL (which is widely employed in the Semantic Web). For that matter, a moral from Smith's [9] challenge to fantology is the "correct" use (rather than the abandonment) of first-order logic in ontologies.

However, many cases of ontology development rely almost exclusively on (modal) first-order logic or the OWL and logics in ontologies have been recently discussed against this background. Barlaiter & Dapoigny [13] elaborate a type-theoretical approach for ontologies that is expressive enough to represent roles (e.g. students) as "dependent types". Borgo et al. [14] suggest that other logics should be pursued in order to ameliorate ontological modeling (e.g. to reduce redundant ontological commitments) with an illustrative example of the application of linear logic [15] to axiomatization of existing definitions of technical artifacts (e.g. screwdrivers). Fillottrani & Keet [16] analyze ontological commitments engrained in ontology languages, including first-order logic and OWL2 DL.

In this paper, we highlight a hitherto largely unexplored topic of ontological commitments of the *semantics* of logic. A logical system is generally characterized by its syntax (language), proof system (theory), and semantics (model). By and large, prior work revolves around ontological commitments of the syntax of logic, as is illustrated by Smith's [9] criticism of fantology. Borgo et al. [14] focus mainly on logical *operators* while presenting Kripke resource frames for linear logic: roughly, a resource-sensitive version of "Kripke frames" (to be explained below). Fillottrani & Keet [16] only touch upon the semantics of logics for ontologies, for example, by pointing out that the semantics of first-order logic and OWL2 DL are both model-theoretic.

A noteworthy exception is Loebe & Herre's [17] development of what they call 'ontological semantics': the kind of model-theoretic semantics that is directly and purely based on ontological entities. To illustrate it, they sketch out an ontological semantics for the syntax of first-order logic. Their motivation is indeed close to ours, but their idea of ontological semantics may be relatively general because it does not constrain *which* ontological entity underpins a given ontological semantics. This is shown by their definition of "ontological structures", by which they mean interpretation structures of ontological semantics:

> **Definition** An ontological structure $\mathcal{O}$ can be described as $\mathcal{O} = (O, c_1, c_2, ...)$ where O is an arbitrary entity and the c_i are entities associated with O.

By contrast, we will consider more specific ontological commitments of the semantics of logic. For this purpose, we focus on ontological commitments of the possible-world semantics of modal logic and motivate the idea of "modal logic without possible worlds" in the context of formal ontology with the example of the modal primacy of dispositions in BFO (Section 2). Next, we present Vetter's [18] potentiality-based theory of possibility and provide its simplified but formally more rigorous reconstruction (Section 3). Then, we discuss how to build a modal semantics that would be underpinned by the BFO ontology of dispositions (Section 4). Finally, we conclude the paper with some brief remarks on future work (Section 5).

2. Modal logic and its Ontological Commitments

2.1. Modal logic and the Possible-World Semantics in Ontologies

We begin by considering the usage of modal logic in ontologies. Modal logic is a family of logical systems for such expressions as "It is necessary that ϕ" ('$\Box\phi$') and "It is possible that ϕ" ('$\Diamond\phi$'). We will sacrifice the use-mention markers at the altar of readability. According to the *possible-world semantics*, such claims about necessity and possibility are to be intuitively understood in terms of possible worlds as follows (note that "iff" stands for "if and only if"):

> $\Box\phi$ is true iff ϕ is true in every accessible possible world.
> $\Diamond\phi$ is true iff ϕ is true in at least one accessible possible world.

To put it formally, a *Kripke frame* $\mathcal{F} = \langle \mathcal{W}, \mathcal{R} \rangle$ is a pair consisting of a non-empty set $\mathcal{W}$ ("possible worlds") and a binary relation $\mathcal{R}$ over $\mathcal{W}$ ("accessibility relation"). A *Kripke model* $\mathcal{M} = \langle \mathcal{F}, \mathcal{I} \rangle$ consists of a Kripke frame $\mathcal{F}$ and an interpretation function $\mathcal{I}$ that assigns truth values (1 or 0) to each atomic sentence relative to each world in $\mathcal{W}$. Then we can define the valuation $\mathcal{V}_\mathcal{M}$ of $\Box\phi$ (resp. $\Diamond\phi$) for a model $\mathcal{M} = \langle \mathcal{W}, \mathcal{R}, \mathcal{I} \rangle$ with respect to a world $w \in \mathcal{W}$ as follows:

