



**HAL**  
open science

## Affordances and their ontological core

Fumiaki Toyoshima, Adrien Barton, Jean-François Ethier

► **To cite this version:**

Fumiaki Toyoshima, Adrien Barton, Jean-François Ethier. Affordances and their ontological core. Applied Ontology, 2022, 17 (2), pp.285-320. 10.3233/AO-220267 . hal-03746033

**HAL Id: hal-03746033**

**<https://hal.science/hal-03746033>**

Submitted on 4 Aug 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# 1 Affordances and their ontological core

2 Fumiaki Toyoshima<sup>a,1</sup>, Adrien Barton<sup>b,a</sup> and Jean-François Ethier<sup>a</sup>

3 <sup>a</sup> *Groupe de Recherche Interdisciplinaire en Informatique de la Santé (GRIIS), Université de*  
4 *Sherbrooke, 2500 Boulevard de l'Université, Sherbrooke (Quebec), J1K 2R1, Canada*  
5 *E-mails: toyo.fumming@gmail.com, ethierj@gmail.com*

6 <sup>b</sup> *Institut de Recherche en Informatique de Toulouse (IRIT), CNRS, 118 Route de Narbonne, F-31062*  
7 *Toulouse Cedex 9, France*  
8 *E-mail: adrien.barton@irit.fr*

9 **Abstract.** The notion of affordance remains elusive, notwithstanding its importance for the representation of agency,  
10 cognition, and behaviors. This paper lays down a foundation for an ontology of affordances by elaborating the idea of “core  
11 affordance” which would serve as a common ground for explaining existing diverse conceptions of affordances and their  
12 interrelationships. For this purpose, it analyzes M. T. Turvey’s dispositional theory of affordances in light of a formal ontology  
13 of dispositions. Consequently, two kinds of so-called “core affordances” are proposed: specific and general ones. Inspired  
14 directly by Turvey’s original account, a specific core affordance is intimately connected to a specific agent, as it is reciprocal  
15 with a counterpart effectivity (which is a disposition) of this agent within the agent-environment system. On the opposite, a  
16 general core affordance does not depend on individual agents; rather, its realization involves an action by an instance of a  
17 determinate class of agents. The utility of such core affordances is illustrated by examining how they can be leveraged to  
18 formalize other major accounts of affordances. Additionally, it is briefly outlined how core affordances can be employed to  
19 analyze three notions that are closely allied with affordances: the environment, image schemas, and intentions.

20 **Keywords.** Affordance, disposition, environment, image schema, intention

21 **Accepted by:**

## 22 1. Introduction

### 23 1.1. Purpose and motivation: Looking for “core affordances”

24 The term “affordance” was coined by Gibson (1979) to pin down precisely the interaction between the  
25 animal and the environment in the context of ecological psychology: “The *affordances* of the environment  
26 are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill” (ibid., p. 127). To take  
27 classical examples, a step affords climbing when it is of a certain proportion relative to a person’s leg  
28 length and a gap affords hiding when it is of a certain size relative to a person’s body size. According to  
29 Kutz et al. (2018), affordances (and image schemas, which will be introduced later) offer a first foundation  
30 upon which agents (e.g. animals) and inanimate objects (e.g. tools) can be distinguished and identified.  
31 Against this theoretical background, the notion of affordance has been investigated in a number of  
32 different agency-related domains: for example, it has been extensively utilized in robotics to foster  
33 flexible planning and behaviors of robots (Şahin et al., 2007; Chemero & Turvey, 2007; Min et al., 2016;  
34 Yamanobe et al., 2017; Beßler et al., 2020, 2021).

---

<sup>1</sup> Corresponding author. E-mail: toyo.fumming@gmail.com.

1 However, the nature of affordances has not been always understood properly. As a matter of fact,  
 2 affordances are all too often conflated with other elements having nothing to do with them, as is illustrated  
 3 by Norman's (1999) remark on a certain graphic designer's confusion of an affordance with "a symbolic  
 4 communication, one that works only if it follows a convention understood by the user" (ibid., p. 40). In  
 5 addition, the elusiveness of affordances has yielded their multifarious theories to date (see Michaels's  
 6 (2003) overview of several issues regarding affordances), but the interrelationships between those  
 7 theories remain underspecified. Here a formal ontology of affordances will be useful, for it will serve as  
 8 a point of reference for comparing various accounts of affordances by making their implicit "ontological  
 9 choices" (Borgo & Masolo, 2010) transparent. An ontological analysis of affordances is thus expected to  
 10 facilitate research dealing with the notion of affordance, especially in the context of information systems.

11 The objective of this paper is to lay down a foundation for such an ontology of affordances along with  
 12 Toyoshima's (2018) and Toyoshima & Barton's (2019a, 2019b) previous works. To achieve this purpose,  
 13 a primary focus will be upon Turvey's (1992) dispositional theory of affordances. For one thing, as Heras-  
 14 Escribano (2019) argues, affordances cannot be fully comprehended unless Gibson's original  
 15 understanding of them within ecological psychology is well appreciated. Turvey's dispositional account  
 16 of affordances is arguably one of the most straightforward and compelling interpretations of "Gibsonian  
 17 affordances". In fact, a dispositional view of affordances has been recently philosophically defended by  
 18 Vetter (2018) and Heras-Escribano (2019) (albeit not necessarily exactly in the same way as by Turvey).  
 19 It has been also formally explored by Ortmann & Kuhn (2010, 2012) in compliance with the upper  
 20 ontology the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE; Masolo et al.,  
 21 2003; Borgo & Masolo, 2010; Borgo et al., 2022) and, in this DOLCE-based direction of research, it has  
 22 been reinterpreted and implemented in robotics (Beßler et al., 2020, 2021).

23 Quite importantly, however, it is *not* the contention of this paper that affordances must be always  
 24 construed in Turvey's (1992) dispositional manner. Rather, this paper embraces a pluralistic stance on  
 25 affordances. That is to say, there can be multiple, equally plausible approaches to affordances and which  
 26 account of affordances is to be practically used hinges on domain-specific assumptions and needs. As  
 27 will be discussed, for instance, Şahin et al. (2007) submit that the "agent perspective" and "observer  
 28 perspective" on affordances are more relevant to autonomous robot control than the "environmental  
 29 perspective" on them, such as Turvey's. To take another example, Oliver (2005) opines that Gibsonian  
 30 affordances may be too deeply rooted in an ecological perspective on perception to be well-suited for  
 31 considering people's learning and creation of contemporary technologies such as computers.

32 It will be nonetheless valuable to provide a "dispositional basis" for a general ontology of affordances.  
 33 As was sketched out by Toyoshima (2018) and Toyoshima & Barton (2019a) and as will be shown in  
 34 more detail below, this is mainly because other major theories of affordances can be formalized as an  
 35 extension of a dispositional interpretation of affordances. In this sense, "Turveian affordances" may be  
 36 called "core affordances": affordances that would serve as a common ground for scrutinizing many  
 37 existing kinds of affordances and hitherto unspecified interconnections among them. Briefly, this paper  
 38 will spell out the hypothesis that core affordances could be advantageously conceptualized and formalized  
 39 as Turveian affordances.

## 40 1.2. Scope and structure of the paper

41 To specify the scope and structure of this paper, it will be useful to refer to Galton's (2010) three  
 42 distinct goals that a complete theory of affordances must achieve:

- 43
- 44 ● The *upper-level goal* is to answer what may be called "ecological" or "environmental" questions  
 45 concerning the role of affordances in the life of an individual, how they can be used to explain

1 features of human and animal behaviour, and how they can be exploited for the better design of  
2 environments.

- 3 ● The *middle-level goal* is concerned with characterising exactly what affordances are: this may be  
4 called the “ontological” question. How is an affordance defined, and what is the logical  
5 relationship between statements about affordances and other statements about the world?
- 6 ● The *lower-level goal* is the answer the “aetiological” question of where affordances come from,  
7 exactly how the physical layout of surfaces determines the affordances it has for any given class  
8 of creatures.

9  
10 As is clear from Section 1.1, this paper aims primarily at the middle-level goal to answer an ontological  
11 question of how to characterize affordances. As a starting point to pursue it, Section 2 provides  
12 preliminaries by presenting a basic ontological framework and a theory of dispositions that both underlie  
13 the inquiry of this paper. Section 3 develops a theory of core affordances based on Turvey’s (1992)  
14 dispositional account of affordances. Section 4 explicates how this account of core affordances can be  
15 extended to other well-known interpretations of affordances. Now it is reasonable to think that an  
16 adequate answer to the ontological question about the characterization of affordances will contribute to  
17 an in-depth inquiry into the ecological question of how to consider the role of affordances in connection  
18 with agents and the environment. With this train of thoughts, Section 5 turns to the upper-level goal and  
19 discusses, from the viewpoint of core affordances, three entities that are intimately connected to this goal:  
20 the environment, image schemas, and intentions. Finally, the lower-level goal is basically off the table in  
21 this paper, but Section 6 concludes the paper with some brief remarks on future work, including a possible  
22 direction of research in which the lower-level goal is to be investigated.

## 23 2. Preliminaries

24 This section offers preliminaries to the development of a theory of core affordances. Section 2.1  
25 specifies a basic ontological framework for the overall study of this paper. Section 2.3 explains an  
26 ontology of dispositions by presenting their general idea, based on Röhl & Jansen’s (2011) and Barton et  
27 al.’s (2018) works (Section 2.3.1) and Barton et al.’s (2017) theory of parthood between dispositions  
28 (Section 2.3.2). Note that the reader who does not want to enter into the details of an ontology of  
29 dispositions may skim through Section 2.3 (especially Section 2.3.2) and return to it later when necessary.

### 30 2.1. Basic ontological framework

31 First of all, the formal investigation of this paper will be conducted in first-order logic (with identity).  
32 Indeed, another language such as the Web Ontology Language (OWL; Horrocks et al., 2007) is often  
33 used in practical ontological modeling, but it may lack the expressiveness to axiomatize the intended  
34 meaning of affordances. One may think that first-order modal logic (Braüner and Ghilardi, 2007) would  
35 be more suitable for representing affordances (e.g. the *climbability* of steps) because they are closely  
36 related to agents’ *possible* actions. Consider, for instance, Galton’s (2010) usage of possibility operators  
37 (“ $\diamond$ ”) in his formalization of affordances. Nonetheless, first-order logic will be employed in this paper  
38 (but see Borgo et al.’s (2014) discussion on other kinds of formalizations of ontologies than first-order  
39 modal logic and OWL). For one thing, first-order logic would have the practical virtue of higher  
40 computational tractability, even if some first-order modal logics are translatable into first-order (non-  
41 modal) logics (Braüner and Ghilardi, 2007).

42 This paper leverages categories and relations that are relatively widely accepted in upper ontologies.  
43 In particular, it avails of the general structure of upper ontologies that have the category of disposition

(which is vital for theorizing on core affordances) such as Basic Formal Ontology (Arp et al., 2015; Otte et al., 2022) and the Unified Foundational Ontology (Guizzardi, 2005; Guizzardi et al., 2015, 2022). In the first place, a distinction is drawn between instances (synonym: “particular”, “individual”) and classes (synonym: “universal”, “kind”). In the text, terms for instances and classes will be italicized and boldfied, respectively: e.g. this particular person **Mary** and the human class *Human*. In formalization, free variables will be assumed to be universally quantified and classes will be represented by unary predicates without being reified: e.g.  $HUMAN(x) \rightarrow ANIMAL(x)$  (“Every human is an animal”).

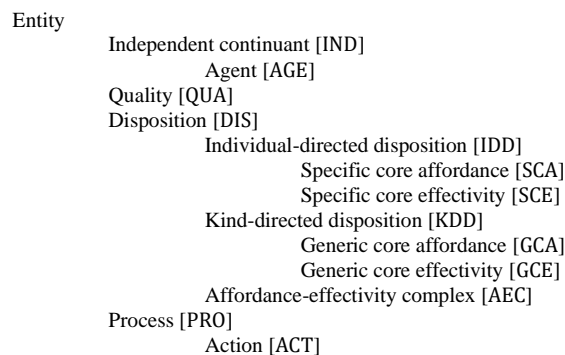
Instances fall into two categories: continuants (aka “endurants”) and occurrents (aka “perdurants”). Roughly speaking, continuants persist in time: they exist at one time and also exist at another different time (refer to Toyoshima (2020b) for details on an ontology of persistence). Continuants can be further divided into independent continuants and dependent continuants. As for the relationship between them, we will assume here that a dependent continuant inheres (INH) in exactly one independent continuant, where inherence is a form of existential dependance (refer to Borgo & Masolo (2010) for details on this inherence relation; and as we will see, there can be relations of existential dependence different from inherence). For instance, Mary’s mass depends on and also inheres in Mary. One paradigmatic example of independent continuants (IND) is objects such as steps. Among objects are agents (AGE) such as Mary.

In contrast, occurrents extend through time and they have temporal parts. This paper will focus on a subtype of occurrents called “process” (PRO): occurrents that independent continuants (especially objects) participate in. Among processes are actions (ACT) such as Mary’s climbing a step (see, for details, Trypuz’s (2007) formal ontology of actions). Note that this differs from the view of processes as so-called “dynamic occurrents” or “continuant-like occurrents” (refer to Toyoshima (2019) for more detailed and critical thoughts on these alleged “dynamic processes”). Formal constraints on those basic categories and relations are outside the scope of this paper.

As for the parthood (P) relation, Casati & Varzi’s (1999) Closed Extensional Mereology (CEM) will be assumed for all practical purposes (see, for instance, Borgo & Mizoguchi’s (2014) usage of CEM in formalizing an upper ontology). It is a binary relation between processes or independent continuants, above all objects (refer to Masolo et al. (2020) for details on parthood involved in objects). Other mereological relations and operators will be defined as usual in CEM, such as O ( $O(x,y)$  for “x and y overlap”), PP ( $PP(x,y)$  for “x is a proper part of y”), and SUM ( $SUM(z,x,y)$  for “z is the sum of x and y”).

## 2.2. Overview of classes and relations introduced in the paper

We will use in the core of this paper (Section 3) the taxonomy as pictured on Figure 1.



**Figure 1.** Taxonomy of entities and associated unary predicates.

1 **Table 1.** Binary relations

Binary relation	Predicate	Domain	Range
has realization	REAL	DIS	PRO
has trigger	TRIG	DIS	PRO
reciprocal of	RECI	IDD	IDD
inheres in	INH	QUA or DIS	IND
proper part of	PP	IND	IND
overlaps	O	IND	IND
has categorical basis	CBA	DIS	QUA
has internal basis	IBA	DIS	QUA
has external basis	EBA	DIS	QUA
add-part of	ADP	DIS	DIS

2  
3  
4 All the axioms reflecting the taxonomic structure in Figure 1 will be accepted, that is, if  $A$  is a subclass  
5 of  $B$ , we accept  $A(x) \rightarrow B(x)$ . We will also introduce the relational terms with the domains and ranges in  
6 Table 1. Here again, all the associated axioms will be accepted: if  $B$  is a binary relation with domain  $D$   
7 and range  $R$ , we accept the axiom  $B(x,y) \rightarrow D(x) \wedge R(y)$ .

### 8 2.3. Ontology of dispositions

#### 9 2.3.1. General idea about dispositions

10 This paper proposes an ontology of dispositions theoretically underpinned by McKittrick’s (2018)  
11 causal approach to dispositions (which she calls “disposition pluralism”). This approach is pragmatically  
12 motivated, as it is useful for representing multifarious entities dispositionally (see Toyoshima et al.’s  
13 (2021) detailed examination of her theory). She embraces a broad conception of dispositions according  
14 to which expressions of the form “the disposition to bring about  $R$  if  $T$  holds” serve, at least partially, as  
15 a reliable guide for identifying dispositions, where  $R$  is a realization (e.g. the glass-breaking) and  $T$  is a  
16 triggering condition (e.g. the glass being forcefully pressed) (but see also Vetter’s (2015) possibility-  
17 based, rather than causal, account of dispositions *solely* in terms of their realizations, which will not be  
18 discussed in this article).

19 More specifically, a characterization of dispositions in the line of Röhl & Jansen (2011) and Barton et al.  
20 (2018) will be utilized. To explain it, two major subtypes of dependent continuants will be introduced:  
21 qualities (sometimes called “categorical” properties) and dispositions (refer to Choi & Fara (2021) for  
22 details on this categorical/dispositional distinction). A disposition is a causal property that can be linked  
23 to a realization, namely a specific process in which an independent continuant that is the bearer of the  
24 disposition participates. To be realized in a process, a disposition needs to be triggered by some other  
25 process, assuming a processual view of triggers of dispositions (McKittrick, 2018).  $REAL(x,y)$  and  
26  $TRIG(x,y)$  state that  $y$  is a realization and trigger of  $x$ , respectively. Classical examples include fragility  
27 (the disposition to break when pressed with a force), solubility (the disposition to dissolve when put in a  
28 solvent), and flammability (the disposition to get combusted when ignited). Dispositions may exist even  
29 if they are not realized or even triggered: for example, a glass is fragile even if it never breaks or even if  
30 it never undergoes any shock.

31 In addition, the notion of “categorical basis” of dispositions will be introduced (Barton et al., 2018).  
32 Synonyms include “causal basis” (Prior et al., 1982), “base” (Röhl & Jansen, 2011), and “categorical  
33 base” (Choi & Fara, 2021). A categorical basis of a disposition is a quality of the disposition bearer such  
34 that the disposition exists in virtue of this quality. Apart from a very special kind of dispositions (which  
35 McKittrick (2018) calls “ungrounded dispositions”), dispositions have some categorical basis (Toyoshima  
36 et al., 2021).  $CBA(x,y)$  means that  $y$  is a categorical basis of  $x$ .

1 For instance, a categorical basis of the fragility of this glass is a molecular structure (a quality) of the  
 2 glass such that the structure makes the glass fragile. In this paper, a main focus will be upon “sure-fire  
 3 dispositions” (Röhl & Jansen, 2011) whose realizations necessarily occur once the disposition has been  
 4 triggered; and also upon “single-track dispositions” (Röhl & Jansen, 2011) which have one (sufficiently  
 5 specific) kind of realizations and one (sufficiently specific) kind of triggering processes, such as the  
 6 fragility of a glass, which has as realizations instances of the classes *Breaking of a glass* and as triggers  
 7 instances of *Pressing a glass*. The term “disposition” will henceforth refer to a sure-fire and single-track  
 8 disposition unless otherwise stated (refer to Röhl & Jansen (2011) for a formalization of such dispositions  
 9 and Barton et al. (2018) for their identity conditions).

### 10 2.3.2. A theory of parthood between dispositions

11 Finally, Barton et al.’s (2017) theory of part-whole relations (DP) between dispositions will be  
 12 presented. We will focus on two subtypes of disposition-parthood: mod-parthood and add-parthood. Note  
 13 that proper mod-parthood (MOD-PP) and proper add-parthood (ADD-PP) can be straightforwardly  
 14 defined, just as proper parthood (PP) is defined in terms of parthood (P) in CEM.

15 First, mod-parthood represents several possible pathways, or *modes*, of realizations of dispositions. For  
 16 example, the ferromagnetic disposition of this magnet has two mod-parts, i.e. its disposition to attract  
 17 another magnet when facing an unlike pole and its disposition to repulse another magnet when facing a  
 18 like pole. Note that a disposition that has several proper mod-parts is a “multi-track disposition” (Barton  
 19 & Jansen, 2016; Barton et al., 2018) which have different kinds of realizations according to different  
 20 kinds of triggers. Second, add-parthood represents the *additive* character of dispositions. For example,  
 21 the solubility disposition of this whole tablet has two add-parts, i.e. the solubility disposition of the left  
 22 half of the tablet and the solubility disposition of the right half of the tablet.

23 Formal constraints on those two subtypes of disposition-parthood will be provided. In the first place,  
 24 disposition-parthood in general (whether mod- or add-) can be characterized in terms of the bearer of the  
 25 disposition.

$$27 \text{ (DP-BEA) } [\text{DP}(d,d') \wedge \text{INH}(d,x) \wedge \text{INH}(d',y)] \rightarrow \text{P}(x,y)$$

28 If  $d$  is a disposition-part of  $d'$ ,  $d$  inheres in  $x$ , and  $d'$  inheres in  $y$ , then  $x$  is part of  $y$ .

29  
 30 Next, mod-parthood satisfies the following axioms about the realization and trigger of the “mod-  
 31 (disposition-)complex”. That is, a mod-complex is realized in a process if and only if at least one of its  
 32 proper mod-parts is realized in this process; and a mod-complex is triggered by a process if and only if at  
 33 least one of its proper mod-parts is triggered by this process.

$$35 \text{ (MOD-PP-REAL) } [\exists d_1 \text{ MOD-PP}(d_1,d_2) \wedge \text{REAL}(d_2,x)] \leftrightarrow \exists d_3 [\text{MOD-PP}(d_3,d_2) \wedge \text{REAL}(d_3,x)]$$

36  $d_2$  has a proper mod-part and  $d_2$  is realized in  $x$  if and only if there is some  $d_3$  such that  $d_3$  is a proper  
 37 mod-part of  $d_2$  and  $d_3$  is realized in  $x$ .

$$39 \text{ (MOD-PP-TRIG) } [\exists d_1 \text{ MOD-PP}(d_1,d_2) \wedge \text{TRIG}(d_2,x)] \leftrightarrow \exists d_3 [\text{MOD-PP}(d_3,d_2) \wedge \text{TRIG}(d_3,x)]$$

40  $d_2$  has a proper mod-part and  $d_2$  is triggered by  $x$  if and only if there is some  $d_3$  such that  $d_3$  is a  
 41 proper mod-part of  $d_2$  and  $d_3$  is triggered by  $x$ .

42  
 43 In the magnet example, the ferromagnetic disposition of this magnet is realized in a process of the magnet  
 44 attracting or repulsing another magnet if and only if its attraction disposition or its repulsion disposition  
 45 is realized in this process. Similarly, the ferromagnetic disposition of this magnet is triggered by a process

1 of another magnet facing an unlike or like pole if and only if its attraction disposition or its repulsion  
2 disposition is triggered by this process.

3 Then, add-parthood satisfies the following axioms about the realization and trigger of the “add-  
4 (disposition-)complex”. That is, if an add-complex is realized in a process, then any of its add-parts is  
5 realized in a part of this process; and if an add-complex is triggered by a process, then any of its add-parts  
6 is triggered by a part of this process.

7  
8 (ADD-PP-REAL)  $REAL(d_1, x) \wedge ADD-PP(d_2, d_1) \rightarrow \exists y[REAL(d_2, y) \wedge P(y, x)]$

9 If  $d_1$  is realized in  $x$  and  $d_2$  is a proper add-part of  $d_1$ , then there is some  $y$  such that  $d_2$  is realized in  
10  $y$  and  $y$  is part of  $x$ .

11  
12 (ADD-PP-TRIG)  $TRIG(d_1, x) \wedge ADD-PP(d_2, d_1) \rightarrow \exists y[TRIG(d_2, y) \wedge P(y, x)]$

13 If  $d_1$  is triggered by  $x$  and  $d_2$  is a proper add-part of  $d_1$ , then there is some  $y$  such that  $d_2$  is triggered  
14 by  $y$  and  $y$  is part of  $x$ .

15  
16 In the tablet example, if the solubility disposition of this whole tablet is realized in a process of dissolving,  
17 then all of its add-parts (i.e. the solubility dispositions of the right and left half tablets) are realized in a  
18 part of this process. Similarly, if the solubility is triggered by a process of the tablet being putting in water,  
19 then all of its add-parts are triggered by a part of this process.

### 20 3. A theory of core affordances

21 This section develops a theory of core affordances by expounding on Toyoshima’s (2018) and  
22 Toyoshima & Barton’s (2019a) preceding works. Section 3.1 presents the basic idea of Turvey’s (1992)  
23 dispositional account of affordances. To examine it, Section 3.2 elaborates the notion of “reciprocal  
24 disposition”. Then Section 3.3 conceptualizes and formalizes core affordances as a special kind of  
25 dispositions. Section 3.4 provides a model of our theory of affordances. Section 3.5 is devoted to the  
26 discussion on core affordances, in particular on their (in)definability (Section 3.5.2) and on the processual  
27 view of their realizations (Section 3.5.3).

28 The climbability of a step will be used as a driving example for explaining affordances. For one thing,  
29 it is a paradigmatic example of affordances taken from the experimental evidence gathered by ecological  
30 psychology (Warren, 1984) and, as Heras-Escribano (2019) says, it is quite useful for illustrating the  
31 nature of Gibsonian affordances, which a theory of core affordances focuses primarily on.

#### 32 3.1. Turvey’s dispositional account of dispositions

##### 33 3.1.1. Basic idea: Affordances as reciprocal dispositions with effectivities

34 Turvey’s (1992) dispositional view of affordances is motivated by an understanding of animal activity  
35 in terms of prospective control: “control concerned with future events, usually interpretable as goals to  
36 be realized” (ibid., p. 174). To walk across a cluttered room, for instance, an agent needs to know what  
37 (bodily movement) is possible. An ecological approach to prospective control thus requires that  
38 affordances should be closely linked with agents’ behaviors enabled by the environment with respect to  
39 which prospective control is conducted.

40 The key ideas of Turvey’s dispositional approach to affordances are well articulated by his following  
41 statements:

42



1 An affordance is a particular kind of disposition, one whose complement is a dispositional property  
2 of an organism. (Turvey, 1992, p. 179)  
3

4 Given that a dispositional property is not defined (i.e., it is a nonexistent property) when there is no  
5 complement, then an affordance is not defined (i.e., is nonexistent) without a complementing animal  
6 property and, in like fashion, an effectivity is not defined (i.e., is nonexistent) without a  
7 complementing environment property. (ibid., pp. 179-180)  
8

9 Therefore, an affordance is a dispositional property found in the environment such that the affordance is  
10 a “complement” of the organism’s dispositional property which Turvey calls “effectivity”. For instance,  
11 the climbability affordance of this step is its disposition to move Mary upward and its complement is  
12 Mary’s disposition (effectivity) to move upward. To develop an account of core affordances, an  
13 affordance and its “complementary” effectivity need to be formalized. For this purpose, Section 3.2  
14 introduces the general notion of “reciprocal disposition” so that affordances and effectivities (which will  
15 be named “specific core affordances” and “specific core effectivities”) can be analyzed as reciprocal  
16 dispositions. (Note that the subject matter for now is the climbability of a step, rather than its  
17 “descendability” or both. However, it would be possible to consider the affordance of a step as its  
18 disposition to move Mary upward *or downward*. As will be shown in Section 3.5.1, this construal of the  
19 affordance of a step can be modeled as an extension of the climbability affordance of the step.)

### 20 3.1.2. Dispositions for affordances: Are they ontic or predicatory properties?

21 Before the introduction of reciprocal dispositions in Section 3.2, it is necessary to understand accurately  
22 what Turvey (1992) means by the term “disposition” or “dispositional property”. He defends what he  
23 calls “property realism” and conceives dispositions as “real properties” (ibid., Section 3). To clarify this  
24 point, it will be helpful to consider Bird’s (2016) argument that the term “disposition” is open to both  
25 “ontic” and “predicatory” interpretations. Interpreted ontically, it refers to a property with dispositional  
26 *essence* that plays a distinctive ontological role. Interpreted predicatorily, by contrast, it is an  
27 ontologically uncommitted, mere *façon de parler*. To take one example, the statement “This fragile glass  
28 is *disposed* to break if it is pressed with a certain force” does not *ipso facto* entail dispositions in the ontic  
29 sense of the term. From Bird’s perspective, Turvey’s view of dispositions as real properties would mean  
30 that dispositions should be construed ontically, rather than predicatorily.

31 However, it may suffice to have a predicatory understanding of dispositions in order to adopt a  
32 dispositional approach to affordances. Bird (2016) maintains that an ontology of dispositions (in the ontic  
33 sense of the term) is not necessarily vindicated by an illuminating dispositional account of something,  
34 such as causation (Bird, 2020). Furthermore, Heras-Escribano’s (2019) dispositional theory of  
35 affordances is based on Ryle’s (1949) “non-factualist” interpretation of dispositions and consequently,  
36 affordances are “not entities per se” but “a special way of explaining the complementarity relationship  
37 between the organism and environment” (Heras-Escribano, 2019, p. 88). This would be equivalent to a  
38 predicatory construal of dispositions.

39 It would be therefore a viable modeling option to combine Turvey’s dispositional view of affordances  
40 with a predicatory interpretation of dispositions. In this case, a different general ontological framework  
41 from the one presented in Section 2.1 may be presupposed, especially a framework that does not adopt  
42 the categorical quality/disposition distinction. Notably, this approach could mesh with upper ontologies  
43 (e.g. DOLCE) that do not have the category of disposition. Consider, for instance, Ortmann & Kuhn’s  
44 (2010, 2012) formalization of Turveian affordances as a subtype of the DOLCE category of quality.

45 Nevertheless, there may be some considerations in favor of a dispositional theory of affordances relying  
46 on an ontology of dispositions. For instance, an ontology of dispositions can meet some modeling

1 purposes that a predicatory understanding of dispositions would fail to, such as the building of a realist  
 2 ontology of the environment (Smith, 2009) (see Section 5 for discussion on affordances and the  
 3 environment). An ontology of dispositions has been undoubtedly subject to criticism. To take one  
 4 example, Guarino (2016) would seem to think that laws of nature could fulfill the ontological role that  
 5 dispositions can. However, dispositions are as relevant to scientific ontologies in general, as causation,  
 6 laws of nature, and counterfactuals are (Toyoshima, 2020a). As for Guarino’s worry, Turvey (1992)  
 7 emphasizes the vital role of laws of nature in his theorizing on affordances (ibid., Section 4). Therefore,  
 8 dispositions and laws of nature may be complementary with each other in Turvey’s dispositional approach  
 9 to affordances (for more thoughts, see Kistler’s (2020) and Ioannidis et al.’s (2021) philosophical  
 10 arguments for dispositions and primitive lawhood in a governing account of laws of nature).

### 11 3.2. Interlude: Reciprocal disposition

#### 12 3.2.1. Basic idea

13 The idea of reciprocal disposition can be attributed to Martin (2008). In formal ontology, it has been  
 14 examined under labels such as “complementary disposition” (Goldfain et al., 2010) and “reciprocal  
 15 dependence” among dispositions (Arp et al., 2015, p. 104). Classical examples include a key (say **key**<sub>1</sub>)  
 16 and a lock (say **lock**<sub>2</sub>) such that **key**<sub>1</sub> opens **lock**<sub>2</sub>. Intuitively, **key**<sub>1</sub> has the disposition **d**<sub>key1</sub> to open **lock**<sub>2</sub>,  
 17 and **lock**<sub>2</sub> has the disposition **d**<sub>lock2</sub> to be opened by **key**<sub>1</sub>. Those two dispositions, **d**<sub>key1</sub> and **d**<sub>lock2</sub>, have  
 18 something in common. That is, they have the same class of realization processes (say *lock*<sub>2</sub>-*opening-by-*  
 19 *key*<sub>1</sub>) and they have the same class of triggering processes (say *key*<sub>1</sub>-*pivoting-in-lock*<sub>2</sub>) (but see Section  
 20 3.5.3 for discussion on this processual view of realizations of dispositions in general). This key/lock  
 21 scenario will be used as a guiding example for characterizing reciprocal dispositions formally.

22 A brief philosophical remark on reciprocal dispositions will be made here. As a matter of fact, Martin  
 23 (2008) proposes his model of reciprocal dispositions as an *alternative* to the traditional “stimulus-  
 24 response” model of dispositions as presented in Section 2.3.1 (see Anjum & Mumford’s (2017) detailed  
 25 discussion on Martin’s model). This new model may take a trigger of a disposition to be its reciprocal  
 26 disposition rather than some process: for instance, the solubility disposition of this salt and the dissolving  
 27 disposition of this water are triggered by each other and mutually realized in a process of the salt  
 28 dissolving in the water. In this paper, by contrast, the notion of reciprocal disposition is developed in the  
 29 context of a trigger-realization account of dispositions. As will be explained in detail below, it turns out  
 30 to be a specific interpretation of “extrinsic dispositions” (McKittrick, 2003, 2018).

31 To formalize reciprocal dispositions, the “reciprocity relation” (RECI) between dispositions is  
 32 introduced (e.g. RECI(**d**<sub>key1</sub>, **d**<sub>lock2</sub>)) and it is characterized by the following axioms:

33  
 34 **A1** RECI(d,d') → RECI(d',d)

35 The reciprocity relation is symmetrical.

36  
 37 **A2** RECI(d,d') ∧ RECI(d,d'') → d'=d''

38 The reciprocity relation is functional.

39  
 40 **A3** RECI(d,d') → [REAL(d,x) ↔ REAL(d',x)]

41 Two reciprocal dispositions have the same realizations.

42  
 43 **A4** RECI(d,d') → [TRIG(d,x) ↔ TRIG(d',x)]

44 Two reciprocal dispositions have the same triggers.

45

1 **A5**  $[\text{RECI}(d,d') \wedge \text{INH}(d,x) \wedge \text{NH}(d',y)] \rightarrow \neg O(x,y)$

2 The bearers of two reciprocal dispositions have no common part. (If  $d$  is reciprocal with  $d'$ ,  $d$  inheres  
3 in  $x$ , and  $d'$  inheres in  $y$ , then  $x$  and  $y$  do not overlap.)

4  
5 A5 trivially implies theorem T1:

6  
7 **T1**  $\neg \text{RECI}(d,d)$

8 The reciprocity relation is non-reflexive.  
9

10 A5 excludes the possibility that the disposition of the door closed by **lock**<sub>2</sub> to be opened by **key**<sub>1</sub> (in  
11 contrast to the disposition of **lock**<sub>2</sub> itself to be opened by **key**<sub>1</sub>) would be reciprocal of **d**<sub>lock2</sub> (the  
12 disposition of **lock**<sub>2</sub> to be opened by **key**<sub>1</sub>), which would be at odds with the intended meaning of  
13 reciprocal dispositions.

14 Turning to the categorical bases of reciprocal dispositions, let **q**<sub>key1</sub> be the categorical basis of **d**<sub>key1</sub>: the  
15 quality of **key**<sub>1</sub> that make it fit with **lock**<sub>2</sub> (for the sake of simplicity, we assume there is only one such  
16 quality). Let **q**<sub>lock2</sub> be the categorical basis of **d**<sub>lock2</sub>: the quality of **lock**<sub>2</sub> that make it fit with **key**<sub>1</sub>. One  
17 defining characteristic of **d**<sub>key1</sub> and **d**<sub>lock2</sub> is that **d**<sub>key1</sub> depends existentially not only on its categorical basis  
18 **q**<sub>key1</sub> that inheres in its bearer **key**<sub>1</sub>, but also on **q**<sub>lock2</sub> which is external to **key**<sub>1</sub>. Similarly, **d**<sub>lock2</sub> depends  
19 existentially not only on its categorical basis **q**<sub>lock2</sub> that inheres in its bearer **lock**<sub>2</sub>, but also on **q**<sub>key1</sub>, which  
20 is external to **lock**<sub>2</sub>.

21 To account for this, we can differentiate two kinds of categorical bases, namely “internal” and “external”  
22 bases. Internal bases are categorical bases of a disposition that inhere in the bearer of this disposition.  
23 External bases are categorical bases that inhere in something that does not overlap the bearer of this  
24 disposition (see definitions D1 and D2 below). Thus, since **q**<sub>lock2</sub> does not inhere in **key**<sub>1</sub>, it is an external  
25 basis of **d**<sub>key1</sub>; and **q**<sub>key1</sub> is an external basis of **d**<sub>lock2</sub> (see also Barton et al.’s (2014) discussion about  
26 external bases of dispositions).

### 27 3.2.2. Individual- and kind-directed dispositions

28 However, dispositions such as **d**<sub>key1</sub> and **d**<sub>lock2</sub> may be non-orthodox from the standpoint of an ontology  
29 of dispositions. To explain this, we will introduce the distinction between intrinsic and extrinsic properties.  
30 A property (particular) is intrinsic if that property exists and inheres in its bearer purely in virtue of the  
31 way the bearer is; and a property is extrinsic otherwise: it exists and inheres in the bearer (at least partially)  
32 in virtue of the way the world that is external to the bearer is (refer to Marshall & Weatherston (2018) for  
33 details). Dispositions are traditionally taken to be intrinsic properties, as is illustrated by BFO  
34 characterizing them as “internally grounded realizable entities”, and UFO classifying them as a subtype  
35 of “intrinsic moments”, respectively (see Toyoshima et al.’s (2021) discussion on dispositions in BFO).  
36 For example, the fragility of a certain glass is intrinsic because the glass is fragile under any external  
37 circumstances, even when packed in a bubble wrap.

38 On the contrary, **d**<sub>key1</sub> and **d**<sub>lock2</sub> are extrinsic, as whether **d**<sub>key1</sub> inheres in **key**<sub>1</sub> depends also on its  
39 external basis **q**<sub>lock2</sub>, and similarly, whether **d**<sub>lock2</sub> inheres in **lock**<sub>2</sub> depends also on its external basis **q**<sub>key1</sub>.  
40 This is in accordance with Shoemaker’s (1980) examination of the key/door example based on Geach’s  
41 (1969) notion of “mere Cambridge change”: roughly, a property change that does not involve any intrinsic  
42 physical change. As a result, **d**<sub>key1</sub> and **d**<sub>lock2</sub> are “extrinsic dispositions” (McKittrick, 2003; but see  
43 Contessa’s (2012) argument that extrinsic dispositions do not need extrinsic bases). According to  
44 McKittrick’s (2018) disposition pluralism, there are many different kinds of dispositions such as “extrinsic  
45 dispositions” and “intrinsic dispositions” (see Toyoshima et al.’s (2021) formal analysis of extrinsic

1 dispositions). As Vetter (2018) claims, Turvey’s (1992) dispositional account of affordances (which will  
2 be scrutinized in Section 3.3) entails an ontological commitment to extrinsic dispositions.

3 In this way of thinking, there is a modeling choice to introduce dispositions that are intimately  
4 connected to but different from  $\mathbf{d}_{\text{key}_1}$  and  $\mathbf{d}_{\text{lock}_2}$ . Let  $Key_1$  be the class of keys that can open  $\text{lock}_2$  (in  
5 particular,  $\text{key}_1$  is an instance of  $Key_1$ ) and  $Lock_2$  the class of locks that can be opened by  $\text{key}_1$  (in  
6 particular,  $\text{lock}_2$  is an instance of  $Lock_2$ ). Let  $Q_1$  be the class of qualities that characterize the structure of  
7 instances of  $Key_1$  that enable them to open  $\text{lock}_2$ , and  $Q_2$  be the class of qualities that characterize the  
8 structures of instances of  $Lock_2$  that enable them to be opened by  $\text{key}_1$ , such that  $\mathbf{q}_{\text{key}_1}$  is an instance of  $Q_1$   
9 and  $\mathbf{q}_{\text{lock}_2}$  is an instance of  $Q_2$ . Now consider the following two dispositions:

- 10
- 11 ● the disposition  $\mathbf{d}_{\text{key}_1}'$  of  $\text{key}_1$  to open a lock instance of  $Lock_2$
- 12 ● the disposition  $\mathbf{d}_{\text{lock}_2}'$  of  $\text{lock}_2$  to be opened by a key instance of  $Key_1$
- 13

14 Notably,  $\mathbf{d}_{\text{key}_1}'$  and  $\mathbf{d}_{\text{lock}_2}'$  are different from  $\mathbf{d}_{\text{key}_1}$  and  $\mathbf{d}_{\text{lock}_2}$  in several ways. For one thing, unlike  $\mathbf{d}_{\text{key}_1}$ ,  
15  $\mathbf{d}_{\text{key}_1}'$  does not depend existentially on  $\text{lock}_2$  or on any individual lock similar to  $\text{lock}_2$ . Likewise, unlike  
16  $\mathbf{d}_{\text{lock}_2}$ ,  $\mathbf{d}_{\text{lock}_2}'$  does not depend existentially on  $\text{key}_1$  or on any individual key similar to  $\text{key}_1$ . That is to say,  
17 neither  $\mathbf{d}_{\text{key}_1}'$  nor  $\mathbf{d}_{\text{lock}_2}'$  has any external bases, and  $\mathbf{d}_{\text{key}_1}'$  and  $\mathbf{d}_{\text{lock}_2}'$  are intrinsic dispositions, whereas  
18  $\mathbf{d}_{\text{key}_1}$  and  $\mathbf{d}_{\text{lock}_2}$  are extrinsic dispositions. For another,  $\mathbf{d}_{\text{key}_1}$  and  $\mathbf{d}_{\text{lock}_2}$  are reciprocal with each other, while  
19  $\mathbf{d}_{\text{key}_1}'$  and  $\mathbf{d}_{\text{lock}_2}'$  are not reciprocal from each other. Indeed,  $\mathbf{d}_{\text{key}_1}'$  and  $\mathbf{d}_{\text{lock}_2}'$  do not have the same class of  
20 realizations or the same class of triggers: for example, there can be a process in which  $\mathbf{d}_{\text{key}_1}'$  is realized  
21 but  $\mathbf{d}_{\text{lock}_2}'$  is not, such as a process of  $\text{key}_1$  opening another lock instance of  $Lock_2$  than  $\text{lock}_2$ . Intuitively,  
22  $\mathbf{d}_{\text{key}_1}$  is a disposition that is directed at the individual  $\text{lock}_2$ , whereas  $\mathbf{d}_{\text{lock}_2}'$  is a disposition that is directed  
23 at the kind  $Lock_2$ . Similarly,  $\mathbf{d}_{\text{lock}_2}$  is directed at the individual  $\text{key}_1$ , whereas  $\mathbf{d}_{\text{key}_1}'$  is directed at the kind  
24  $Key_1$ . In other words,  $\mathbf{d}_{\text{key}_1}$  and  $\mathbf{d}_{\text{lock}_2}$  are “individual-directed dispositions” and  $\mathbf{d}_{\text{key}_1}'$  and  $\mathbf{d}_{\text{lock}_2}'$  are “kind-  
25 directed dispositions” (where the latter is a renaming of Toyoshima & Barton’s (2019a) “family-directed  
26 dispositions”).

27 The “having as internal basis” relation (IBA) and “having as external basis” relation (EBA) are formally  
28 defined by definitions D1 and D2. A6 states that every disposition has at least one internal basis. A7  
29 specifies the relationship between the internal bases of a disposition and some external bases of its  
30 reciprocal disposition. Individual-directed dispositions (IDD) and kind-directed dispositions (KDD) are  
31 characterized in terms of external bases with the axioms A8 and A9, respectively (and as a reminder,  
32 RECI was defined earlier as holding on IDD).

33

34 **D1**  $\text{IBA}(d,q) :=_{\text{def}} \text{CBA}(d,q) \wedge \exists x [\text{INH}(d,x) \wedge \text{INH}(q,y)]$

35 An internal basis of a disposition is a categorical basis of this disposition that inheres in the  
36 disposition bearer. (d has q as external basis, and there is some x in which both d and q inhere.)  
37

38 **D2**  $\text{EBA}(d,q) :=_{\text{def}} \text{CBA}(d,q) \wedge \exists x,y [\text{INH}(d,x) \wedge \text{INH}(q,y) \wedge \neg O(x,y)]$

39 An external basis of a disposition is a categorical basis of this disposition that inheres in something  
40 that does not overlap the disposition bearer. (d has q as external basis, and there is some x and y that  
41 do not overlap such that x inheres in x and q inheres in y.)  
42

43 **T2**  $[\text{EBA}(d,q) \wedge \text{INH}(d,x)] \rightarrow \neg \text{INH}(q,x)$

44 An external basis of a disposition does not inhere in the bearer of the disposition. (If d has q as  
45 external basis and d inheres in x, then q does not inhere in x.)

46 *Proof:* Suppose that  $\text{EBA}(d,q)$  and  $\text{INH}(d,x)$ . Assume for *reductio* that  $\text{INH}(q,x)$ . By D2,  $\neg O(x,x)$ .

47 This contradicts the axiom that anything overlaps with itself. QED.  
48

1 **A6**  $\text{DIS}(d) \rightarrow \exists q \text{IBA}(d,q)$

2 Every disposition has at least one internal basis. (If  $d$  is a disposition, then there is some  $q$  such that  
3  $d$  has  $q$  as internal basis.)

4  
5 **A7**  $\text{RECI}(d,d') \wedge \text{IBA}(d,q) \rightarrow \text{EBA}(d',q)$

6 Any internal basis of a disposition that has a reciprocal disposition is an external basis of this  
7 reciprocal disposition (If  $d$  is reciprocal with  $d'$  and  $d$  has internal basis  $q$ , then  $d'$  has external basis  $q$ )  
8

9 Note that we do not suppose the contraposed: the external basis of a disposition  $d$  that has a reciprocal  
10 disposition  $d'$  might not be an internal basis of  $d'$ . Indeed, there are several ways for a disposition to have  
11 an external basis, and having a reciprocal disposition is only one of those ways (refer to Barton et al.  
12 (2014) for alternative ways).  
13

14 We can prove that any reciprocal disposition has an external basis:

15  
16 **T3**  $\text{RECI}(d,d') \rightarrow \exists q \text{EBA}(d,q)$

17 *Proof:* Suppose that  $\text{RECI}(d,d')$ . By A6, there is an internal basis  $q$  of  $d'$ . By A7,  $q$  is an external  
18 basis of  $d$ . QED.  
19

20 We actually accept the axiom A8 that any individual-directed has an external basis (which is stronger  
21 than T3, as we do not exclude there might be some individual-directed dispositions that are not reciprocal  
22 dispositions):  
23

24 **A8**  $\text{IDD}(d) \rightarrow \exists q \text{EBA}(d,q)$

25 An individual-directed disposition is a disposition and has an external basis. (If  $d$  is an individual-  
26 directed disposition, then  $d$  is a disposition and there is some  $q$  such that  $d$  has  $q$  as external basis.)  
27

28 **A9**  $\text{KDD}(d) \rightarrow \neg \exists q \text{EBA}(d,q)$

29 A kind-directed disposition is a disposition and has no external basis. (If  $d$  is a kind-directed  
30 disposition, then  $d$  is a disposition and there is no  $q$  such that  $d$  has  $q$  as external basis.)  
31

32 T3 and A9 yield together the theorem T4 that is relevant to the nature of kind-directed dispositions.  
33

34 **T4**  $\text{KDD}(d) \rightarrow \neg \exists d' \text{RECI}(d,d')$

35 No kind-directed disposition is reciprocal with anything. (If  $d$  is a kind-directed disposition, then  
36 there is no  $d'$  such that  $d$  is reciprocal with  $d'$ .)

37 *Proof:* Suppose that  $\text{KDD}(d)$ . Then by A9 there is no  $x$  such that  $\text{EBA}(d,x)$ . Suppose for *reductio*  
38 that there is some  $d'$  such that  $\text{RECI}(d, d')$ . Then by T3, there is some  $q$  such that  $\text{EBA}(d,q)$ .  
39 Contradiction. Therefore,  $\neg \exists d' \text{RECI}(d,d')$ . QED.

### 40 3.3. Formalizing core affordances

#### 41 3.3.1. The affordance/effectivity complex

42 As was explained in Sections 3.1 and 3.2, the crux of Turvey's (1992) dispositional approach to  
43 affordances can be formulated, in the terminology of this paper, as the statement that affordances and  
44 effectivities are reciprocal dispositions from each other, and are therefore individual-directed dispositions  
45 (which are extrinsic). Additionally, it was shown that there are also dispositions that are intimately related

1 with individual-directed ones: kind-directed dispositions (which are intrinsic). In what follows, Turvey’s  
 2 account of affordances will be more fully presented and be formalized by means of this ontology of  
 3 dispositions. Its central idea is that an affordance is to be understood not only in terms of an effectivity  
 4 (the reciprocal disposition with the affordance) but also in terms of a third property that is borne by the  
 5 “system” composed of the affordance bearer and the effectivity bearer. This “third property” of a system  
 6 will be explored below (for more theoretical details on extrinsic dispositions, see Vetter’s (2015) systemic  
 7 account of extrinsic dispositions, which she calls “extrinsic potentialities”, and its formal examination by  
 8 Toyoshima et al. (2021)).

9 Imagine a scenario in which a person (say **Mary**) climbed this step (say **step<sub>0</sub>**). This concrete example  
 10 will be called “CLIMB”. Let **a<sub>0</sub>** be the climbability affordance of **step<sub>0</sub>** and let **e<sub>0</sub>** be **Mary**’s corresponding  
 11 effectivity such that RECI (**a<sub>0</sub>**,**e<sub>0</sub>**) holds. That is to say, **a<sub>0</sub>** and **e<sub>0</sub>** have the same class of realizations (say  
 12 *Mary-climbing-up-step<sub>0</sub>*) (A3), they also have the same class of triggers (say *Mary-contracting-her-legs-*  
 13 *on-step<sub>0</sub>*) (A4), and they are different because their bearers do not overlap (A5). Consider now a system  
 14 (say the **Mary/step<sub>0</sub>** system) composed of **Mary** and **step<sub>0</sub>**. A system is, roughly, a complex object (or  
 15 an aggregate of objects) with specific kinds of parts and relationships between them. However, an  
 16 accurate ontological characterization of systems is beyond the scope of this paper (refer to Röhl (2012)  
 17 for some considerations) and the **Mary/step<sub>0</sub>** system will be assumed to be analyzable simply as the sum  
 18 of **Mary** and **step<sub>0</sub>**, namely an entity written **Mary+step<sub>0</sub>** such that  
 19 SUM (**Mary+step<sub>0</sub>**, **Mary**, **step<sub>0</sub>**) holds. According to Turvey’s (1992, p. 180) semi-formal explication,  
 20 **Mary+step<sub>0</sub>** bears neither **a<sub>0</sub>** nor **e<sub>0</sub>** and there is a third property instance (say **ae<sub>0</sub>**) such that **Mary+step<sub>0</sub>**  
 21 bears **ae<sub>0</sub>** and neither **Mary** nor **step<sub>0</sub>** bears **ae<sub>0</sub>**. The bearer (i.e. **Mary+step<sub>0</sub>**) of **ae<sub>0</sub>** is the sum of the  
 22 bearers (i.e. **Mary** and **step<sub>0</sub>**) of **a<sub>0</sub>** and **e<sub>0</sub>**. Accordingly, **ae<sub>0</sub>** would be formalized as being in some sense  
 23 the “sum” of **a<sub>0</sub>** and **e<sub>0</sub>**.

24 To formalize this third property, a ternary relation (CES) between dispositions will be introduced such  
 25 that CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) is read as “**d<sub>1</sub>** is a causally equivalent sum of and **d<sub>2</sub>** and **d<sub>3</sub>**” and e.g.  
 26 CES (**ae<sub>0</sub>**,**a<sub>0</sub>**,**e<sub>0</sub>**) holds. This relation can be characterized by the axioms A10 to A14, and the theorems T5  
 27 and T6 trivially follow from the preceding axioms.

28  
 29 **A10** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) → DIS(**d<sub>1</sub>**) ∧ DIS(**d<sub>2</sub>**) ∧ DIS(**d<sub>3</sub>**) ∧ RECI(**d<sub>2</sub>**,**d<sub>3</sub>**)

30 If **d<sub>1</sub>** is a causally equivalent sum of **d<sub>2</sub>** and **d<sub>3</sub>**, then **d<sub>1</sub>**, **d<sub>2</sub>**, and **d<sub>3</sub>** are dispositions and **d<sub>2</sub>** is reciprocal  
 31 with **d<sub>3</sub>**.

32  
 33 **A11** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) ↔ CES(**d<sub>1</sub>**,**d<sub>3</sub>**,**d<sub>2</sub>**)

34 The causally equivalent sum of **d<sub>2</sub>** and **d<sub>3</sub>** is the same as that of **d<sub>3</sub>** and **d<sub>2</sub>**.

35  
 36 **A12** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) → [REAL(**d<sub>1</sub>**,**x**) ↔ REAL(**d<sub>2</sub>**,**x**)]

37 A causally equivalent sum has the same realizations as the first of its two reciprocal dispositions.

38  
 39 **A13** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) → [TRIG(**d<sub>1</sub>**,**x**) ↔ TRIG(**d<sub>2</sub>**,**x**)]

40 A causally equivalent sum has the same triggers as the first of its two reciprocal dispositions.

41  
 42 **T5** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) → [REAL(**d<sub>1</sub>**,**x**) ↔ REAL(**d<sub>2</sub>**,**x**) ↔ REAL(**d<sub>3</sub>**,**x**)]

43 A causally equivalent sum has the same realizations as its two reciprocal dispositions.

44 *Proof.* Omitted. It trivially follows from A3, A10 and A12.

45  
 46 **T6** CES(**d<sub>1</sub>**,**d<sub>2</sub>**,**d<sub>3</sub>**) → [TRIG(**d<sub>1</sub>**,**x**) ↔ TRIG(**d<sub>2</sub>**,**x**) ↔ TRIG(**d<sub>3</sub>**,**x**)]

47 A causally equivalent sum has the same triggers as its two reciprocal dispositions.

1 *Proof.* Omitted. It trivially follows from A4, A10 and A13.

2  
3 **A14**  $[\text{CES}(d_1, d_2, d_3) \wedge \text{INH}(d_1, x) \wedge \text{INH}(d_2, y) \wedge \text{INH}(d_3, z)] \rightarrow \text{SUM}(x, y, z)$

4 The bearer of a causally equivalent sum is the sum of the bearers of the two reciprocal dispositions.  
5 (If  $d_1$  is a causally equivalent sum of  $d_2$  and  $d_3$ ,  $d_1$  inheres in  $x$ ,  $d_2$  inheres in  $y$ , and  $d_3$  inheres in  $z$ ,  
6 then  $x$  is a sum of  $y$  and  $z$ .)  
7

8 Moreover, this CES relation can be further elucidated in terms of add-parthood between dispositions. For  
9 instance, ADD-PP ( $\mathbf{a}_0, \mathbf{ae}_0$ ) and ADD-PP ( $\mathbf{e}_0, \mathbf{ae}_0$ ) would both hold, as hinted by the fact that  $\mathbf{a}_0$  and  $\mathbf{ae}_0$ ,  
10 as well as  $\mathbf{e}_0$  and  $\mathbf{ae}_0$ , satisfy the three axioms characterizing add-parthood, respectively:

11 (DP-BEA) The bearers of  $\mathbf{a}_0$  and  $\mathbf{e}_0$  (i.e. **Mary** and **step<sub>0</sub>**) are (proper) parts of the bearer (i.e.  
12 **Mary+step<sub>0</sub>**) of  $\mathbf{ae}_0$ .

13 (ADD-PP-REAL) If  $\mathbf{ae}_0$  is realized in a process of **Mary** climbing up **step<sub>0</sub>**, then both  $\mathbf{a}_0$  and  $\mathbf{e}_0$   
14 are realized in a part of this process (namely, this very process).

15 (ADD-PP-TRIG) If  $\mathbf{ae}_0$  is triggered by a process of **Mary** positioning her feet on **step<sub>0</sub>**, then both  
16  $\mathbf{a}_0$  and  $\mathbf{e}_0$  are triggered by a part of this process (namely, this very process).  
17  
18

19 In general, the following axiom holds:

20  
21 **A15**  $\text{CES}(d_1, d_2, d_3) \rightarrow \text{ADP}(d_2, d_1) \wedge \text{ADP}(d_3, d_1)$

22 A causally equivalent sum has as add-parts its two reciprocal dispositions. (If  $d_1$  is a causally  
23 equivalent sum of  $d_2$  and  $d_3$ , then  $d_1$  is an add-part of  $d_2$  and  $d_3$  is an add-part of  $d_1$ .)  
24

25 All these considerations can lead to the conceptualization of what Turvey (1992) calls “third property”  
26 as an “affordance/effectivity complex”: the “causally equivalent add-whole” that has as add-parts an  
27 affordance and its reciprocal effectivity. An affordance (e.g.  $\mathbf{a}_0$ ), its corresponding effectivity (e.g.  $\mathbf{e}_0$ ),  
28 and their affordance/effectivity complex (e.g.  $\mathbf{ae}_0$ ) have the same realizations and triggers. In this sense,  
29 all those three dispositions may be informally said to play the same causal role. Nevertheless, they have  
30 different bearers, as the bearers of add-parts are a part of the bearer of the add-complex. In other words,  
31 two reciprocal dispositions can be seen as two “causal aspects” of a more encompassing disposition, when  
32 viewed from the perspective of a part of the bearer of this disposition. Consider, for example, the  
33 disposition  $\mathbf{d}_3$  of the “**key<sub>1</sub>/lock<sub>2</sub>** system” which is the causally equivalent sum of  $\mathbf{d}_{\text{key}1}$  and  $\mathbf{d}_{\text{lock}2}$ . Then  
34  $\mathbf{d}_{\text{key}1}$  would be a causal aspect of  $\mathbf{d}_3$ , when viewed from the perspective of **key<sub>1</sub>**, and  $\mathbf{d}_{\text{lock}2}$  would be a  
35 causal aspect of  $\mathbf{d}_3$ , when viewed from the perspective of **lock<sub>2</sub>**.

36 Additionally, an affordance, its reciprocal effectivity, and their affordance/effectivity complex have  
37 different categorical bases. We can assume that the categorical basis of  $\mathbf{ae}_0$  is closely related to the  
38 categorical bases of  $\mathbf{a}_0$  and  $\mathbf{e}_0$ . (However, the general axiomatization of this claim requires a theory of  
39 parthood between qualities, which is outside the scope of this paper; for an account of parthood that  
40 encompasses parthood between qualities, refer to Borgo & Masolo (2010)) An affordance, its reciprocal  
41 effectivity, and their affordance/effectivity complex are different because they do not have the same  
42 internal and external bases. This accords well with Turvey’s view of a “third property” for affordances  
43 (and effectivities).

### 44 3.3.2. Two kinds of core affordances

45 There are two major ways of formalizing core affordances depending on whether they are taken as  
46 individual-directed or kind-directed dispositions. On the one hand, a straightforward interpretation of

1 Turvey’s (1992) dispositional account of affordances yields the triad of an affordance (an individual-  
 2 directed disposition), an effectivity (the reciprocal disposition with the affordance), and an  
 3 affordance/effectivity complex (the causally equivalent sum of the affordance and the effectivity). As  
 4 said, affordances as construed this way are “extrinsic dispositions”, as they are dispositions that have an  
 5 external basis. This interpretation may well capture the “specificity” of affordances, which Heras-  
 6 Escribano (2019) regards as one of the distinguishing features of Gibsonian affordances: there is a strong  
 7 correlation between “ecological information” of the environment and the available affordances for the  
 8 agent. In this sense, affordances conceived as *individual*-directed dispositions may coincide better with  
 9 Gibsonian affordances than when conceived as kind-directed dispositions.

10 In this line of thinking an affordance in the case of an individual-directed disposition will be called  
 11 “specific core affordance” (SCA), and its corresponding term “specific core effectivity” (SCE) is  
 12 introduced. They are inherently related to an affordance/effectivity complex (AEC). The axioms A16 to  
 13 A21 characterize specific core affordances and effectivities, affordance/effectivity complexes, and their  
 14 interrelations. The theorems T7 and T8 say that specific core effectivities and affordance/effectivity  
 15 complexes are realized in actions (ACT) as well.

16  
 17 **A16**  $SCA(x) \rightarrow \exists y[IND(y) \wedge \neg AGE(y) \wedge INH(x,y)]$

18 A specific core affordance inheres in a non-agentive object.

19  
 20 **A17**  $SCE(x) \rightarrow \exists y[AGE(y) \wedge INH(x,y)]$

21 A specific core effectivity inheres in an agent.

22  
 23 **A18**  $[SCA(x) \wedge REAL(x,y)] \rightarrow ACT(y)$

24 A specific core affordance is realized only in actions.

25  
 26 **A19**  $SCA(x) \rightarrow \exists y,z[SCE(y) \wedge AEC(z) \wedge CES(z,x,y)]$

27 For any specific core affordance, there is some specific core effectivity and some  
 28 affordance/effectivity complex that is the causally equivalent sum of the affordance and the  
 29 effectivity.

30  
 31 **A20**  $SCE(x) \rightarrow \exists y,z[SCA(y) \wedge AEC(z) \wedge CES(z,x,y)]$

32 For any specific core effectivity, there is some specific core affordance and some  
 33 affordance/effectivity complex that is the causally equivalent sum of the effectivity and the  
 34 affordance.

35  
 36 **A21**  $AEC(x) \rightarrow \exists y,z[SCA(y) \wedge SCE(z) \wedge CES(x,y,z)]$

37 For any affordance/effectivity complex, there is some specific core affordance and some specific  
 38 core effectivity that are causally equivalent add-parts of the affordance/effectivity complex.

39  
 40 **T7**  $[SCE(x) \wedge REAL(x,y)] \rightarrow ACT(y)$

41 Specific core effectivities are only realized in actions.

42 *Proof.* Suppose that  $SCE(x) \wedge REAL(x,y)$ . Then by  $SCE(x)$  and A20, there exist  $z$  and  $w$  such that  
 43  $SCA(z) \wedge AEC(w) \wedge CES(w,x,z)$ . Then by  $REAL(x,y)$ ,  $CES(w,x,z)$ , and T5, we have  $REAL(z,y)$ .  
 44 From  $SCA(z)$ ,  $REAL(z,y)$ , and A18,  $ACT(y)$  can be deduced. QED.

45  
 46 **T8**  $[AEC(x) \wedge REAL(x,y)] \rightarrow ACT(y)$

47 Affordance/effectivity complexes are only realized in actions.



1 *Proof.* Suppose that  $AEC(x) \wedge REAL(x,y)$ . Then by  $AEC(x)$  and A21, there exist  $z$  and  $w$  such that  
 2  $SCA(z) \wedge SCE(w) \wedge CES(x,z,w)$ . Then by  $REAL(x,y)$ ,  $CES(x,z,w)$ , and T5,  $REAL(z,y)$ . From  $SCA(z)$ ,  
 3  $REAL(z,y)$ , and A18,  $ACT(y)$  can be deduced. QED.

4  
 5 On the other hand, kind-directed dispositions would characterize what will be called “general core  
 6 affordances” (GCA) and “general core effectivities” (GCE). For instance, **step<sub>0</sub>** has a general core  
 7 affordance **a<sub>0</sub>**’ to let instances of a class *Person<sub>0</sub>* climb **step<sub>0</sub>**, where all instances of *Person<sub>0</sub>* can climb  
 8 **step<sub>0</sub>**. Relatedly, **Mary** has a general core effectivity **e<sub>0</sub>**’ to climb instances of a class *Step<sub>0</sub>*, where all  
 9 instances of *Step<sub>0</sub>* can be climbed by **Mary**. Although they may be somewhat distant from Turveian  
 10 affordances, general core affordances can be useful for formalizing Reed’s (1996) and Chemero’s (2003)  
 11 accounts of affordances (see Section 4) and image schemas (see Section 5). General core affordances and  
 12 effectivities are characterized by the axioms A22 to A25.

13  
 14 **A22**  $GCA(x) \rightarrow \exists y[IND(y) \wedge \neg AGE(y) \wedge INH(x,y)]$

15 A general core affordance inheres in a non-agentive independent continuant.

16  
 17 **A23**  $GCE(x) \rightarrow \exists y[AGE(y) \wedge INH(x,y)]$

18 A general core effectivity inheres in an agent.

19  
 20 **A24**  $[GCA(x) \wedge REAL(x,y)] \rightarrow ACT(y)$

21 A general core affordance is realized only in actions.

22  
 23 **A25**  $[GCE(x) \wedge REAL(x,y)] \rightarrow ACT(y)$

24 A general core effectivity is realized only in actions.

25  
 26 To specify the interlink between general core affordances and effectivities on the one hand and specific  
 27 core counterparts on the other, it will be useful to employ Toyoshima et al.’s (2021) “existential reliance”  
 28 relation (REON for “relies on”) between an intrinsic disposition and an extrinsic disposition. For instance,  
 29 **d<sub>key1</sub>** relies existentially on the intrinsic disposition **d<sub>key1</sub>**’ of **key<sub>1</sub>** to open any instance (including **lock<sub>2</sub>**)  
 30 of the type *Lock<sub>2</sub>*. Hence:  $REON(d_{key1}, d_{key1}')$ . We can accept the following axiom (inspired by Toyoshima  
 31 et al.’s (2021) axiom a5): if  $d$  relies on  $d'$ , then every internal basis of  $d$  is an internal basis of  $d'$ :  
 32

33 **A26**  $REON(d,d') \wedge IBA(d',q) \rightarrow IBA(d,q)$

34 A disposition has as internal basis any internal basis of a disposition that relies on it.

35  
 36 From this, we can show the theorem:

37  
 38 **T9**  $REON(d,d') \wedge INH(d',o) \rightarrow INH(d,o)$

39 A disposition inheres in the bearer of a disposition that relies on it.

40 *Proof:* Suppose that  $d$  relies on  $d'$  and  $d'$  inheres in  $o$ . By A6,  $d'$  has some internal basis  $q$ , which  
 41 therefore inheres in  $o$ . By A26,  $q$  is an internal basis of  $d$ . Thus, the bearer of  $d$  is the bearer of  $q$ , namely  $o$ .  
 42 QED.

43  
 44 The contraposited is then a trivial consequence, using the unicity of the bearer of a dependent continuant:

45  
 46 **T10**  $REON(d,d') \wedge INH(d,o) \rightarrow INH(d',o)$

47 A disposition inheres in the bearer of a disposition on which it relies.

1  
2 We can also accept the following axioms (corresponding to Toyoshima et al. (2021)'s axioms a3 and  
3 a4): if d relies on d', then every realization of d is a realization of d', and every trigger of d is a trigger  
4 of d':

5  
6 **A27**  $REON(d,d') \wedge REAL(d,p) \rightarrow REAL(d',p)$

7 A realization of a disposition is a trigger of the disposition on which it relies.  
8

9 **A28**  $REON(d,d') \wedge TRIG(d,p) \rightarrow TRIG(d',p)$

10 A trigger of a disposition is a trigger of the disposition on which it relies.  
11

12 We can ground the relation between specific core affordances/effectivities and generic ones on the  
13 "relies on" relation, with the following axioms:  
14

15 **A29**  $SCA(x) \rightarrow \exists y (GCA(y) \wedge REON(x,y))$

16 A specific core affordance relies on some general core affordance.  
17

18 **A30**  $SCE(x) \rightarrow \exists y (GCE(y) \wedge REON(x,y))$

19 A specific core effectivity relies on some general core effectivity.  
20

21 From those axioms, T10, and the axiom that every dependent continuant inheres in some independent  
22 continuant, we can deduce trivially the following more specific assertions:  
23

24 **T11**  $SCA(x) \rightarrow \exists y,o (GCA(y) \wedge REON(x,y) \wedge INH(x,o) \wedge INH(y,o))$

25 A specific core affordance relies on some general core affordance that inheres in the same bearer.  
26

27 **T12**  $SCE(x) \rightarrow \exists y,o (GCE(y) \wedge REON(x,y) \wedge INH(x,o) \wedge INH(y,o))$

28 A specific core effectivity relies on some general core effectivity that inheres in the same bearer.  
29

30 That is, reusing Toyoshima et al.'s (2021) vocabulary, every specific core affordance has an intrinsic  
31 dependee which is a general core affordance, that we will call its "general core affordance dependee",  
32 inhering in the same bearer; and every specific core effectivity has an intrinsic dependee which is a  
33 general core effectivity (its "general core effectivity dependee"), inhering in the same bearer. To illustrate,  
34  $REON(\mathbf{a}_0, \mathbf{a}_0')$  and  $REON(\mathbf{e}_0, \mathbf{e}_0')$  hold:  $\mathbf{a}_0'$  is an intrinsic dependee of  $\mathbf{a}_0$ , and  $\mathbf{e}_0'$  is an intrinsic dependee  
35 of  $\mathbf{e}_0$ .

36 From axioms A27-A30, we can derive easily the following four theorems:  
37

38 **T13**  $SCA(x) \wedge GCA(y) \wedge REON(x,y) \wedge REAL(x,p) \rightarrow REAL(y,p)$

39 When a specific core affordance is realized, then its general core affordance dependee is realized in  
40 the same process.  
41

42 **T14**  $SCA(x) \wedge GCA(y) \wedge REON(x,y) \wedge TRIG(x,p) \rightarrow TRIG(y,p)$

43 When a specific core affordance is triggered, then its general core affordance dependee is triggered  
44 by the same process.  
45

46 **T15**  $SCE(x) \wedge GCE(y) \wedge REON(x,y) \wedge REAL(x,p) \rightarrow REAL(y,p)$

1 When a specific core effectivity is realized, then its general core effectivity dependee is realized in  
 2 the same process.

3  
 4 **T16**  $SCE(x) \wedge GCE(y) \wedge REON(x,y) \wedge TRIG(x,p) \rightarrow TRIG(y,p)$

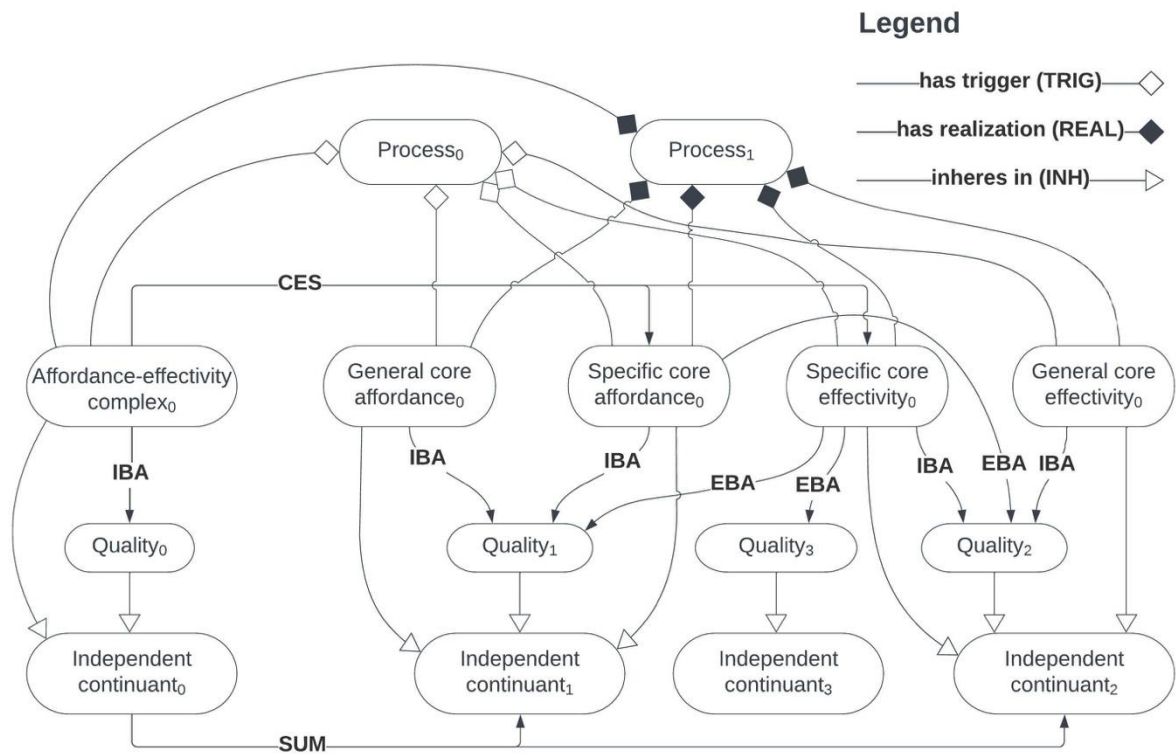
5 When a specific core effectivity is triggered, then its general core effectivity dependee is triggered  
 6 by the same process.

7  
 8 We might also add that every categorical basis of the general core affordance (alternatively: effectivity)  
 9 dependee of some specific core affordance (alternatively: effectivity) is a categorical basis of the latter.

10 It is worth noting that some above-given axioms about specific core affordances/effectivities turn out  
 11 to be theorems that can be derived from axioms about general core counterparts (such as A29 and A30)  
 12 and axioms regarding this existential reliance relation (REON). To take one example, the axiom A18  
 13 follows from A24, A27, and A29. Here, we formalized first a theory of specific core affordances based  
 14 on Turvey's (1992) extrinsically dispositional view of affordances. As a result, specific core affordances  
 15 and effectivities were formalized primarily in terms of axioms (as illustrated by A18) rather than theorems  
 16 derivable from axioms on general core affordances and effectivities.

17 **3.4. Model**

18 We have presented a logical theory including definitions D1 and D2 and axioms A1 to A30. The theory  
 19 was implemented in Alloy4 (Jackson, 2012) and the model represented in Figure 2 was found, proving  
 20 its consistency (facts involving ADP, CBA and O are omitted):



21 **Figure 2.** A model of the theory.  
 22

### 1 3.5. Discussion

2 As was announced, this subsection is devoted to the discussion about an alternative formulation of an  
3 affordance of a step (Section 3.5.1), the (in)definability of core affordances (Section 3.5.2), and the  
4 formalization of core affordances with dispositions and processes (Section 3.5.3).

#### 5 3.5.1. An alternative formulation of an affordance of a step

6 Regarding the CLIMB example, it is interesting to note that one may want to consider the affordance  
7 of **step<sub>0</sub>** not in terms of climbability alone but in terms of climbability *and* “descendability”. When  
8 specific core affordances are concerned, one may want to characterize the affordance of **step<sub>0</sub>** by dint of  
9 its disposition **a<sub>0</sub>** to move **Mary** upward and its disposition (say **a<sub>0</sub>\***) to move **Mary** downward. This  
10 more general, specific core affordance (say **a<sub>0</sub>+a<sub>0</sub>\***) of **step<sub>0</sub>** would be a mod-complex of those two  
11 dispositions, as is hinted by the fact that it satisfies the three axioms relating to mod-parthood:

- 12
- 13 (DP-BEA) The bearer (i.e. **step<sub>0</sub>**) of **a<sub>0</sub>+a<sub>0</sub>\*** is an improper part of the bearers (i.e. **step<sub>0</sub>**) of **a<sub>0</sub>** and  
14 **a<sub>0</sub>\***.
- 15 (MOD-PP-REAL) **a<sub>0</sub>+a<sub>0</sub>\*** is realized in a process of **Mary** moving using **step<sub>0</sub>** if and only if at  
16 least one of its proper mod-parts (i.e. **a<sub>0</sub>** or **a<sub>0</sub>\***) is realized in this process.
- 17 (MOD-PP-TRIG) **a<sub>0</sub>+a<sub>0</sub>\*** is triggered by a process of **Mary** positioning her feet on **step<sub>0</sub>** if and  
18 only if at least one of its proper mod-parts (i.e. **a<sub>0</sub>** or **a<sub>0</sub>\***) is realized in this process.

#### 19 3.5.2. The (in)definability of core affordances

20 Definitions are crucial for ontology construction (Smith, 2008; see also Seppälä et al.’s (2016) detailed  
21 discussion). Definitions are composed of at least two types of features. First, the main part of a definition  
22 is known as the genus and it refers to the type into which the defined entity falls. Second, further one or  
23 more parts of the definition are the differentia(e) and they distinguish the defined type from other types  
24 of the same genus. For instance, the definition of a human being as a rational animal consists of the genus  
25 part of being an animal and the differentia part of being rational. Definitions can be also divided into two  
26 kinds in respect of their form: textual definitions, which are human-readable by being written in natural  
27 language, and logical definitions, which are machine-readable by being written in formal language such  
28 as OWL. To ensure the consistency of ontology development and use, ontologies are advised to include  
29 systematically both textual and logical definitions that convey the same content of the term.

30 One may then expect an ontological definition of affordances from an account of core affordances.  
31 However, it is not straightforward to define core affordances explicitly. Consider, for instance, specific  
32 core affordances. Given their logical axioms presented above, a first attempt to provide their textual  
33 definition may be the following (while leaving aside the notion of affordance/effectivity complex for  
34 simplicity):

35

36 specific core affordance =<sub>def.</sub> A disposition that inheres in an environment within an agent-  
37 environment system and that is realized by this agent interacting with that environment.

38

39 specific core effectivity =<sub>def.</sub> A disposition that inheres in an agent within an agent-environment  
40 system and that is realized by this agent interacting with that environment.

41

42 Nonetheless, to be non-circular, such definitions would require providing explanations of “agent” and  
43 “environment” that do not make a substantive appeal to the notions of “affordances” and “effectivities”,

1 but this is a non-trivial goal that exceeds the purpose of this paper (see also Section 5.1 for the relationship  
2 between affordances and the environment).

3 Moreover, core affordances (whether specific or general) may be in nature indefinable and they may  
4 be at best *elucidated* with informal explanation, formal axioms, and/or illustrative examples, as is often  
5 the case with upper-level entities (consider e.g. continuants and occurrents, cf. Arp et al., 2015, p. 89).  
6 To see this point, consider Sanders's (1997) opinion about affordances which is motivated by his criticism  
7 of Turvey's (1992) reductive dispositional analysis of Gibsonian affordances. Its main claim is:  
8 "affordances themselves seem like excellent candidates not only for primitive terms in the explanation of  
9 perception, but as primitive to the deeper tasks of ontology itself" (Sanders, 1997, p. 111). Consequently,  
10 for Sanders, affordances may be more fundamental than objects and processes, for example.

11 On the one hand, Sanders's view of affordances as fundamental primitives would be too radical to  
12 mesh with the general ontological background of this paper. On the other hand, the present theory of core  
13 affordances could subscribe to a weaker version of his thesis: that is, affordances should be treated  
14 ontologically rather than epistemically or semantically (see Section 3.1.2), and more specifically, as a  
15 basic component of an ontology of cognition, agency, and actions *à la* Kutz et al. (2018). In this respect,  
16 it may be reasonable to take core affordances as something that would defy definition but whose nature  
17 can still be elucidated through additional clarifications.

### 18 3.5.3. Formalizing core affordances with dispositions and processes

19 The current theory of core affordances stipulates, partly for the sake of simplicity, that core affordances  
20 are sure-fire dispositions (which will be necessarily realized when triggered) whose realizations are  
21 processes (see Section 2.3.1). Doubts can be nevertheless raised over the plausibility of this claim. Using  
22 the CLIMB example, suppose that **Mary** positioned her feet on **step<sub>0</sub>**. In particular, she contracted her  
23 muscles adequately in an effort to climb up **step<sub>0</sub>**. However, a gust of wind blew so strongly that **Mary**  
24 failed to climb up **step<sub>0</sub>**. Following Williams (2019, 2020), a dilemma can arise as to whether the specific  
25 core affordance **a<sub>0</sub>** (which is a sure-fire disposition) of **step<sub>0</sub>** was realized or not. On the first horn of the  
26 dilemma, if **a<sub>0</sub>** was realized, then a whole process of **Mary** climbing up **step<sub>0</sub>** must have occurred. On the  
27 second horn, if **a<sub>0</sub>** was not realized, then it contradicts the fact that **a<sub>0</sub>** was indeed triggered by a process  
28 of **Mary** contracting her legs on **step<sub>0</sub>**.

29 Being inspired by Williams (2019, 2020), one way to resolve this dilemma is to introduce *powers* being  
30 *manifested in states of affairs* (Armstrong, 1997) by analogy with dispositions being realized in processes.  
31 Construed within the present general ontological framework, powers may form a subtype of *Dependent*  
32 *continuant* (just as dispositions are) and a state of affairs would be, very roughly, an independent  
33 continuant bearing some dependent continuant(s) (including powers) such that this state of affairs "holds"  
34 or "obtains" at instants and for longer, such as the state of affairs of Mary's being six feet tall and the  
35 state of affairs of Alice loving Bob.

36 In Williams's view, a processual realization of a disposition can be roughly seen as a causal sequence  
37 of states of affairs which are manifestations of powers. In the current "failed affordance" version of the  
38 CLIMB example, the realization of **a<sub>0</sub>** (namely, a process of **Mary** climbing up **step<sub>0</sub>**) would be analyzed  
39 as a causal series of many states of affairs (e.g. of **Mary** being in a certain physical posture) the last of  
40 which is the state of affairs (say **soa<sub>1</sub>**) of **Mary** being on **step<sub>0</sub>**, but **soa<sub>1</sub>** did not hold because the strong  
41 wind led to a different causal chain of states of affairs. To borrow Williams's expression, dispositions are  
42 "process initiators": "To have a disposition is for it to be the case that the powers of the constituent entities  
43 are poised to bring about one of a range of process types" (Williams, 2019, p. 231).

44 This line of reasoning may motivate the avoidance of the usage of sure-fire dispositions in theorizing  
45 upon affordances. Turvey's (1992) dispositional approach to affordances might then be alternatively  
46 articulated based on powers and states of affairs, perhaps with the help of a previous formal ontology of

1 states (of affairs) in first-order logic (Benevides & Masolo, 2014; Masolo, 2016; Masolo et al., 2018).  
2 However, the present account of core affordances presupposes the idea of dispositions being realized in  
3 processes while leaving examination of their “sure-fireness” for future work. For one thing, the nature of  
4 states (of affairs) may be controversial because it remains unclear whether states are classified as a  
5 subtype of continuants or occurrents (see, for thoughts, Galton’s (2018) ontological analysis of states).  
6 This can be problematic, because a theory of core affordances aims to serve as the most general ontology  
7 of affordances. Furthermore, states of affairs might yield a departure from the currently accepted,  
8 traditional continuant/occurrent distinction (refer to Kassel (2019, 2020) for this line of inquiry). For  
9 another, modelers of affordances would be typically interested in processes (e.g. **Mary** climbing up **step**<sub>0</sub>)  
10 that are successfully (i.e. with no interruption) brought about by affordances (e.g. **a**<sub>0</sub>), as illustrated by  
11 Michaels’s (2003) view of “affordances as actions” and Moralez’s (2016) view of “affordances as  
12 perceptual events”. Thus, it may be practically virtuous to formalize affordances in terms of dispositions  
13 and processes.

#### 14 4. Extension

15 This section examines the articulation between our theory of core affordances and other major  
16 interpretations of affordances by drawing on Toyoshima’s (2018) and Toyoshima & Barton’s (2019a)  
17 preliminary studies. For this purpose, Şahin et al.’s (2007) overview of accounts of affordances will be  
18 leveraged. It will be scrutinized how the dispositional account of core affordances can be expanded  
19 towards three different perspectives from which to characterize the affordance notion: the environmental  
20 perspective (Section 4.1), the agent perspective (Section 4.2), and the observer perspective (Section 4.3).

##### 21 4.1. Environmental perspective

22 Firstly, the environmental perspective “attaches affordances over the environment as extended  
23 properties that [are] perceivable by the agents” (Şahin et al., 2007, p. 457). For instance, Şahin et al.  
24 (2007) classify Turvey’s (1992) dispositional account of affordances (around which a theory of core  
25 affordances centers) as an environmental approach to them. However, it is contentious whether and to  
26 what extent perceptions are pivotal to Turveian affordances. The environmental perspective on  
27 affordances may well be thus interpreted more widely *vis-à-vis* those properties of the environment which  
28 have to do with agents.

##### 29 4.1.1. Reed’s “affordances as resources”

30 There may be nonetheless other environmental understandings of affordances than Turvey’s (1992)  
31 that Şahin et al. (2007) do not bring up for discussion. Among them is Reed’s (1996) conception of  
32 affordances (which will be called “Reedian affordances”) as resources in the environment that are linked  
33 with natural selection:

34  
35 The fundamental hypothesis of ecological psychology (...) is that *affordances and only the relative*  
36 *availability (or nonavailability) of affordances create selection pressure on the behavior of*  
37 *individual organisms; hence, behavior is regulated with respect to the affordances of the*  
38 *environment for a given animal. (Reed, 1996, p. 18)*

39  
40 The resources encountered by an animal are the affordances of the environment. (...) Resources - or,  
41 to be more precise, special combinations of resources commonly found in certain habitats - *become*  
42 *affordances* when natural selection works to evolve such specific regulatory activity. (ibid.)

1  
2 Moreover, Reed emphasizes that “affordances exist independently of organisms” (ibid., pp. 26-27), in  
3 contradistinction to Şahin et al.’s own characterization of the environmental perspective on affordances  
4 that relates to their perceivability by agents (including organisms).

5 Consider how Reed’s resource view of affordances can be conceptualized with recourse to a theory of  
6 core affordances. Since Reedian affordances do not depend existentially on individual organisms, their  
7 conceptualization would require the usage of general core affordances (which are intrinsic dispositions).  
8 The notion of resource has been utilized in formal ontology, e.g. in the Resource-Event-Agent (REA)  
9 ontology in which business processes are modeled upon the exchange of resources between agents (Hruby,  
10 2006; Laurier et al., 2018) as well as in the manufacturing domain (Sanfilippo et al., 2019). The general  
11 nature of resources remains nebulous, however. Although resources (e.g. minerals) are usually taken to  
12 be something to be used to meet a particular purpose (e.g. for good health), resources in Reed’s sense of  
13 the term could be identified with dispositions, or more specifically general core affordances. Since  
14 resources in the environment “become” affordances when they pertain to natural selection, one possible  
15 textual definition of Reedian affordances may be given as follows:

16  
17 Reedian affordance =<sub>def.</sub> A general core affordance that creates selection pressure on the behavior of  
18 organisms.

19  
20 Note that all resources in Reed’s sense of the term may be general core affordances, yet they “become”  
21 Reedian affordances only when they create such selection pressure. It is also interesting to remark that  
22 Reed’s resource-based account of affordances may lack practical utility owing to its appeal to  
23 evolutionary theory, especially when it comes to the modeling of affordances of artifacts (Cosentino,  
24 2021). To take the CLIMB example, the climbability affordance  $\mathbf{a}_0$  of **step**<sub>0</sub> would not be Reedian because  
25 **step**<sub>0</sub> is not a product of natural selection.

## 26 4.2. Agent perspective

### 27 4.2.1. Stoffregen’s “affordances as emergent properties”

28 In contradistinction with the environmental perspective, the agent perspective takes affordances to be  
29 something that resides “within the agent interacting in the environment through his [sic] own behaviors”  
30 (Şahin et al., 2007, p. 457). To take one of Şahin et al.’s (2007) examples, Stoffregen (2003) argues that  
31 affordances are emergent properties of the animal-environment system. In more detail, an affordance is a  
32 property that is “defined” by the relation between a property of the animal and a property of the  
33 environment such that this affordance is borne by the animal-environment system, but neither by the  
34 animal nor by the environment.

35 Stoffregen’s account of affordances may admit of multiple interpretations, mainly owing to the  
36 meaning of the “defining” of a property by some relation. Seen from the standpoint of core affordances,  
37 however, a “Stoffregenian affordance” could be formalized as an affordance/effectivity complex (such as  
38  $\mathbf{ae}_0$  in the CLIMB example; see Section 3.3.1). For it is “defined” in some sense by the relationship  
39 between a property (i.e. a specific core affordance such as  $\mathbf{a}_0$ ) of (an object in) the environment and a  
40 property (i.e. a specific core effectivity such as  $\mathbf{e}_0$ ) of an agent, and it inheres in the agent-environment  
41 system, but not in the environment or in the agent.

### 42 4.2.2. Chemero’s “affordances as relations”

43 As for Şahin et al.’s other example of the agent perspective, Chemero (2003) thinks of affordances as  
44 relations between the abilities of animals and features of the environment. This relational account of

1 affordances has been widely employed, as in Fiebich’s (2014) analysis of the role of social cognition for  
2 the perception of ecological affordances. According to his semi-formal characterization of affordances:

3  
4 Affordances (...) are relations between the abilities of organisms and features of the environment.  
5 Affordances, that is, have this structure:

6  
7 Affords- $\phi$  (feature, ability).

8 (Chemero, 2003, p. 189)

9  
10 To borrow Chemero’s illustration, a climbability affordance involved in the CLIMB scenario is a relation  
11 between the height of **step<sub>0</sub>** and **Mary**’s ability to raise her legs. Furthermore, Chemero argues for the  
12 ontological autonomy (which is not his term, though) of affordances in the following sense:

13  
14 There will be affordances in which that feature [of the environment] takes part as long as some  
15 animal exists with the appropriate ability [of the animal]. This is the case even if that animal is  
16 nowhere in the vicinity of the situation that affords something to it. Affordances do not disappear  
17 when there is no local animal to perceive and take advantage of them. (Chemero, 2003, p. 193)

18  
19 Consider how Chemero’s view of affordances as binary relations (CAF) can be formalized by means  
20 of a theory of core affordances. To characterize the first relatum of a “Chemeran (relational) affordance”,  
21 namely what he calls “feature of the environment”, general core affordances will be helpful because they  
22 are properties of (objects in) the environment and, unlike specific counterparts, exist independently of  
23 individual agents, in line with his emphasis on the ontological autonomy of affordances.

24 It would then be natural to analyze the ability of agents (which is the second relatum of a Chemeran  
25 affordance) in terms of a general core effectivity, which is an agentive counterpart of a general core  
26 affordance. This would imply that abilities are a subtype of dispositions. Nevertheless, Chemero objects  
27 to a dispositional understanding of abilities and proposes the view of abilities as what he calls “functional  
28 properties”:

29  
30 A better way to understand abilities [than as dispositions] is as functional properties of animals.  
31 Functional properties of animals depend on the individual animal’s developmental history or the  
32 evolutionary history of the species. They are properties of the animal that came to play the role they  
33 do in the behavioral economy of the animal because, at some point in the past, they were helpful in  
34 helping the animal (or its ancestor) survive, reproduce, or flourish. (Chemero, 2003, pp. 189-190)

35  
36 *Pace* Chemero, however, abilities of agents can be construed dispositionally while retaining his  
37 understanding of them as “functional properties”. Given an ontology of dispositions, abilities (synonym:  
38 “capacity”, “capability”) can be represented as a subtype of dispositions in formal ontology (Miranda et  
39 al., 2016; Merrell et al., 2021; Merrell et al., 2022), in spite of some philosophical challenges involved  
40 (Vetter & Jaster, 2017; Vetter, 2019). Moreover, functional properties in his sense of the term could also  
41 be dispositionally characterized, along with Spear et al.’s (2016) general account of functions as  
42 dispositions of the bearers with a specific kind of historical development (which has been criticized by  
43 Röhl & Jansen (2014) and Jansen (2018), though).

44 In short, a Chemeran affordance can be analyzed as a relation between a general core affordance and a  
45 general core effectivity based on a theory of core affordances, hence the following axiom:

46  
47 
$$\text{CAF}(x,y) \rightarrow \text{GCA}(x) \wedge \text{GCE}(y)$$

48 A Chemeran affordance is a relation between a general core affordance and a general core effectivity.



Further axioms can also be added to specify the relationality of Chemeran affordances with connection with general core affordances:

$$\text{GCA}(x) \rightarrow \exists y \text{CAF}(x,y)$$

If  $x$  is a general core affordance, then there is some  $y$  such that  $x$  bears the Chemeral affordance relation towards  $y$ .

$$\text{GCE}(y) \rightarrow \exists x \text{CAF}(x,y)$$

If  $y$  is a general core effectivity, then there is some  $x$  such that  $x$  bears the Chemeral affordance relation towards  $y$ .

#### 4.3. Observer perspective

Finally, the observer perspective “is used when the interaction of an agent with the environment is observed by a third party” and “one must also have the capability of taking the observer perspective when perceiving affordances, at least for the agents of the same species as the observer” (Şahin et al., 2007, p. 457). Şahin et al. (2007) argue for the relevance of the observer perspective to affordance-based robot control. Although not being referred to in their argument, examples to illustrate the observer perspective may include Ortmann & Kuhn’s (2010, 2012) extension of their ontology of observation to Turvey’s (1992) dispositional account of affordances and its application to what Ortmann et al. (2014) call an “egocentric semantic reference system for affordances”; as well as Beßler et al.’s (2020) definition of affordances as “descriptions of dispositions” (rather than as dispositions themselves) in ameliorating autonomous robot control (Beßler et al., 2021).

While a theory of core affordances aims at a foundation for an ontology of affordances, the observer perspective may rather pertain to epistemology of affordances, since it is about how the agent-environment interaction is *observed* by a third agent outside it. It might be indeed worthwhile to consider the observer perspective in terms of core affordances, mainly because of its importance for the practical application of affordances, as in robotics. There are nonetheless so multiple possible ways of modeling the observer perspective depending on its more specific interpretations that their complete articulation is outside the purview of this paper. To take one example, the notion of observer can be analyzed in terms of *roles* (e.g. students), as is indicated by Şahin et al.’s own expression “observer role”. However, the understanding of roles varies greatly from one upper ontology to another (Toyoshima, 2021) and clarification of the observer perspective on affordances will require choosing a particular account of roles based on some additional foundational and domain-specific assumptions.

## 5. Application

This section discusses, from the viewpoint of core affordances, three entities that are closely intertwined with affordances: the environment (Section 5.1), image schemas (Section 5.2), and intentions (Section 5.3). Since these notions each merit careful investigation, the goal of this section is not to provide a full ontological analysis of them, but rather to demonstrate that the theory of core affordances developed above has the potential to serve as a solid basis for their ontologies. Note that an affordance-based approach (to appear below) to the environment, image schemas, and intentions is preliminarily considered by Toyoshima (2018), Toyoshima & Barton (2019b), and Toyoshima et al. (2020), respectively.

### 1 5.1. Environment

2 The notion of environment plays such a vital role in contemporary society that its ontological  
 3 characterization will be beneficial to many domains (Smith, 2009; Bennett, 2010). For instance, the  
 4 Environmental Ontology (EO; Buttigieg et al., 2016) has been developed to satisfy the needs for  
 5 environmental semantics in alignment with BFO and the Open Biomedical Ontologies (OBO) Foundry  
 6 (Smith et al., 2007): a collaborative project to coordinate ontologies to support biomedical data integration.  
 7 Although the EO includes the term “environmental system” (ENVO\_01000254), its current definition “A  
 8 system which has the disposition to environ one or more material entities” leaves room for improvement  
 9 partly owing to the “environing relation” therein under development. Other environment-related terms  
 10 are also of growing importance in formal ontology and other domains. Examples of such terms include  
 11 “niche” (Smith & Varzi, 1999; Keet, 2006; Corris, 2020), “habitat” (Bennett, 2010), “Umwelt” (Ortmann  
 12 & Michels, 2011), “place” (Jordan et al., 1998; Scheider & Janowicz, 2014), and “locality” (Garbacz et  
 13 al., 2018, 2020).

14 A theory of core affordances may help to understand better the nature of the environment. In fact, an  
 15 affordance-based representation of places has been advanced in the field of Geographic Information  
 16 Systems (GIS) (Jordan et al., 1998; Scheider & Janowicz, 2014) and an intimate connection between  
 17 affordances and the Umwelt has been pointed out (Ortmann & Michels, 2011). On a more practical side,  
 18 it is argued that affordances can serve as a guiding heuristic for environmental policy (Kaaronen, 2017).

19 In the current framework, the environment (ENV) can be approached in terms of specific core  
 20 affordances, since they are inherently linked with the environment in the sense of emerging from the  
 21 system constituted of the object and the agent. More specifically, it would be an entity that has as part a  
 22 bearer of some specific core affordance, hence the following axiom:

23

$$24 \text{ ENV}(x) \rightarrow \exists y,z(\text{SCA}(y) \wedge \text{INH}(y,z) \wedge \text{P}(z,x))$$

25 The environment is an entity that has as part a bearer of a specific core affordance.

26

27 In the CLIMB example, the environment would be something that has as part a bearer (namely, **step**<sub>0</sub>) of  
 28 the climbability specific core affordance (namely, **a**<sub>0</sub>). One apparent difficulty with this view of the  
 29 environment is that it is explanatorily uninformative, for the very idea of specific core affordance is  
 30 understood only in the context of the animal-environment system. In this sense, the notion of environment  
 31 (as with core affordances) may be at best “elucidated” with some additional explanations, axioms, and  
 32 examples (see Section 3.5.2) and this issue is to be grappled with in the future.

### 33 5.2. Image schema

34 As was alluded to in Section 1.1, the notion of image schema (as well as affordances) provides a first  
 35 foundation upon which agents and inanimate objects can be distinguished and identified (Kutz et al.,  
 36 2018). Usually attributed to Lakoff (1987) and Johnson (1987), image schemas are nowadays used in a  
 37 number of different domains, ranging from cognitive linguistics and developmental psychology to  
 38 artificial intelligence and robotics (Hedblom et al., 2021). They may be explained somewhat differently  
 39 in different contexts, for example:

40

- 41 ● “An image schema is a recurring, dynamic pattern of our perceptual interactions and motor  
 42 programs that gives coherence and structure to our experience.” (Johnson, 1987, p. xiv)
- 43 ● “an image schema is a condensed redescription of perceptual experience for the purpose of  
 44 mapping spatial structure onto conceptual structure.” (Oakley, 2010, p. 215)

- “Image schemas are generally viewed as redescrptions of perceptual events, or even more broadly as generalizations over perceived similarities.” (Mandler & Cánovas, 2014, p. 526)

Nevertheless, image schemas can be generally characterized as mental patterns or “conceptual building blocks” that are extracted from the sensory and motile experiences. They are presumed to be learnt during early infancy (Mandler, 1992) and their complete understanding requires considering carefully prelinguistic conceptual development (Mandler & Cánovas, 2014). They are also multimodal (just as embodied experiences are), as they are extracted from all sensorimotor inputs (Hampe, 2005). Quite often, however, image schemas are practically associated with generic spatiotemporal relationships that are learnt from the repetitive interactions with the environment (and the objects therein), as is illustrated by Kuhn’s (2007) simple explanation of image schemas as “patterns abstracting from spatio-temporal experiences” (ibid., p. 155).

One of the most intensively studied image schemas is CONTAINMENT: broadly, the recognition that objects can be inside other objects or (container-shaped) places (Bennett & Cialone, 2014; Davis et al., 2017; Hedblom et al., 2018; Pomarlan & Bateman, 2020). (Note that image schemas are conventionally written in upper case letters in the relevant literature.) CONTAINMENT is most basically defined as the relationship between an inside, an outside, and the border between them (Johnson, 1987). Seen dynamically, however, CONTAINMENT could be characterized in terms of more “fine-grained” image schemas such as INTO and OUT OF (Mandler & Cánovas, 2014). Other paradigmatic examples of image schemas include SUPPORT (which denotes a relationship between two objects in which one provides support to the other), PATH (which represents movement of objects from one point to another), and LINK (an enforced connection between objects where one linked object reacts to the stimuli of the other).

However, image schemas are still ill-defined and there is an increasing demand for a formal approach that would provide their unifying conception devoid of terminological confusion (Hedblom et al., 2015a, 2015b). Here it may be well worth examining possible (formal) connections between image schemas and affordances, as these two notions are the twin pillars on which general theorizing on agency is built (Kutz et al., 2018). To take one example, Kuhn (2007) develops an image-schematic and algebraic account of affordances and it has been widely applied e.g. in Cunha et al.’s (2018) visual representation of concepts. More specifically, the main focus will be upon the kind of image schemas that pertain to affordances, which will be called “image schemas of the affordance-based type” or more simply “Type A image schemas” (where “A” stands for *affordances*).

To consider Type A image schemas, Galton’s (2010) following concise statement will serve as a useful start point:

Examples of image schemas include CONTAINER and PATH: the link with affordances is obvious, since to be a container is precisely to *afford containment*, while to be a path is to *afford passage*. Thus at least in many cases image schemas may be characterized in terms of the affordances of actual exemplars of those schemas. (Galton, 2010, p. 1)

Seen from the viewpoint of core affordances, Type A image schemas would be better analyzed in terms of general core affordances than specific core affordances; for, image schemas are “general” in the sense of being extracted from individual sensorimotor experience, as Kuhn (2007) argues for the following thesis as an “ontological property” of image schemas: “Image schemas *generalize over concepts* (e.g., the CONTAINMENT schema abstracts container behavior from concepts like cups, boxes, or rooms)” (ibid., p. 156).

To illustrate this point with CONTAINMENT (as it is one of the most typical image schemas), take for example the “containment affordance”, taking a cue from Galton’s (2010) foregoing remark. Consider now the CONTAINMENT image schema of the Type A, especially **John**’s CONTAINMENT image

1 schema of the Type A (which will be termed “ $\text{CON}_{\text{John}}$ ”). Assuming that a gap is a kind of container,  
 2 several affordances and effectivities can be considered to explicate  $\text{CON}_{\text{John}}$ : first, the specific core  
 3 affordance  $\mathbf{a}_1$  of a gap (say  $\text{gap}_1$ ) to contain a person **John** and its reciprocal, specific core effectivity  $\mathbf{e}_1$   
 4 of a person **John** to be contained in  $\text{gap}_1$ ; second, the general core affordance  $\mathbf{a}_1'$  of  $\text{gap}_1$  to contain any  
 5 instance (e.g. **John**) of a general class  $\text{Agent}_1$  (namely, the class of agents with the appropriate dimensions  
 6 to be contained in  $\text{gap}_1$ ) and the general core effectivity  $\mathbf{e}_1'$  of **John** to be contained in any instance (e.g.  
 7  $\text{gap}_1$ ) of a general class  $\text{Gap}_1$  (namely, the class of gaps with the appropriate dimensions to contain **John**).  
 8 Since  $\text{CON}_{\text{John}}$  is a Type A image schema, it is general and should be construed *vis-à-vis*  $\mathbf{a}_1'$  and  $\mathbf{e}_1'$ ,  
 9 rather than *vis-à-vis*  $\mathbf{a}_1$  and  $\mathbf{e}_1$ .

10 However, there is a second dimension according to which general core affordances and effectivities  
 11 that relate to Type A image schemas can be further generalized. Indeed,  $\mathbf{a}_1'$  is an instance of the class  $A_1'$   
 12 whose instances are general core affordances of gaps (not necessarily  $\text{gap}_1$ ) to contain any instance of  
 13 agent that can fit in. Similarly,  $\mathbf{e}_1'$  is an instance of the class  $E_1'$  whose instances are general core  
 14 effectivities of agents (not necessarily **John**) to be contained in gaps of appropriate dimensions. Then,  
 15  $\text{CON}_{\text{John}}$  would be formed not only from John’s experience (perceptual or cognitive) with the gaps where  
 16 *he* could fit, but also from his recognition of the class *Gap* and of the agents that could fit in each particular  
 17 gap. To generalize, the image schema CONTAINMENT of the Type A would be construed in terms of  
 18 such classes of general core affordances and effectivities as  $A_1'$  and  $E_1'$ .

19 Even this view would be nonetheless too restrictive to accommodate the general notion of image  
 20 schema. Indeed, the image schema CONTAINMENT may well be characterizable with the containment  
 21 of *material objects* (not only *agents*) of appropriate dimensions, for it is reasonable to think that  $\text{CON}_{\text{John}}$   
 22 is formed from John’s recognition of the class of gaps and the class of all kinds of *material objects* that  
 23 could fit in each of those gaps. Since many material objects are not agents, but affordances and  
 24 effectivities always involve some agent, such containment features exceed the framework of affordances  
 25 or effectivities. That is, Type A image schema might have to be construed in terms of classes of  
 26 dispositions that are neither affordances nor effectivities.

27 In addition, Type A image schemas might be plausibly taken to be *about* (synonym: “refer to”) some  
 28 entities. This is because image schemas can be generally seen as “redescriptions” of perceptual experience,  
 29 as is illustrated by Oakley’s (2010, p. 215) and Mandler & Cánovas’s (2014, p. 526) explanations cited  
 30 above, and the notion of description has a referential dimension. Building on what has been just said,  
 31 some Type A images schemas might be about affordances and effectivities. In particular,  $\text{CON}_{\text{John}}$  would  
 32 typically be about  $A_1'$  and  $E_1'$ . Following the remarks above, though, some Type A images schemas might  
 33 be about (classes of) dispositions that are neither affordances nor effectivities. Additionally, some Type  
 34 A image schemas, such as THING, might be about non-dispositional entities (Toyoshima & Barton,  
 35 2019b). Finally, it must be emphasized that the aboutness of Type A image schemas does not need to be  
 36 generalized into the aboutness of the traditional notion of image schema. Indeed, image schemas can be  
 37 minimally characterized as abstract patterns emanating from repeated experiences with the external world  
 38 and aboutness may not be a key feature of all image schemas.

39 Nonetheless, analysis of Type A image schemas should be helpful in developing a successful unifying  
 40 theory of image schemas. Even though it is presently restricted to Type A image schemas, the core  
 41 affordance-based approach may suggest a novel perspective on the nature of image schemas. For instance,  
 42 one of Tseng’s (2007) features of image schemas is that they are static and dynamic, although that may  
 43 sound contradictory: “Image schemas can be experienced as states of being or as a process. For example,  
 44 the PATH schema can be experienced in a dynamic way - the process of moving from one place to another.  
 45 Or it can be realized ‘as a static thing’, the road, track or passage that has been traversed” (ibid., p. 143)  
 46 (see also Hedblom et al.’s (2015b) ontological structuring of PATH). Similarly, Kuhn (2007) contends:  
 47 “[image schemas] are internally *structured* (e.g., the CONTAINMENT schema involves behavior

1 associated with an inside, an outside, a contained entity, and possibly a boundary)” (ibid., p. 156) (see  
 2 also Hedblom et al.’s (2018) formalization of dynamism involved in CONTAINMENT).

3 As far as Type A image schemas are concerned, their paradoxical nature may be (at least partially)  
 4 explained by the claim that they are about general core affordances and effectivities, or more generally  
 5 about dispositions. As a matter of fact, dispositions have both static and dynamic dimensions in the sense  
 6 that: “dispositions connect the *static* structure of the world, i.e. the natural kinds of continuants, with the  
 7 *dynamical* structure, i.e. the types of possible and actual causal processes” (Röhl & Jansen, 2011, p. 3,  
 8 italicization added). For instance, the PATH image schema of the Type A can be about the class of general  
 9 core affordances (i.e. dispositions) inhering in (static) material pathways that can be realized by an agent  
 10 (dynamically) moving along such pathways.

11 There are still some challenges to be met in order for this core affordance-based analysis of Type A  
 12 image schemas to be more meticulous. On the formal side, because the present approach to image  
 13 schemas says that many Type A image schemas would be about *classes* of secondary core affordances  
 14 and effectivities, a first-order representation of image schemas would require treating classes as first-  
 15 order entities, which goes beyond the scope of this paper. This line of inquiry is to be pursued together  
 16 with careful consideration of existing formalizations of image schema (Hedblom et al., 2017, 2018;  
 17 Pomarlan & Bateman, 2020) and of the vexed problem of how to represent type-level entities in  
 18 ontologies (Barlatier & Dapoigny, 2012; Schutz et al., 2014; Brodaric & Grüniger, 2018).

19 On the conceptual side, the elusive notion of aboutness needs to be properly conceptualized and  
 20 formalized, notwithstanding some previous works in philosophy (Yablo, 2014; Hawke, 2018) and in  
 21 formal ontology (Ceusters & Smith, 2015; Biccheri et al., 2020; see also Sanfilippo’s (2021) brief  
 22 discussion on aboutness of information entities). Here it is interesting to note growing awareness of the  
 23 relevance of Peirce’s (1998) semiotics to formal ontology (Sowa, 2015), especially in respect of closer  
 24 examination of aboutness (Bateman, 2019). As a matter of fact, Ortmann & Kuhn (2012) outline a  
 25 semiotic account of affordances while highlighting the commonalities between Peirce’s theory of  
 26 semiotics and Gibson’s (1979) theory of affordances. Semiotic considerations may be thus expected to  
 27 strengthen an aboutness-based linkage between core affordances and Type A image schemas.

### 28 5.3. *Intention*

29 One of the traditional approaches to cognition and actions is the BDI (Belief-Desire-Intention) model  
 30 of agency (Wooldridge, 2000). Inspired by Bratman’s (1987) philosophy, the BDI model recognizes the  
 31 primacy of the BDI entities in practical reasoning and rational actions. It has been utilized in formal  
 32 ontology of mind (Ferrario & Oltramari, 2004) and actions (Trypuz, 2007). Relatedly, the notion of goal  
 33 and related entities (e.g. trying, success, and failure) have been formally investigated, as it plays a vital  
 34 role in the BDI model (Hobbs & Gordon, 2010). An important motivation behind the BDI model is that  
 35 belief, desire, and intention (which will be called “BDI entities”) are valuable for examining cognition  
 36 and actions, at least in commonsense psychology (Kashima et al., 1998). It will be therefore promising to  
 37 couple a theory of (core) affordances with an ontology of the BDI entities. For instance, Joo (2013)  
 38 develops a human agent model for behavior simulation in a human-environment complex system by  
 39 combining the BDI model with Turvey’s (1992) theory of affordances (and effectivities). This line of  
 40 inquiry nonetheless remains largely unexplored.

41 Here it will be a useful starting point to refer to Heras-Escribano’s (2019) sketch of an ecological  
 42 approach to agency. He argues that Reed’s (1982, 1996) theory of action systems can provide a basis for  
 43 such a framework. The central idea of this theory is that actions stem from an “action system” that is  
 44 constituted by the agent and the environment, and intentions are “shaped” by this action system in the  
 45 sense that a particular action is understood as motivated or intentional with respect to some affordance  
 46 emerging from the action system.

1 This Reedian understanding of agency would indicate that, so as to integrate core affordances and the  
 2 BDI entities, it will be necessary to consider how specific core affordances and effectivities (emerging  
 3 from the agent-environment system) can be linked with intentions and (intentional) actions. To take some  
 4 first steps along this line, it will be helpful to avail of Toyoshima et al.'s (2020) ontological analysis of  
 5 intentions as mental dispositions that can be realized in actions: for example, **Mary**'s intention to climb  
 6 up **step<sub>0</sub>** is a disposition to be realized in a process of **Mary** climbing up **step<sub>0</sub>** (see also their discussion  
 7 on triggers of dispositional intentions). The term "mental disposition" roughly refers to a disposition  
 8 whose bearer is an agent (e.g. **Mary**) and whose categorical basis is some mental structure of the bearer  
 9 (e.g. that part of **Mary**'s cerebral structure which is relevant to her mental functioning).

10 There are many different ways of considering the relationship between intentions and specific core  
 11 affordances or effectivities, depending on which specific theory of intentions and (intentional) actions is  
 12 endorsed. (For the sake of readability, the terms "affordance" and "effectivity" refer to a specific core  
 13 affordance and effectivity, respectively, until the end of this section.) Discussed below is the  
 14 representation of the connection between intentions (INT) and effectivities (SCE), for it will be a central  
 15 topic in this direction of research how to specify the link between those two kinds of dispositions while  
 16 they both inhere in agents. One of the simplest observations is arguably that the realization of an agent's  
 17 intention is also the realization of some effectivity inhering in the agent. Using the CLIMB example, the  
 18 realization of **Mary**'s intention to climb up **step<sub>0</sub>** is the process of **Mary**'s climbing and this process is  
 19 also the realization of **Mary**'s effectivity **e<sub>0</sub>** (and so is the realization of its reciprocal affordance **a<sub>0</sub>**  
 20 of **step<sub>0</sub>** to move **Mary** upward). This claim can be generally axiomatized as follows.

$$21 \quad \text{INT}(x) \wedge \text{INH}(x,y) \wedge \text{REAL}(x,z) \rightarrow \exists w(\text{SCE}(w) \wedge \text{INH}(w,y) \wedge \text{REAL}(w,z))$$

22 The realization of an intention is the realization of some specific core effectivity inhering in the  
 23 bearer of the intention. (If  $x$  is an intention,  $x$  inheres in  $y$ , and  $x$  is realized in  $z$ , then there is some  
 24  $w$  such that  $w$  is a specific core effectivity,  $w$  inheres in  $y$ , and  $w$  is realized in  $z$ .)  
 25

26  
 27 The next steps along this line of exploration should include meticulous analysis of many relevant notions,  
 28 such as actions (Trypuz, 2007) and the mental objects of intentions (Biccheri et al., 2020).

## 29 6. Conclusion and future work

30 Going back to Galton's (2010) three distinct goals that a full-fledged account of affordances must attain  
 31 (see Section 1.2), this paper focused mainly on the middle-level goal of how to characterize affordances  
 32 accurately. To answer this ontological question, a theory of core affordances was developed based on  
 33 Turvey's (1992) dispositional approach to affordances. As a result, two kinds of core affordances were  
 34 proposed. On the one hand, specific core affordances are individual-directed and extrinsic dispositions  
 35 that are reciprocal with counterpart effectivities and that emerge from the agent-environment system. On  
 36 the other hand, general core affordances are kind-directed and intrinsic dispositions. The article then  
 37 examined whether and how this theory of core affordances can be extended to Şahin et al.'s (2007) three  
 38 perspectives on affordances (viz. environmental, agent, and observer). Finally, so as to undertake the  
 39 upper-level goal to consider the role of affordances in the realm of agents and the environment, it was  
 40 outlined how the theory of core affordances can be applied to the analysis of three entities that are closely  
 41 related to this goal: the environment, image schemas, and intentions.

42 There are many future directions of research in which the present theory of core affordances will be  
 43 able to proceed. On the theoretical side (having to do with Galton's (2010) three goals), the middle-level  
 44 goal is to be further explored. For instance, the temporal dimension of affordances (Galton, 2010) will  
 45 need to be taken into account, as core affordances are something to be realized in actions and actions are

usually reckoned to be temporally extended. To take another example, Steedman (2002) formalizes affordances based on linear dynamic event calculus, i.e. “a formalism for reasoning about causal relations over events” (ibid., p. 834), where his term “event” would be synonymous with the term “process” used in this paper. It will warrant scrutiny how this first-order theory of core affordances can harmonize with his linear logical formulation of affordances. Pointers to this line of inquiry may include Borgo et al.’s (2014) illustrative usage of linear logic (Girard, 1987) in ontologies and the preceding discussion on the relationship between dispositions and causation (Toyoshima, 2020a; Toyoshima et al., 2021).

In addition, the upper-level goal will require future investigation as well (see, for instance, Toyoshima & Barton’s (2019b) detailed discussion on the core affordance-based approach to Type A image schemas as sketched in Section 5.2).

Lastly, the lower-level goal (addressing the aetiological question of where affordances come from) will need to be within the scope of this theory of core affordances. A key to addressing this question would be a closer examination of the notion of categorical basis of dispositions, because a core affordance (which is a disposition) is “causally based” on some qualities of the affordance bearer.

On the practical side, an affordance-based study of learning and creativity is well worth pursuing, as there is a growing demand for such an approach e.g. in communication technology (Nagy & Neff, 2015; Tenenboim-Weinblatt & Neiger, 2018). In this direction, the present theory of core affordances will require further refinement in order to accommodate people’s (especially children’s) exploratory behaviors to discover “non-canonical affordances” (Glăveanu, 2012; Withagen & van der Kamp, 2018). This work may contribute to the development of mechanical systems (e.g. softwares) guiding humans into cognitively enhanced and imaginative acts (Asprino et al., 2017). To take another example, given the importance of affordances to agency and actions, this theory of core affordances can be expected to facilitate an ontology-based approach to the integration of diverse theories in behavioral science (Hastings et al., 2020) and also to behavior change interventions, as they are key elements of health policy and practice (Michie et al., 2017). Finally, one can mention Barton et al.’s (2020) formalization of Baldoni et al.’s (2006) view of “roles as affordances” by means of specific core affordances (and effectivities), the possible application of core affordances to the analysis of functions and artifacts (Cosentino, 2021), and how this theory of affordance can be leveraged to account for the nature of nudges, namely arrangements of the environment that are designed to influence people’s behavior in order to contribute to people’s welfare (Barton, 2022).

## Acknowledgements

We thank Maria M. Hedblom for her valuable comments on our discussion as to image schemas. FT acknowledges financial support by the SPOR Canadian Data Platform (CIHR).

## References

- Anjum, R. L. & Mumford, S. (2017). Mutual manifestation and Martin’s two triangles. In J. D. Jacobs (Ed.), *Causal Powers* (pp. 77-89). Oxford: Oxford University Press.
- Armstrong, D. M. (1997). *A World of States of Affairs*. Cambridge: Cambridge University Press.
- Arp, R., Smith, B. & Spear, A. D. (2015). *Building Ontologies with Basic Formal Ontology*. Cambridge, MA: MIT Press.
- Asprino, L., Nuzzolese, A. G., Russo, A., Gangemi, A., Presutti, V. & Nolfi, S. (2017). An ontology design pattern for supporting behaviour arbitration in cognitive agents. In K. Hammar, P. Hitzler, A. Krisnadi, A. Ławrynowicz, A. G. Nuzzolese and M. Solanki (Eds.), *Advances in Ontology Design and Patterns* (pp. 85-95). Amsterdam: IOS Press.
- Baldoni, M., Boella, G. & van der Torre, L. (2006). Modelling the interaction between objects: Roles as affordances. In J. Lang, F. Lin and J. Wang (Eds.), *Proceedings of the 1st International Conference on Knowledge Science, Engineering and*

- 1        *Management (KSEM 2006)*, Guilin, China, August 5-8, 2006. Lecture Notes in Computer Science (Vol. 4092, pp. 42-54).  
2        Berlin, Heidelberg: Springer.
- 3    Barlatier, P. & Dapoigny, R. (2012). A type-theoretical approach for ontologies: The case of roles. *Applied Ontology*, 7(3), 311-  
4        356.
- 5    Barton, A. (2022). Foundations for an ontology of nudges. In J. Hastings and A. Barton (Eds.), *Proceedings of the 12th*  
6        *International Conference on Biomedical Ontology (ICBO 2021)*, Bozen-Bolzano, Italy, September 16-18, 2021. CEUR  
7        Workshop Proceedings (Vol. 3073, pp. 174-183).
- 8    Barton, A., Grenier, O., Jansen, L. & Ethier, J.-F. (2018). The identity of dispositions. In S. Borgo, P. Hitzler and O. Kutz (Eds.),  
9        *Proceedings of the 10th International Conference on Formal Ontology in Information Systems (FOIS 2018)*, Cape Town,  
10       South Africa, September 17-21, 2018 (pp. 113-126). Amsterdam: IOS Press.
- 11   Barton, A. & Jansen, L. (2016). A modelling pattern for multi-track dispositions for life-science ontologies. In F. Loebe, M.  
12       Boeker, H. Herre, L. Jansen and D. