# Approaching Roles with Affordances

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**Abstract.** We develop an affordance-based approach to a subkind of roles, namely roles that have a causal component and that involve an agent and an environment. This approach is based on a previous dispositional ontology of affordances and effectivities. More specifically, such roles are analyzed as identical to mereological sums of affordances or effectivities when they are realized. We illustrate this theory on the example of the roles of addresser (analyzed as a sum of effectivities when they are realized) and addressee (analyzed as a sum of affordances when they are realized). We discuss the import of this analysis for the category of role in the upper ontology Basic Formal Ontology (BFO), and the relation between this approach and Loebe's tripartition of roles.

**Keywords.** Role, affordance, disposition, realizable entity, Basic Formal Ontology (BFO)

## 1. Introduction

The world is replete with roles, e.g. students, presidents, lovers, and mothers. Roles are particularly useful for characterizing multifarious entities. For instance, modeling organizations (totally or partially) upon interrelations among roles is nowadays well-established [1–3]. Despite having been the topic of many interdisciplinary investigations, roles still remain nebulous entities, as is indicated by Boella et al.'s [4] list of open questions about roles, e.g. whether a single definition of roles is possible.

In this paper we will investigate the relationship between roles and *affordances* along a line of argument that has been proposed by Baldoni et al.'s [5]. The term "affordance" was coined by Gibson [6] to pin down precisely the interaction between animals and the environment: "The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill" (p. 119). For instance, a gap affords hiding (or being trapped) when it is of a certain size relative to the size of a person, and a stair affords climbing when it is a certain proportion of a person's leg length. As we will explain below, this affordance-based approach to roles captures a key interactional feature of roles [5]. It has been nonetheless arguably less explored in formal ontology, partly because affordances as such are difficult to analyze from an ontological point of view. We will provide below an affordance-based perspective on specific roles, namely roles 1) implying a causal interaction (which we will call "causal roles") and

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2) that involve an agent and an environment, with recourse to a dispositional ontology of affordances that we have previously developed [7–9].

The underlying motivation behind this work lies in part in the category of role in the upper ontology Basic Formal Ontology (BFO) [10]. The BFO notion of role has been extensively utilized in various domains, ranging from the Ontology of Medically Related Social Entities (OMRSE) [11] in the biomedical domain to BFO-compliant industrial ontologies [12]. Roles in BFO merit further clarification, however. For one thing, there are few in-depth studies (but see [10,13–15]) on their "realizable" or "potential" nature (to be delineated below) about which many questions and concerns can be raised [16]. As will be detailed below, our affordance-based view of roles can be developed based on the BFO foundational background (against which fruitful results on dispositions have been produced [17–19]); and it may also help to elucidate some aspects of the BFO conception of role, and more generally in other upper ontologies.

The remainder of the paper is structured as follows. Section 2 presents the basic structure of BFO (especially its role category) and our theory of dispositions. Taking a cue from Baldoni et al. [5], Section 3 develops an affordance-based approach to roles by employing our previous dispositional account of affordances. Section 4 is devoted to discussion. Section 5 concludes with some brief remarks on future work.

## 2. Preliminaries

### 2.1. The Basic Structure of Basic Formal Ontology (BFO)

Our work will be generally anchored to the BFO upper ontology, since we are motivated to clarify the nature of some roles in BFO. Entities fall into two kinds: particulars (written in bold, e.g. **John**), and classes (written in italic, e.g. *Human*). We will use standard first-order logic, formalizing classes as unary predicates.

BFO introduces a top-level division between continuants, which persist across time while having no temporal part; and occurrents (e.g. processes), which extend through time (by having temporal parts). Among continuants are independent continuants (e.g. objects) and dependent continuants. Among the latter, a specifically dependent continuant inheres ("INH") in a specific independent continuant, and thus depend existentially on it: e.g. John's mass $\mathbf{mass_{John}}$ ceases to exist if he does (formally: INH($\mathbf{mass_{John}}$, **John**)).

Dependent continuants can be further divided into qualities and realizable entities. A quality (e.g. mass and shape) is "fully manifested" in its bearer; whereas a realizable entity can be realized in ("REAL") associated processes of specific correlated types in which the bearer participates. BFO presently identifies two immediate subtypes of realizable entities: roles and dispositions, which will be explained below in order.

### 2.2. Roles in BFO

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)" ([10], pp. 99-100). Examples include: "the role of an instance of a chemical compound to serve as analyte in an experiment, the role of a portion of penicillin to serve as a drug,

and the role of a stone in marking a boundary" ([10], p. 100). Social roles include, for example, the role of a health professional or the role of a patient.

Because of its ambiguity, we will not use the phrase "play a role", in contrast with its prevalence in the relevant literature on roles [20–23]. Mizoguchi et al. [23] maintain that "play a role" has two components which they call "holding a role" and "performing a role". To take their example, if Mary is employed as a teacher, she is still a teacher when she is asleep: she holds a teacher role even when she is asleep and does not perform this role (by e.g. giving classes at school). "Holding a role" and "performing a role" in their terminology would coincide with the bearing and realization of BFO:roles, respectively (see **Table 1**).

Table 1. "play a role" in Mizoguchi et al. (2015) [23] and in BFO [10] with an illustrative example

| Mizoguchi et al. (2015) | BFO | Example: Mary's teacher role |
|---|---|---|
| *hold* a role | *bear* a role | Mary being hired as a teacher. |
| *perform* a role | a role is *realized* | Mary giving classes at school. |

## 2.3. A Theory of Dispositions

We will explain dispositions as a preliminary to presenting our dispositional view of affordances. BFO considers a disposition as an "internally grounded realizable entity", that is "a realizable entity that exists because of certain features of the physical make-up of the independent continuant that is its bearer" ([10], p. 101) (see below Section 3.2.1 for how we understand "grounding" here). Classical examples of dispositions include fragility (the disposition of a glass to break when pressed with a certain force) and solubility (the disposition of salt to dissolve when put in a solvent).

We will be more specific about dispositions in two respects. First, following Röhl and Jansen [17], what causes a disposition to be realized (the "trigger") will be restricted to a process, to simplify the representation: e.g. the fragility of a glass is triggered by a process of pressing the glass with a certain force. We thus use the **has_trigger** relation between a disposition and its triggering process [17]. Second, we utilize Röhl & Jansen's [17] framework for dispositions, in which a disposition is characterized by relatively specific processes (see Barton et al. [19] for a discussion), characterizing e.g. fragility as a disposition that is triggered only by pressuring processes exceeding a given intensity, and realized only by processes of the object breaking.

We will also use a theory of mereology among dispositions [18], which introduces several kinds of disposition-parthood relations. A first one holds, for example, between the general attractive and repulsive character of a magnet on one hand, and its disposition to attract unlike pole (as well as its disposition to repulse like pole) on the other hand. It is called "mod-parthood", as a mod-part characterizes a "mode" in which the disposition-whole can behave. A second kind of disposition-parthood, named "add-parthood", is the one that holds between, for example, the solubility of a tablet on one hand, and the solubility of its left half (or the solubility of its right half) on the other hand (see [18] for more details, and a formal description of the axioms satisfied by those relations). We will say, in such a case, that the solubility of the tablet is the "add-sum" of the solubility of its left half and the solubility of its right half.

### 3. Modeling Roles with Affordances

#### 3.1. Baldoni et al.'s "Roles as Affordances" and Beyond

According to Boella et al. [4], Baldoni et al. [5] propose to consider roles as "sets" (which we will understand here as sums or aggregates) of (Gibsonian) affordances. Their basic idea is that the animal and the environment (in the Gibsonian account of affordances) are respectively the bearer of a role, and something or someone that influences the role-bearer. For example, in a treatment relation between a health professional Mary and a patient John, John is (part of) an "environment" in which Mary can perform treatments. Thus, John's "patient of Mary" role would be identified with an affordance, and Mary's role of John's caregiver would be identified with her agent's effectivity (the counterpart of affordance, as we will explain below) to treat John.

Baldoni et al. [5] provide thus a first step towards an affordance-based approach to roles. As Boella et al. [4] say, their idea of connecting roles with affordances is motivated by the widely acknowledged, relational or interactional character of roles [21]. As a matter of fact, affordances are inherently interactional: they exist only in virtue of the complementary animal-environment interrelationship. Their initial proposal needs further elaboration, however, in order to become a full-fledged affordance-based ontology of roles. First, affordances cannot be fully understood unless their "reciprocal effectivities" are (and *vice versa*) [8]. An affordance-based view of roles must therefore take into account effectivities and their combinations with affordances as well. For another, roles are intimately related with contexts [21–23] (see [24] and [25] for their general discussion and their ontological analysis, respectively), as is indicated by the optionality of BFO:*Role*. The contextuality of roles needs to be ontologically connected to affordances and effectivities.

The extent of the analysis needs to be specified though. First, the notion of role can be understood in a very general sense in ontology (see e.g. [22]), and not all of them are accountable in terms of affordance and effectivities (consider, e.g. the role of the rose as a bearer of its red color quality). We will thus restrict our investigation to what we will call "causal roles", which we define informally, for now, as roles that characterize some causal relationship – e.g. the causal role of this stairs into John moving upwards (here we leave open the question whether all instances of BFO:*Role* are causal roles or not).

Second, not all causal roles can be analyzed in terms of affordances and effectivities. For example, the causal role of **gear₁** to rotate **gear₂** inside **watch₀** does not involve any agent (**gear₁** has arguably no agentivity), and is therefore not analyzable in terms of affordances and effectivities. Therefore, our analysis will be limited to causal roles that involve an agent (typically, an animal, a robot, etc.) and an environment (we will not address here the intricate problem of characterizing formally the notions of agent and environment).

#### 3.2. Affordances as Reciprocal Dispositions with Respect to Effectivities

As mentioned earlier, affordances are something that the environment "affords" agents such as animals. Classical examines include the climbability of stairs and the capability of gaps to hide. Our ontology of affordances [7–9] draws upon Turvey's [26] dispositional construal of affordances: "An affordance is a particular kind of disposition, one whose complement is a dispositional property of an organism" (p. 179). He also calls this complement an "effectivity". For instance, the affordance of stairs is their disposition

to support an organism as it moves upward or downward on it, and its complement is the disposition (effectivity) of an organism to move upward or downward when using stairs. This dispositional view of affordances is arguably the most straightforward interpretation of Gibson's original notion of affordance (see [27] for a discussion); and it meshes well with Baldoni et al.'s [5] affordance-based approach to roles that is inspired by Gibsonian affordances.

### 3.2.1. Reciprocal Dispositions and their Causally Equivalent Sum

To formalize affordances along with Turvey's line of argument, we elaborated in a former work [8] on the idea of reciprocal disposition (see [28,29]). Classical examples of reciprocal dispositions include a key and a lock such that the former opens the latter: e.g. $key_1$ has the disposition $d_1$ to open $lock_2$, and $lock_2$ has the disposition $d_2$ to be opened by $key_1$ (hence: $INH(d_1, key_1)$ and $INH(d_2, lock_2)$). We introduced [8] the relation of being reciprocal dispositions, that we will write here as the binary relation "REC". REC is non-reflexive, symmetric, and is constrained by axioms claiming that 1) two reciprocal dispositions are triggered by exactly the same processes, 2) they are realized in exactly the same processes and 3) their bearers have no common part. $d_1$ and $d_2$ were analyzed as reciprocal dispositions in this sense (that is, we have $REC(d_1, d_2)$) : 1) they are triggered by processes of $key_1$ being inserted and turned in $lock_2$, 2) they are realized by processes of $key_1$ opening $lock_2$, and 3) $key_1$ and $lock_2$ have no common parts.

We also introduced [8] the notion of "causally equivalent sum" $d_3$ (disposition) of $d_1$ and $d_2$, that we will formalize using the ternary relation CES (here: $CES(d_1,d_2,d_3)$) Like $d_1$ and $d_2$, $d_3$ is triggered by $key_1$ being inserted and turned in $lock_2$, and realized by processes of $key_1$ opening $lock_2$. However, $d_3$ is borne by the mereological sum of $key_1$ and $lock_2$ (which we will write by "$key_1+lock_2$"), whereas $d_1$ is borne by $key_1$ and $d_2$ by $lock_2$. Since $d_1$, $d_2$, and $d_3$ have the same triggers and realizations, they have, intuitively, the same "causal import". We can say intuitively that $d_1$ describes the causal situation from the perspective of $key_1$, $d_2$ describes it from the perspective of $lock_2$, and $d_3$ describes it from the perspective of $key_1+lock_2$. Note that two reciprocal dispositions are always add-part of their causally equivalent sum [8]. In particular, $d_1$ and $d_2$ are add-parts of $d_3$. Since $d_1$ is inherently directed towards $lock_2$, and $d_2$ is inherently directed towards $key_1$, we call reciprocal dispositions such as $d_1$ and $d_2$ "individual-directed".

As seen earlier, the distinction between roles and dispositions in BFO is formulated partly in terms of grounding. This notion could be formalized in various ways, that exceed the scope of this paper (but see [30], and the section 4.3 for an alternative view). In this paper, we will understand grounding as ontological (existential) dependence (see [31] for a discussion of the connections between both). More specifically, dispositions will be considered here as ontologically dependent on their bearers, but not any external entity; and roles as ontologically dependent not only on their bearers, but also on some external entity.

What we called "reciprocal dispositions" in [8] depend existentially on the physical make-up of some entities that are external to them. For instance, $d_1$ (of $key_1$) and $d_2$ (of $lock_2$) depend existentially on the physical make-ups of both $key_1$ and $lock_2$. Consequently, $d_1$ and $d_2$ can be subject to so-called "Cambridge change" [32]: if $key_1$ disappears, then so does $d_2$, even if $d_2$'s bearer, namely $lock_2$, did not change. Similarly, if $lock_2$ disappears, then so does $d_1$, even if $d_1$'s bearer, namely $key_1$, did not change. Thus, $d_1$ and $d_2$ cannot be classified as dispositions if we follow strictly BFO's current characterization of dispositions as being "internally grounded". Therefore, we will call
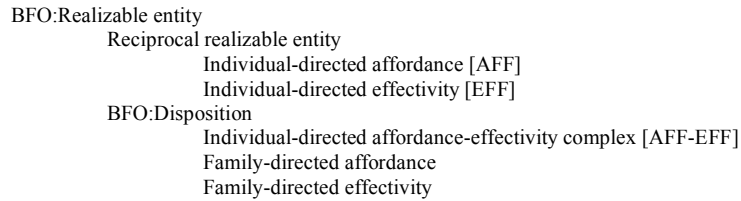
them here more cautiously "reciprocal realizable entities" (abbreviated "reciprocal REs") – see section 4.3 for a discussion of what kind of realizable entities those could be. Two reciprocal REs can intuitively be seen as two aspects of a more encompassing disposition, when viewed from the perspective of a part of the bearer of this disposition; for example, $d_1$ would be an aspect of $d_3$, when viewed from the perspective of $key_1$; and $d_2$ would be an aspect of $d_3$, when viewed from the perspective of $lock_2$.

Reciprocal REs are very similar to dispositions as they are "potentialities" that can be triggered and realized by processes; and they differ from dispositions by not being internally grounded. Therefore, the mereological theory of dispositions mentioned above (add-parthood, mod-parthood, etc.) can be directly adapted to reciprocal REs.

### 3.2.2. Individual-directed Affordances and Affectivities and Affordance/Effectivity Complex

Any individual-directed effectivity (resp. affordance) has some individual-directed affordance (resp. effectivity) as a reciprocal RE. For instance, the affordance $a_0$ of $stairs_0$ enabling **John** to move up and **John**'s effectivity $e_0$ to move up using $stairs_0$ are reciprocal REs: they both can be triggered by (something like) the process of **John** contracting some leg muscles on $stairs_0$ and be realized in the process of **John** climbing up $stairs_0$. Formally, we endorse the two following axioms (using the taxonomy described in Fig.1):

$$AFF(a) \rightarrow \exists e, [EFF(e) \wedge REC(a,e)]$$
$$EFF(e) \rightarrow \exists a, [AFF(a) \wedge REC(e,a)]$$

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BFO:Realizable entity
        Reciprocal realizable entity
                Individual-directed affordance [AFF]
                Individual-directed effectivity [EFF]
BFO:Disposition
                Individual-directed affordance-effectivity complex [AFF-EFF]
        Family-directed affordance
        Family-directed effectivity
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**Figure 1.** Taxonomy of relevant classes and their associate first-order predicates

Finally, according to Turvey [26], affordances depend existentially not only on effectivities but also on what we called "affordance/effectivity complex" [8]. To illustrate this: the affordance $a_0$ and the effectivity $e_0$ both exist if and only if there exists the corresponding affordance/effectivity complex: a dispositional property $c_0$ that is borne by **John**+$stairs_0$. In our analysis [8], $c_0$ is the "causally equivalent sum" of $a_0$ and $e_0$ (it is to $a_0$ and $e_0$ what $d_3$ above was to $d_1$ and $d_2$). Note that $a_0$ and $e_0$ inherit their causal import from the disposition $c_0$: $a_0$ can be seen as the perspective from the point of view of $stairs_0$ on $c_0$, and $e_0$ as the perspective from the point of view of **John** on $c_0$.

More generally, any affordance and its reciprocal effectivity can be associated to an affordance-effectivity complex (AFF-EFF), a disposition that is their causally equivalent sum:

$$AFF(a) \wedge EFF(e) \wedge REC(a,e) \rightarrow \exists c, [CES(a,e,c) \wedge AFF\text{-}EFF(c)]$$

### 3.3. Roles and Individual-directed Affordances/Effectivities

#### 3.3.1. Counter-role and Contextuality

Since an affordance-based perspective on roles highlights their relational feature, let us focus upon the intuition (mentioned by Boella [4]) that every role should have at least one related "counter-role". In our **John**/**stairs$_0$** example, **John**'s effectivity $e_0$ is a "potential climber-of-**stairs$_0$** RE" whose (potential) realizations comprise processes of **John** climbing **stairs$_0$**. Note the use of the term "potential": indeed, **John** has this effectivity even when he is not climbing **stairs$_0$**, including the extreme scenario in which he will never climb **stairs$_0$**. Symmetrically, **stairs$_0$** bears the affordance $a_0$, which is a "potential climbee-by-**John** RE" (here again, this RE inheres in **stairs$_0$** even when it is not climbed by **John**). The fact that $a_0$ and $e_0$ are reciprocal REs will be the basis for formalizing the aforementioned intuition of role and counter-role.

Our affordance-based account of roles may also allow us to analyze the contextuality of roles more carefully than Baldoni et al. According to Baclawski et al. [24], a context is something in terms of which something (else) can be determined. In our **John**/**stairs$_0$** scenario, $a_0$ and $e_0$ are reciprocal REs; but to understand their causality, one needs to consider their affordance/effectivity complex $c_0$ because it is the primary source of their causality. $c_0$ is triggered (like $a_0$ and $e_0$) by John contracting some leg muscles and realized (like $a_0$ and $e_0$ too) by **John** moving up **stairs$_0$**; but contrarily to $a_0$ and $e_0$, it is a *bona fide* disposition, and inheres in the sum **John**+**stairs$_0$**. In this sense, $c_0$ provides the contextuality of $a_0$ and $e_0$, because their causal import is determined by the causal import of $c_0$.

#### 3.3.2. Role as a Realized Affordance or as a Realized Effectivity

To be sure, the terms "potential climber" and "potential climbee" are not commonly used. We are usually more interested in someone being an actual "climber", or something being actually climbed – that is, being an actual "climbee". Therefore, the terms "climber role" and "climbee role" typically describe roles that are being performed (remember the distinction we introduced in 2.2). We can formalize John's "climber-of-**stairs$_0$** role" as being $a_0$, but only *when it is realized* in **John** climbing **stairs$_0$**. Similarly, we can formalize **stairs$_0$**'s "climbee-by-**John** role" as being $e_0$, but only when it is realized in a process of **John** climbing **stairs$_0$**. That is, when a process of **John** climbing **stairs$_0$** obtains, $e_0$ become an instance of climber-role, and $a_0$ becomes an instance of climbee-role. More generally, and said differently: a climber role is a "potential climber" effectivity that is being realized, and a climbee role is a "potential climbee" affordance that is being realized. Introducing the first-order, temporalized predicates of climber role (CLIMBER), climbee role (CLIMBEE), potential climber effectivity (P-CLIMBER), potential climbee affordance (P-CLIMBEE), and realized in (REAL), we could formalize this by the following definitions:

$$\text{CLIMBER}(r,t) =_{def} \text{P-CLIMBER}(r,t) \wedge \exists p\, \text{REAL}(r,p,t)$$
$$\text{CLIMBEE}(r,t) =_{def} \text{P-CLIMBEE}(r,t) \wedge \exists p\, \text{REAL}(r,p,t)$$

#### 3.3.3. Role as a Sum of Affordances or Effectivities

We have seen a case in which a role can be identified with either an affordance or an effectivity. As Baldoni et al. [5] observe, however, one needs to consider roles with respect to multiple affordances (and effectivities) in order to articulate complex

behaviors of objects (such as agents) in the real world. Suppose that Pat addresses Sam: Pat bears an addresser role relatively to Sam and Sam bears an addressee (counter-)role relatively to Pat. Suppose also for simplicity that to address a person consists in 1) looking at and 2) speaking to the person.

In this scenario, we can recognize two affordances inhering in **Sam** (see Fig. 2): 1) $a_{look}$, his affordance to be looked by **Pat** and 2) $a_{speak}$, his affordance to be spoken to by **Pat** (note that we are not speaking of him *authorizing* Pat to talk to him, but him *affording* Pat to talk to him by constituting part of Pat's environment). We can also identify two counterpart effectivities in **Pat**: 1) $e_{look}$, her effectivity to look at **Sam** and 2) $e_{speak}$, her effectivity to speak to him.

$a_{look}$ is a reciprocal RE of $e_{look}$:

$$REC(a_{look}, e_{look})$$

In particular $a_{look}$ and $e_{look}$ (i) are both triggered by the same process of Sam being into Pat's field of vision and Pat directing her attention at Sam and (ii) are both realized in the same process of Pat looking at Sam.

Similarly, $a_{speak}$ is a reciprocal RE of $e_{speak}$:

$$REC(a_{speak}, e_{speak})$$

They are both triggered by Sam being into Pat's voice range and Pat closing her vocal cords and exhaling, and both realized by Pat speaking to Sam. Note also that all those affordances and effectivities are individual-directed, in the sense that they depend on the individuals **Pat** and **Sam** (see section 4.1 for the contrast with family-directed affordances and effectivities).
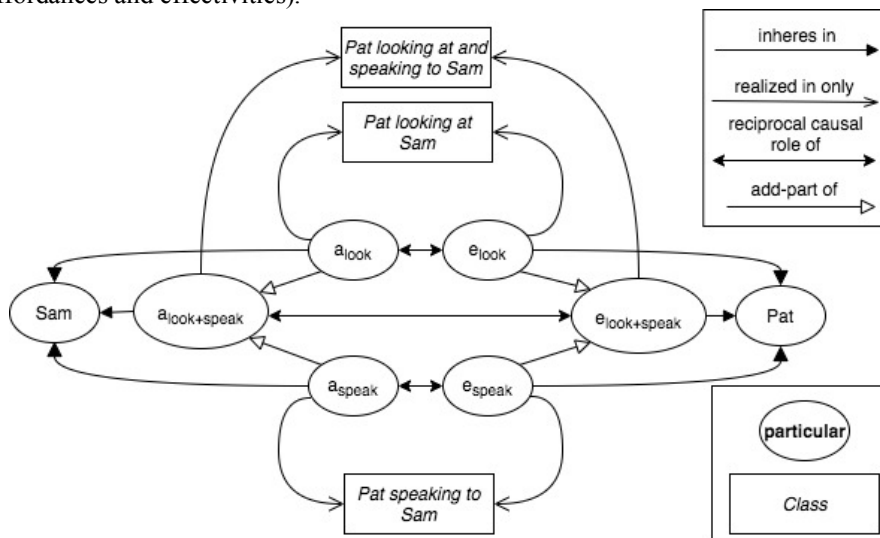


**Figure 2**. Examples of affordances and effectivities that can become roles when realized

Let us consider some relevant basic roles here, namely Pat's speaker-to-Sam role and Sam's speakee-by-Pat role (that is, the role of being spoken to by Pat; note that this is not identical to a role of Pat-listener, as Pat may speak to Sam while Sam is not listening to her). Informally, and similarly to the terms "climber role" and "climbee role", the term "speaker role" and "speakee role" typically need to be performed to exist. Indeed, one would not say that Pat plays a role of speaker-to-Sam by her merely having the

possibility to speak to him: we typically say that she has this role when she *actively* speaks to him. Therefore, the use of the term "speaker" differs from the use of, say, the term "nurse". Indeed, we state that a person has a "nurse" role even if she is not actively performing nursing action (see below section 4.2 for more discussion on social roles); however, we say that a person has a "speaker" role only if she is actively speaking (except in some cases, when the term "speaker" denotes e.g. an invited speaker to a conference, which is a role that the person keeps some time before and after the event).

Therefore, Pat's speaker-to-Sam role cannot be always identified with $\mathbf{e}_{speak}$, nor Sam's speakee-by-Pat role always with $\mathbf{a}_{speak}$. Indeed, those affordance and effectivity exist even when Pat does not speak to Sam. The fact that Pat bears the effectivity $\mathbf{e}_{speak}$ does not mean that she is actively speaking to Sam, but that she has the *potential*, in the right set of circumstances, to speak to Sam. Therefore, $\mathbf{e}_{speak}$ is a Pat's "*potential* speaker-to-Sam" effectivity: should Pat decide to speak to Sam, she could do so. Similarly $\mathbf{a}_{speak}$ is a "*potential* speakee-by-Pat" affordance. As we did for the climber and climbee roles, we can formalize Pat's (actual) speaker-to-Sam role as being identical to $\mathbf{e}_{speak}$, but only *when it is realized* in a process of Pat speaking to Sam. Similarly, we can formalize Sam's (actual) speakee-by-Pat role as being identical to $\mathbf{a}_{speak}$, but only *when it is realized* in a process of Pat speaking to Sam. More generally: a speaker role is a potential speaker effectivity that is realized, and a speakee role is a potential speakee affordance that is realized. Introducing the first-order, temporalized predicates of speaker role (SPEAKER), speakee role (SPEAKEE), potential speaker effectivity (P-SPEAKER), potential speakee affordance (P-SPEAKEE), and realized in (REAL), we could formalize this by the following definitions:

SPEAKER(r,t)$=_{def}$ P-SPEAKER(r,t) $\wedge$ $\exists$ p REAL(r,p,t)

SPEAKEE(r,t)$=_{def}$ P-SPEAKEE(r,t) $\wedge$ $\exists$ p REAL(r,p,t)

We can now turn to analyzing Sam's addressee role and Pat's addresser role using the above-mentioned mereological theory between dispositions (which we adapt straightforwardly to a mereological theory between reciprocal REs, as explained earlier). Let's start with the former. The add-sum of $\mathbf{a}_{look}$ and $\mathbf{a}_{speak}$, which we call "$\mathbf{a}_{look+speak}$", is the affordance inhering in Sam that can be realized by Pat looking at Sam and speaking to Sam: by being in Pat's environment, Sam affords her to look at him and speak to him – that is, affords her to address him. Since this RE exists even if Pat is not actively looking at and speaking to Sam, it cannot be always identified with Sam's addressee-by-Pat role; it is rather Sam's *potential* addressee-by-Pat affordance. However, similarly to what we just described, Sam's addressee-by-Pat role can be identified with $\mathbf{a}_{look+speak}$ *when it is realized*, that is, when Pat does indeed look at and speak to Sam. And Pat's addresser-to-Sam role also can be identified with the effectivity $\mathbf{e}_{look+speak}$ *when it is realized*.

It is also well worth noting that some roles are explicable in terms of both affordances *and* effectivities. Consider e.g. Sam's "Pat-interlocutor role" that is manifested when Pat addresses him and he addresses Pat in turn: it can be minimally characterized with his addressee-by-Pat role (whose counter-role is Pat's addresser-to-Sam role) *and* his addresser-to-Pat role (whose counter-role is Pat's addressee-by-Sam role), which can be in turn analyzed using affordances and effectivities, respectively. A straightforward suggestion would be to represent this interlocutor role as a sum of her the affordances and effectivities underlying his addressee role and his addresser role, when this sum is realized (note that this could not be an add-sum, as one is usually not both addressing a person and addressed by this person at the same time). This line of work will be left for the future.

Finally, note that some roles would better be analyzed as having some affordances and effectivities as *mod*-parts, rather than add-parts. For example, the role of a health professional could be (in a first approximation) considered as having as mod-part their effectivity to diagnose a patient and as another mod-part their effectivity to treat them. Indeed, a health professional will typically diagnose a patient, or treat a patient, but generally not both at the same time. Hence, this role can be realized by one *or* the other effectivity being realized. Future work should analyze in more details the various kinds of parthood that can be involved in such causal roles.

*3.4. A Brief Summary*

Let us summarize the connections between the entities introduced above. The contextuality of reciprocal causal REs can be analyzed in terms of their causally sum equivalent, which is a disposition; for example, the reciprocal REs $d_1$ of $key_1$ to open $lock_2$, as well as $d_2$ of $lock_2$ to be opened by $key_1$, get their causality from the more fundamental disposition $d_3$ borne by $key_1 + lock_2$. In particular, individual-directed affordances and effectivities are reciprocal REs that can be analyzed in terms of their affordance/effectivity complex (a disposition), from which they get their contextuality; e.g. the effectivity of **John** to climb up $stairs_0$ and the affordance of $stairs_0$ to be climbed by **John** are merely aspects of the more fundamental disposition $c_0$, an affordance/effectivity complex that depends existentially on the physical make-up of its bearer **John**+$stairs_0$. Subsequently, we have introduced more elaborate REs, such as Sam's *potential* addressee-by-Pat affordance ($a_{look+speak}$) and Pat's *potential* addresser-to-Sam effectivity ($e_{look+speak}$), which can be analyzed as add-sums of more basic affordances or effectivities (and some other relevant REs might be identified instead with mod-sums of such affordances or effectivities). Finally, and most importantly, we have explained how Sam's addressee-by-Pat role and Pat's addresser-to-Sam role can be identified with those affordances and effectivities *when they are realized*.

## 4. Discussion

*4.1. Family-directed Affordances and Effectivities*

In the aforementioned key-lock example, $d_1$ and $d_2$ are "individual-directed": they depend (existentially) on individual entities $lock_2$ and $key_1$. However, we can introduce dispositions $d^f_1$ and $d^f_2$ that are entwined with, but differ from $d_1$ and $d_2$, and not subject to Cambridge change [8,9]. Let *Lock_2* and *Key_1* be classes whose instances are locks (qualitatively) similar to $lock_2$ and keys (qualitatively) similar to $key_1$, respectively. Then let us define $d^f_1$ and $d^f_2$ as follows:

- $d^f_1$ as the disposition of $key_1$ to open instances of *Lock_2*.
- $d^f_2$ as the disposition of $lock_2$ to be opened by instances of *Key_1*.

Contrary to $d_1$ and $d_2$, $d^f_1$ and $d^f_2$ are "family-directed": they depend on the families *Lock_2* and *Key_1*, respectively.

We can then accordingly introduce the notion of individual-directed and family-directed affordances and effectivities [8]. Recall the John-stairs example in which we can introduce the affordance $a_0$ of $stairs_0$ for **John** to move up, and **John**'s effectivity $e_0$

to move up using **stairs$_0$**. Here **a$_0$** and **e$_0$** are individual-directed because they depend existentially on **John** and **stairs$_0$**, respectively. By introducing the general classes *Person* and *Stairs* (whose instances include **John** and **stairs$_0$**, respectively), we can introduce a family-directed affordance **a$^f_0$** that is closely related with **a$_0$**, namely the affordance of **stairs$_0$** to enable instances of *Person* to move up. Similarly, we can introduce a family-directed effectivity **e$^f_0$**, closely related with **e$_0$**, of **John** to move up using instances of *Stairs*. As we will now discuss, such family-directed affordances and effectivities could then be used as a basis to represent social roles.

*4.2. Loebe's Three Kinds of Roles*

Loebe [22] proposes three kinds of roles (that are not necessarily mutually exclusive): relational, processual, and social. (His proposal is based on the upper ontology General Formal Ontology [33], but its general utility is recognized by Guarino [16]) That is:

- **Relational roles** correspond to the way in which the role-bearers are related with respect to their "actual relationship" [16].
- **Processual roles** correspond to the role-bearer's ways of participation in processes: e.g. the mover role (i.e. a process) when John moves a pen.
- **Social roles** correspond to the way in which the role-bearer behaves in the social world. To take Masolo et al.'s [21] examples: professors and presidents.

Our theory can account (at least partially) for the former two kinds of roles. First, causal roles such as looker and lookee roles are arguably relational roles (although not all relational roles involve a causal component, cf. the example above of the rose having a role of bearer of its red-quality). In addition, at least some processual roles are (parts of) realizations of reciprocal REs: e.g. John's **pen$_0$**-mover processual role is (part of) the realization of John's "potential **pen$_0$**-mover effectivity" (whose reciprocal RE is the "potential movee-by-John affordance" of **pen$_0$**).

However, social roles are more intricate, as Loebe explains. Some roles that have a social component, such as "addresser" or "addressee", have been analyzed above. But a full analysis of social roles is out of scope of the present paper. As a matter of fact, generally, we can identify three central features of social roles. First, a *behavioral* dimension: a social role-bearer behaves in a given way; e.g., a nurse provides care for his patient. This dimension can be captured in many cases by the *family*-directed affordances and effectivities that have been presented above. For example, a nurse has a family-directed effectivity to provide care to patients in general, or to patients of a given kind – and not only an individual-directed effectivity to provide care to a particular patient. Some of them might however be captured by individual-directed affordances and effectivities: consider e.g. professions that only serve a specific queen or emperor. Second, some social roles have a *directive* dimension. Indeed, some social role-bearers behave in a way that is described by some guidelines, e.g. a nurse following a nurse guidebook about how to treat his patients (see [21] for a few pointers on this dimension). Third, some social roles have a *normative* dimension (see [34] for more considerations on the difference between the directive and normative dimensions). Indeed, some social role-bearers have some obligation to behave in the above-mentioned way, and/or other related agents have some associated rights. For example, a nurse has an *obligation* to provide care to his patients, and a patient has a *right* to receive care from nurses at a

health institution. Therefore, a closer analysis of social roles, especially their normative dimensions, will require an established theory of social ontology [35,36].

### 4.3. What is the Nature of Reciprocal REs?

We have so far left open the nature of reciprocal REs. There are at least three ways to classify them more precisely in BFO. A first possibility would be to classify them, as in our former work [8], as dispositions. This would require to modify BFO's definition of disposition to include relational dispositions that can be partly externally grounded – similarly to BFO's relational qualities or UFO's relators [37–39]. A second possibility would be to argue from their external groundedness that they should be classified under BFO:Role. However, as mentioned earlier, roles are also characterized in BFO by their optionality: a role "exists because the bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be". For example, the RE $d_1$ of $key_1$ to open $lock_2$ exists because $key_1$ is in a world where $lock_2$ exists. However, it remains debatable whether this can be counted as a "physical circumstance in which the bearer does not have to be"; if not, then such reciprocal REs could not be classified under BFO:Role. Finally, a last possibility would be to introduce a new class of realizable entities in BFO that would include reciprocal REs. We will leave the considerations of those three options for future work.

## 5. Conclusion

We developed an affordance-based account of some causal roles based on the BFO understanding of roles (as optional and externally grounded realizable entities), Baldoni et al.'s [5] insights into "roles as affordances", and our previous dispositional ontology of affordances [7–9]. More specifically, we developed an analysis of some causal roles in terms of individual-directed affordances/effectivities (or sums of those). The overall contention here is that some roles, namely causal roles that involve an agent and an environment, can be identified with sum of such affordances and/or effectivities when they are realized, because they are deeply connected to the agent-environment interrelationship. Note that this could easily be generalized in analyzing causal roles that do not involve an agent and an environment (such as the role of $gear_1$ in rotating $gear_2$) as (sum of) reciprocal REs *when they are realized* (such as the RE of $gear_1$ to potentially rotate $gear_2$ when it is realized). We also briefly discussed our theory of causal roles in regard to Loebe's [22] three kinds of roles. Our analysis aimed at being compatible with the BFO framework, and we strive to adapt it to other upper ontologies.

This work leaves open several questions, such as an investigation of the articulation between the processes that an affordance enables (e.g. moving up) and the states that this affordance enables to reach (e.g. reaching the second floor). Another theoretical question would be how to relate this model with Martin's model of dispositions that are activated in the presence of mutual activation partners [28]. In the future we will further our affordance-based account of roles to the social domain, thereby contributing to the development of a mid-level ontology for the social domain [40]. This requires e.g. spelling out formally the relationship between individual-directed and family-directed affordances/effectivities, and also considering the cases where the bearer of a (counter-)role is the collective [2] (i.e. the group of individuals). The latter task may warrant exploration of group agency [1] and organizational identity [3].

## Acknowledgments

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