> $\mathcal{V}_\mathcal{M}(\Box\phi, w) = 1$ iff for each $v \in \mathcal{W}$, if $\mathcal{R}wv$, then $\mathcal{V}_\mathcal{M}(\phi, v) = 1$
> $\mathcal{V}_\mathcal{M}(\Diamond\phi, w) = 1$ iff there is some $v \in \mathcal{W}$ such that $\mathcal{R}wv$ and $\mathcal{V}_\mathcal{M}(\phi, v) = 1$

Different formal conditions on an accessibility relation $\mathcal{R}$ will determine the truth conditions of different modal axioms. The next table shows some well-known modal axioms and their corresponding accessibility conditions:

Modal axiom	Accessibility $\mathcal{R}$ is	Conditions on Frame $\mathcal{F}$
(K) $\Box(\phi \to \psi) \to (\Box\phi \to \Box\psi)$	(no requirement)	(no requirement)
(T) $\Box\phi \to \phi$	reflexive	$\mathcal{R}ww$
(B) $\phi \to \Box\Diamond\phi$	symmetric	$\mathcal{R}wv \Rightarrow \mathcal{R}vw$
(4) $\Box\phi \to \Box\Box\phi$	transitive	$(\mathcal{R}wv$ and $\mathcal{R}vu) \Rightarrow \mathcal{R}wu$
(5) $\Diamond\phi \to \Box\Diamond\phi$	Eucledian	$(\mathcal{R}wv$ and $\mathcal{R}wu) \Rightarrow \mathcal{R}vu$

As Borgo et al. [14] say, modal logic is an exceptional use case of non-classical logics in ontologies (as compared to OWL languages, which can be thought to be classical, as they are

roughly decidable fragments of first-order logic). Furthermore, many modal formulations of ontologies are based on the so-called system S5: the logical system that has the Kripke model where the accessibility relation $\mathcal{R}$ is an equivalence relation (i.e. reflexive, symmetric, and transitive). Examples include the S5 formalization [19] of the notion of rigidity in the OntoClean [20] methodology, Bittner's [21] two-dimensional S5 formulation of physical possibilities in classical physics, and the S5 axiomatizations of such upper ontologies as the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [22] and the Unified Foundational Ontology (UFO) [23, 24, 25].[1]

Let us now turn to the issue of ontological commitments in modal logic, especially those of the possible-world semantics. To be sure, the possible-world semantics is a convenient formal tool and its usage does not *ipso facto* entail any ontological commitment to possible worlds (whether concrete [26] or abstract [27, 28]). However, it would be as natural to problematize ontological commitments of the semantics of logic, just as those of the logical syntax (which we discussed in Section 1). In the present case study, that is to say, we should not read off an ontology of possible worlds naively from the possible-world semantics. As a matter of fact, aforesaid modally formalized ontologies seem to be neutral on the nature of possible worlds, as they do not endorse a specific theory of them. At the same time, the question can arise as to what is an ontological underpinning of the possible-world semantics. For instance, the modal formalizations of DOLCE [22] and UFO [23, 24, 25] subscribe to the possibilist account of modality, whereby there are merely possible individuals ("possibilia") in other possible worlds than our actual one, as is often illustrated by Lewis's [26] example of talking donkeys. It is not clear what possibilia are supposed to mean in these ontologies, if we do not take seriously possible worlds.

Another issue can be raised concerning the widespread usage of the system S5 in ontologies. To consider this point, it would be useful to understand varieties of modality [29]:

- Logical modality: "*Necessarily*, $2 + 2 = 4$."
- Metaphysical modality: "I *could* not have been born of different parents."
- Nomic modality (aka nomological/physical modality): "Nothing *can* travel faster than light."
- Dynamic modality (aka circumstantial modality): "I *can* swim because the pool is there."
- Deontic modality: "You *must* wash your hands before lunch."
- Epistemic modality: "He *must* be the real murderer."

Quite importantly, the system S5 is generally reckoned to be a congruous formal system for representing metaphysical modality. It would be therefore reasonable to think that existing modalized ontologies tend to embrace the system S5 because of their primary interest in

[1] To be more precise, the S5 formalizations of rigidity [20] and DOLCE [22] are also committed to the Barcan formula ($\forall x \Box \phi(x) \rightarrow \Box \forall x \phi(x)$); and those of Bittner's ontology [21] and UFO [23, 24, 25] are to the converse Barcan formula ($\Box \forall x \phi(x) \rightarrow \forall x \Box \phi(x)$) as well as the Barcan formula.

metaphysical modality, as is witnessed by the fact that the UFO [23, 24, 25] modal formalization explicitly refers to alethic modality (roughly, logical and metaphysical modalities).

However, it is controversial whether the system S5 is *the* correct logic of metaphysical modality. For instance, the system S5 validates the axioms (B), (4), and (5); but they are questioned with respect to metaphysical modality by Dummett [30], Salmon [31], and Wedgwood [32], respectively. Moreover, it is not obvious whether the system S5 is the most suitable choice for ontologies in many contexts, as other non-metaphysical kinds of modality (e.g. nomic modality) may be sometimes a main focus of ontologies. It might be thus worth exploring other weaker systems than S5 in modal formalizations of ontologies.

2.2. Modal Logic without Possible Worlds: A Motivating Example of the Modal Primacy of Dispositions in BFO

We have brought for discussion the subject of ontological commitments of the semantics of logic, above all of the possible-world semantics of modal logic. One may be still skeptical of the value of careful consideration of the ontological significance of the possible-world semantics (see also Loebe & Herre's [17] discussion on what they call 'motivating problems' with their idea of ontological semantics). For one thing, being detached from logical semantics, the notion of possible worlds (often together with Lewis's [33] accompanying idea of "counterparts") is highly helpful for ontological modeling (e.g. of properties [34] and spatial information [35]) and possible worlds may be construed epistemically as information systems or contexts/situations. It may be a pragmatic decision to utilize the possible-world semantics with no serious engagement in its ontological import.

To motivate the current inquiry, let us consider the BFO ontological category of dispositions. A disposition is a property that is associated with a realization, namely to a specific *possible* behavior of the bearer of the disposition such that the disposition exists in virtue of certain features of the physical makeup of the disposition bearer [36, 37]. To take a canonical example, the fragility of this glass is the disposition to be realized in the glass being broken when the glass is pressed with a certain degree of force; and this fragility exists in virtue of some specific molecular structure of the glass. Note that BFO adopts a realist methodology for ontology development according to which ontologies should represent what exists in (scientific) reality [38]; and dispositions have a modal nature: they *can* realize themselves in some associated circumstances.

We focus on the following explanation of the BFO category of dispositions:

> Incorporation of dispositions into the BFO ontology provides a means to deal with those aspects of reality that involve possibility or potentiality without the need for complicated appeals to modal logics or possible worlds. [5, p. 102]

How should we understand this statement? First of all, it is questionable whether and how an ontology of dispositions can help BFO to dispense with modal logic. Logic is supposed to explicate implicit characteristics of (conceptualization of) reality in formal ontologies. Granted that modality is a key component of reality (and thus deflationism about modality is off the table), modal logic can be plausibly taken to be an appropriate language for specifying more

fully the BFO ontology, which is presently available only in classical logics such as first-order logic and the OWL, to the best of our knowledge.

The excerpt under discussion can be arguably better understood in terms of ontological commitments of the semantics of logic. That is, even if BFO is formalized with the possible-world semantics, it is an ontology of dispositions, but not of possible worlds, that serves, as it were, as the main source of modality within the BFO framework. Then, we encounter a variant of the thorny problem that we specified in Section 2.1: how to find a dispositional underpinning of the possible-world semantics. More concretely: what is a dispositional interpretation of a non-empty set $\mathcal{W}$ of "possible worlds" and an "accessibility relation" $\mathcal{R}$ over $\mathcal{W}$ in a Kripke frame? This question may be too difficult to answer, at least momentarily.

However, we could work around this conundrum by adopting another approach to the connection between logic and ontologies. To enhance practical knowledge formalism, Guarino [8] proposes to develop formal languages whose constructs are ontologically "non-neutral". As Borgo & Hitzler [12] say, his idea is to have ontological commitments built directly into the language so that the user does not need to code the ontological assumptions of the representation constructs. If we apply this strategy to the level of semantics and reinterpret the issue of a dispositional grounding of the possible-world semantics, our focal point will be an alternative semantics to the possible-world one which would have a built-in BFO ontology of dispositions.

3. B. Vetter's Potentiality-Based Theory of Possibility

We are now interested in a "dispositionally modal semantics" with no ontological commitment to possible worlds which can be imported into the BFO ontology. In point of fact, the conception of "modal semantics without possible worlds" has been explored before in philosophical logic, although it may not be mainstream there. For instance, Kearns [39] develops a four-value and non-deterministic hierarchic semantics for such normal logical systems as S5 (which is furthered with more general results [40]). While his proposal aims for general ontological neutrality, we will consider a modal semantics that is rooted in a dispositional theory of modality [41, 42] according to which, roughly, a state of affairs (e.g. of this glass being broken) is possible just in case there is some disposition with a primitive modal profile (e.g. the fragility of the glass) the realization of which is (or included in) that state of affairs.

There are several preceding works on dispositionally modal semantics (see Warmke's [43] general overview): for example, Jacob's [44] proposal to define modality in terms of counterfactuals, which are in turn defined in terms of dispositions (or "powers" in his terminology) (but see Warmke's [43] criticism). In the interest of space, we will focus on Vetter's [18] framework for modality that is based on her ontology of *potentialities* (which she distinguishes from dispositions, as we will explain below), because it is arguably one of the most well-developed dispositional (in its broad sense) accounts of modality.

3.1. Conceptual Framework

Let us adumbrate the conceptual core of Vetter's [18] potentiality-based theory of modality. She begins by thinking that the ordinary conception of dispositions may be ill-suited for ensuring a whole range of modal truths. As we said, for instance, the modal proposition "Possibly, this glass

breaks" can be made true in virtue of the fragility of the glass such that this disposition *can* be realized in the glass being broken. Consider however the fact that a (new) steel bridge can also break e.g. owing to a huge explosion. Since we usually do not ascribe fragility to this bridge, the truth of the modal proposition "Possibly, this steel bridge breaks" would be inexplicable in terms of dispositions of the bridge (refer to Wang [45] for detailed discussion).

This observation motivates Vetter to elaborate her notion of *potentiality* which undergirds the modality of dispositions. According to her analogical explanation, potentiality is to disposition what height is to tallness, in spite of the fact that, being a theoretical posit, potentiality is intuitively harder to grasp than height. Tallness admits of degrees and to be qualify as tall (in a context), a person needs to have a sufficiently great height (in that context). Similarly, dispositions are gradable and to have some disposition (in a context), an object needs to possess the relevant potentiality to a sufficiently high degree (in that context). Going back to the example of fragility, both modal propositions "Possibly, this glass breaks" and "Possibly, this steel bridge breaks" can be made true in virtue of the fact that both the glass and the bridge have some potentiality that is relevant to fragility (disposition), albeit to a differing degree.

To generalize, one of the basic tenets of Vetter's potentiality approach to modality, *inter alia* to possibility, is that: "It is possible that p just in case something has a potentiality for it to be the case that p" [18, p. 103]. However, several important tweaks are to be added for this characterization to be a full-fledged account of metaphysical modality. Consider the following modal truths (which are extracted from her discussion):

(A) It is possible that Hannah and Jane together play a duet for flute and piano.

(B) It is possible that my granddaughter is a painter (assuming that I presently have no granddaughter).

Since neither Hannah nor Jane can play a duet on her own, the explanation of the modal truth (A) requires introducing *joint potentialities*: potentialities possessed by several objects together. As a result, the modal truth (A) is grounded in the joint potentiality of Hannah and Jane to play a duet. Moreover, in Vetter's view, joint potentialities ground *extrinsic potentialities*, and *vice versa*. That is to say, an object has a joint potentiality together with other objects if and only if the object has some extrinsic potentiality: a potentiality that the object would lose with the change of such external objects. To illustrate this point, Hannah has an extrinsic potentiality to play the flute for the duet with Jane.

In contrast, the modal truth (B) may be more problematic for the potentiality account of possibility, for my granddaughter does not exist at present or even in no way exists. Such cases can be accommodated by recourse to *iterated potentialities*. Then, the modal truth (B) is grounded in my potentiality to have a child who has the potentiality to have a daughter who has the potentiality to be a painter. To use Vetter's expression, I serve as a "witness" for the possibility of my granddaughter being a painter. Given these three varieties of potentialities (joint, extrinsic, and iterated), Vetter provides the following potentiality-based definition of possibility:

> POSSIBILITY: It is possible that $p =_{df}$ Something has a (...) potentiality for it to be the case p. [18, p. 247]

3.2. Formal Framework

Here we shall give a somewhat simplified account of Vetter's formal semantics described in [18, Appendix]. In comparison to the formulation below, the original semantics includes plural terms and has a more relaxed (informal) account of truth. We shall see that ours is a sound specification of the original formalisation.

The system **P** of Vetter uses an enhanced first-order language $\mathcal{L}$. For each variable x and a sentence $\phi[x/c]$, we include $\lambda x.\phi$ ("x is such that ϕ": a device to turn a formula into a predicate) as a unary predicate. Furthermore, for each unary predicate Φ, we include $POT[\Phi]$ ("potentially Φ") as another unary predicate. The primitive connectives of $\mathcal{L}$ are $\{\neg, \wedge, \vee, \rightarrow, \equiv\}$, and the first-order quantifiers are $\{\forall, \exists\}$.

Then the notion of a model is introduced by first defining a larger class of *pre-models*.

Definition 1. A *pre-model* is a triple $\langle \mathcal{D}, v, I \rangle$ where $\mathcal{D}$ is a non-empty domain, and v is an interpretation such that:

- it assigns to each constant a an element $v(a) \in \mathcal{D}$.
- it assigns to each n-place predicate Φ an n-ary relation $v(\Phi)$.

Let $\mathcal{L}(\mathcal{D})$ be the language extended with constants $\bar{d}$ for each $d \in \mathcal{D}$, such that $v(\bar{d}) = d$. Then I is a mapping that assigns a value $I(\phi) \in \{0, 1\}$ for each sentence ϕ of $\mathcal{L}(\mathcal{D})$, according to the following conditions.

- $I(\Phi(t_1, \ldots t_n)) = 1$ iff $\langle v(t_1), \ldots, v(t_n) \rangle \in v(\Phi)$.
- $I(\neg\phi) = 1$ iff $I(\phi) = 0$.
- $I(\phi \wedge \psi) = 1$ iff $I(\phi) = 1$ and $I(\psi) = 1$.
- $I(\phi \vee \psi) = 1$ iff $I(\phi) = 1$ or $I(\psi) = 1$.
- $I(\phi \rightarrow \psi) = 1$ iff $I(\phi) = 0$ or $I(\psi) = 1$.
- $I(\phi \equiv \psi) = 1$ iff $I(\phi) = I(\psi)$.
- $I(\forall x\phi) = 1$ iff $I(\phi[x/\bar{d}]) = 1$ for all $d \in \mathcal{D}$.
- $I(\exists x\phi) = 1$ iff $I(\phi[x/\bar{d}]) = 1$ for some $d \in \mathcal{D}$.

Next, we pick out from the class of pre-models the ones that satisfy some desirable properties required by Vetter. A pre-model is a *model* if I further satisfies the following conditions.

- $I((\lambda x.\phi)(t)) = 1$ iff $I(\phi(t)) = 1$.
- If $I(\Phi(t) \equiv \Psi(t)) = 1$ then $I((POT[\Phi](t) \equiv POT[\Psi](t)) = 1$.
- $I(POT[\lambda x.\phi \vee \psi](t)) = 1$ iff $I(POT[\lambda x.\phi](t) \vee POT[\lambda x.\psi](t)) = 1$.
- If $I(\Phi(t)) = 1$ then $I(POT[\Phi](t)) = 1$.

- $I(POT[\lambda x.\phi \wedge \neg\phi](t)) = 0$.

We write $\models A$ if $I(A) = 1$ for any model $\langle \mathcal{D}, v, I\rangle$. It is then straightforward to check that the conditions for λ and potentiality given for **P** in [18, p. 306] are satisfied in our formulation as well. Hence our semantics validates the principles required for the original semantics to define modality. We therefore claim that it is a sound specification of Vetter's account.

As a preliminary notion for possibility, an operator stating 'something has a potentiality to be such that ϕ' (where this potentiality can be extrinsic or joint) is implemented in **P** by the following.

$$\Diamond\phi := \exists y POT[\lambda x.\phi](y).$$

Note however that this original formulation can be problematic.[2] Given a predicate of the form $\phi(x, y)$, the formula $\Diamond\Phi$ is ambiguous because it is unclear whether the relevant potentiality is $POT[\lambda x.\phi(x, y)]$ or $POT[\lambda y.\phi(x, y)]$. If the above formulation is in fact defective, then one possible solution would be to restrict the number of occurrence of free variables in ϕ to ≤ 1.

For a notion of modality adequate for metaphysical possibility, we need some further machinery. Let us define $\Diamond^0\phi = \phi$ and $\Diamond^{n+1}\phi = \Diamond(\Diamond^n\phi)$. Then we introduce a new operator $\Diamond^*$, such that we have the following additional clause for the sentences of the form $\Diamond^*\phi$.

- $I(\Diamond^*\phi) = 1$ iff $I(\Diamond^n\phi) = 1$ for some $n \in \mathbb{N}$.

We can see this as the formal counterpart of the iterated potentiality discussed in Section 3.1 (e.g. my potentiality to have a child who has the potentiality to have a daughter who has the potentiality to be a painter). Finally, the desired notion of necessity is defined in a classical manner, namely $\Box\phi := \neg\Diamond^*\neg\phi$.

3.3. Ontological commitments of Vetter's potentiality semantics

We make some brief remarks on Vetter's "potentiality semantics" as compared to the possible-world one in respect of ontological commitments. First and foremost, the potentiality semantics strives to steer clear of an ontology of possible worlds. In the system **P**, the "iterative possibility operator" $\Diamond^*$ is defined in terms of the "non-iterative possibility operator" $\Diamond$, which is in turn defined in terms of the "potentiality (unary) predicate" $POT[\Phi]$. This stands in marked contrast with the definition of the possibility operator by means of the accessibility relation between possible worlds (see Section 2.1). Relatedly, the potentiality semantics would espouse the ontological priority of possibility over necessity, as the necessity operator is defined in terms of the (iterative) possibility operator ($\Box\phi := \neg\Diamond^*\neg\phi$), but not *vice versa*. In the possible-world semantics, by contrast, it may be sometimes taken to be conventional whether the necessity operator defines the possibility one ($\Diamond\phi := \neg\Box\neg\phi$) or the other way around ($\Box\phi := \neg\Diamond\neg\phi$).

[2] There is another possibly odd feature in the system. $POT[\lambda x.\phi \rightarrow \phi](a)$ and $POT[\lambda x.\neg(\phi \rightarrow \phi)](a)$ are (by the first condition of a model) equivalent to $\phi \rightarrow \phi$ and $\neg(\phi \rightarrow \phi)$, respectively. Hence $(POT[\Phi](a) \equiv POT[\lambda x.\phi \rightarrow \phi](a)) \vee (POT[\Phi](a) \equiv POT[\lambda x.\neg(\phi \rightarrow \phi)](a))$ follows from an instance of the law of excluded middle $(POT[\Phi](a) \vee \neg POT[\Phi](a))$, for general Φ; this may be counterintuitive as a relation between potentialities.

4. Discussion: Towards a Dispositionally Modal Semantics for BFO

Our investigation is motivated by a modal semantics that would dovetail with the modal primacy of dispositions in BFO without recourse to possible worlds (see Section 2.2). In this section, we will discuss how to develop such a "dispositionally modal semantics" for BFO in terms of Vetter's [18] potentiality-based semantics for metaphysical modality. Moreover, we will consider how a dispositionally modal semantics can cohere with the system S5. For one thing, the integration of BFO with the notion of *rigidity* [20] of property types have been investigated because of its usefulness in BFO [46] and rigidity is formalized in the system S5 [19]. In particular, we will discuss the axioms (T) and (5) of S5 (which were explained in Section 2.1) because they would raise noteworthy foundational issues.

4.1. Potentialities in BFO

First of all, it is necessary to consider where Vetter's notion of potentiality is to be located within the BFO framework that claims to embrace the modal primacy of dispositions. An apparent problem is that Vetter sharply distinguishes potentialities from dispositions. However, potentialities can be dispositionally construed under some auxiliary assumptions. McKitrick [47] develops a pragmatically motivated, very broad conception of dispositions that is useful for characterizing multifarious entities dispositionally, according to which potentialities could be a subtype of dispositions (see Toyoshima et al.'s [48] detailed discussion). Following McKitrick, we can provide a dispositional reformulation of Vetter's potentiality-based theory of metaphysical modality. For instance, iterated potentialities can be understood as "predispositions" [49]: dispositions to acquire further dispositions.

Nonetheless, potentialities may not be restricted only to the BFO category of dispositions, even if they are dispositionally interpreted in McKitrick's manner. Consider for example extrinsic potentialities (in Vetter's terms) or extrinsic dispositions (in McKitrick's terms). 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. Now, BFO describes a disposition as an *internally grounded* realizable entity: if a disposition ceases to exist, then the physical makeup of the disposition bearer is thereby changed. As Toyoshima et al. [48] say, it would be reasonable to think that extrinsic dispositions are not dispositions in BFO because they are not internally grounded. For example, Hannah's extrinsic disposition to play the flute for the duet with Jane can cease to exist even without Hannah's physical changes, e.g. when Jane ceases to exist. This means that, to be modally formalized *à la* Vetter, the BFO thesis of the modal primacy of dispositions would need to be softened in such a way that the term 'disposition' therein refers to dispositions in McKitrick's sense of the term, beyond the BFO category of dispositions.

4.2. Validating the Axiom (T)

Vetter [18] says that her potentiality semantics validates the axiom (T), to be exact, its "potentiality translation": that is, $\models \Box\phi \rightarrow \phi$ or equivalently $\models \phi \rightarrow \Diamond^*\phi$. However, Yates [50] questions the plausibility of this result because it is based on the introduction of problematic kinds of

potentialities. His driving example is the mathematical truth $2+2=4$ and we write $\langle 2+2=4\rangle$ as this true proposition for convenience. From the axiom (T), it follows that $\models \Diamond^*\langle 2+2=4\rangle$. Informally, there is a witness with a potentiality for the possibility that $\langle 2+2=4\rangle$.

The issue here is which entity would serve as such a witness. Vetter's answer is that this potentiality is possessed by anything whatsoever and it is always manifested (where manifestations of potentialities can be understood by analogy with realizations of dispositions). To put it differently, everything has a potentiality to be such that $\langle 2+2=4\rangle$ (note that this non-orthodox expression corresponds to the unary predicate $\lambda x.\Phi$ in Vetter's formal system). Yates argues that this approach is *ad hoc* in the sense of being committed to what he calls a 'plenitude of powers' and Vetter's potentiality-based theory of modality fails to validate the axiom (T), which Vetter (as well as Yates) takes to be a requirement of a logic of metaphysical modality.

Controversy continues as to whether a general dispositional approach to modality (including Vetter's) can validate the axiom (T) [51, 52, 53, 54]. Instead of sifting through this debate, we will briefly consider how Vetter's strategy would be available to a BFO-based dispositionally modal semantics. Consider the example of a potentiality to be such that $\langle 2+2=4\rangle$. Unlike other potentialities that we have seen so far, such potentialities are possessed by anything and always manifested. While it might be safe to postulate dispositions possessed by anything, these potentialities would be better characterized in terms of the BFO category of *qualities* than of realizable entities (including dispositions), because they are *always* manifested and would fit well with the BFO conception of qualities (e.g. shape, mass, and color): "if [a quality] inheres in an entity at all, [it] is fully exhibited, manifested, or realized in that entity" [5, p. 183].

This can raise an interesting question about qualities, realizable entities, and their relationship from a modal point of view. As was shown in Section 4.1, potentialities would correspond to a wide range of realizable entities, including dispositions in BFO. Discussion on the validity of the axiom (T) would imply that the notion of potentiality could also apply to some qualities, beyond realizable entities. At the same time, the modal feature of qualities would not be as salient as that of realizable entities. This will motivate us to consider carefully the distinction between qualities and realizable entities, especially from a modal perspective. This topic can be further linked with the general ontological distinction between categorical and dispositional properties (cf. [47]). In short, the building of a dispositionally modal semantics for BFO will necessitate closer scrutiny of specifically dependent continuants in general, as they are a parent type of qualities and realizable entities.

4.3. Validating the Axiom (5): Is Modal Dispositionalism Very Limited?

We will move onto the axiom (5). While being agnostic as to whether the logic of metaphysical modality should comprise (5) (or even (4)), Vetter [18] submits, albeit tentatively, that her potentiality-based theory of possibility can validate (5) under some auxiliary assumptions. Her argument begins by discussing potentialities in time, above all of "past-concerning potentialities": to borrow her example, my potentiality to be in London on January 1, 2000.[3] To figure out

[3]This is an example of "tenseless potentialities" and there can be also such "tensed potentialities" as my potentiality to *have been* in London. For our expository purpose, it will suffice to discuss tenseless potentialities only. For details on potentialities and time, refer to Vetter [18, Chapters 5.8, 6.1 and 7.9].

past-concerning potentialities, she considers what she calls the 'triviality thesis'. According to this thesis: "past-concerning potentialities are possessed if and only if their manifestation properties are, and hence are possessed to maximal degree if they are possessed at all" [18, p. 189], where an object possesses a potentiality to be ϕ to the maximal degree if and only if the object lacks the potentiality not to be ϕ. The pivotal idea is that, granted that the past is "fixed", we cannot change the past. To paraphrase it, we have no potentiality for the past to have been different from the way as it was actually so. Therefore, if I now have a potentiality to be in London on January 1, 2000, then this potentiality must be maximal-degree in the sense that I now lack the potentiality not to be in London on January 1, 2000.

Let us focus on the axiom (5): $\Diamond\phi \rightarrow \Box\Diamond\phi$. A "potentiality reading" of (5) is $\Diamond^*\phi \rightarrow \Box\Diamond^*\phi$ or equivalently $\Diamond^*\phi \rightarrow \neg\Diamond^*\neg\Diamond^*\phi$: if something has an iterated potentiality for ϕ, then nothing has an iterated potentiality for it to be the case that nothing has an iterated potentiality for ϕ. In other words: "given an iterated potentiality, there are no potentialities for that iterated potentiality never to be possessed" [18, p. 212]. Consider now some entity *e* (or entities) that existed at the very first moment of the universe. Given the triviality thesis, nothing ever has a potentiality for *e* to have different potentialities at the first moment of the universe, to wit, to have their potentialities never been possessed. The potentialities of *e* are "fixed" in this sense. Suppose that *e* is the necessary existent (which Kimpton-Nye [55] calls the 'NEC') which: "already had iterated potentialities for every potential development of the universe" [18, p. 213], namely iterated potentialities for all other potentialities that exist at any time of the universe. Because of the "fixedness" of the potentialities of the NEC, it follows that: "for every iterated potentiality, nothing has an even iterated potentiality for it to be the case that nothing has an iterated potentiality for the same ultimate manifestation" (ibid.). This line of reasoning, or the "NEC story" [55], leads to the validity of (5) within the potentiality framework.

Prima facie, nothing would hinder BFO from postulating the NEC and the NEC story would allow a dispositionally modal semantics to validate the axiom (5). There are nonetheless two concerns as to the NEC story. First, it may be criticized for being *ad hoc*, as with the validation of (T) based on a "plenitude of powers". Second, it may conflict with the intuition that many actual entities are contingent beings and none of the actual (contingently) existing entities may have existed [43, 45]. More broadly, there is a classical objection to a general dispositional approach to modality (including Vetter's) which is sometimes called 'modal dispositionalism': it fails to account for so-called 'global modality' [45] (e.g. the possibility of talking donkeys) because dispositions are properties of locally existing individual entities and dispositional modality can only cover local possibilities (and, at best, their limited generalization, as illustrated by iterated potentialities in Vetter's theory).

There are at least two ways of responding to this objection from global modality. One is that it may not be clear whether modal dispositionalism must cover all the possibilities that one would be willing to recognize pre-theoretically. We are primarily concerned with how modal dispositionalism can explain metaphysical possibility (which is assumed to correspond to the system S5). The objection seems to assume that pre-theoretical intuition ("conceivability") about possibility is good guide to metaphysical possibility, but this is highly questionable (see Borghini & Williams's [41] detailed discussion). To say the least of it, conceivability does not determine metaphysical possibility and their alleged strong connection may be due to a dominant possible-world-based understanding of modality [55]. It may be thus unproblematic

that the possibility of talking donkey is outside the reach of modal dispositionalism.

The other, more positive response is that modal dispositinalism could accommodate such possibilities as talking donkeys. Vetter's theory can allow for *merely possible* (as well as actual) potentialities because it introduces iterated potentialities and, when an entity has a potentiality to have a potentiality, the latter potentiality may be merely possible (cf. [41]). We can therefore think, for example, that this donkey has a potentiality to have a potentiality to talk. If one is agnostic as to such iteration-based merely possible potentialities, another interpretation available would be that the donkey "type" (rather than individual monkeys) has a potentiality to talk. This reply requires types to be able to have potentialities, but Vetter's approach could accept it because it would be compatible with the claim that mathematical objects (e.g. numbers) have potentialities [18, Chapter 7.7].

5. Conclusion

To recapitulate briefly, we spotlighted ontological commitments of the semantics of logic. In particular, we focused on ontological commitments of the possible-world semantics of modal logic and their potential problems. Being motivated by the idea of modal logic without possible worlds, we presented a reconstructed version of Vetter's [18] potentiality-based theory of possibility and discussed how to develop a modal semantics that would cohere with the modal primacy of dispositions in BFO.

In the future, we will further this discussion in a formally more rigorous way in order to take concrete steps towards a BFO-based dispositionally modal semantics. This line of inquiry is expected to shed light on the largely unexplored modal aspect of dispositions (partly because they tend to be investigated with a pragmatic emphasis on their OWL representation [36, 37]) and also to facilitate a better ontological and formal comparison between BFO and other upper ontologies such as DOLCE and UFO. Regarding this direction of study, it may be helpful to look into a modal formalization of agency based on the deliberative STIT ("Seeing To It That") operator [56] because agency is intimately connected with the capability to do something and capabilities could seen as a kind of potentialities (see also Troquard et al.'s [57] analysis of ontological assumptions of the STIT logic).

Finally, it is well worth registering that we thought, more or less conservatively, that a BFO-based dispositionally modal semantics needed to capture metaphysical modality and this modality corresponded to the system S5. We made these assumptions partly because our argumentation would be otherwise difficult to comprehend owing to the disconnection from the orthodox view of modality and modal logic. As we explained in Section 2.1, however, we can have good reason to doubt or even deny these premises. A radical departure from such restrictions will yield a number of different approaches to modal semantics. As this outlook exemplifies, semantics matters when it comes to ontological commitments of logic.

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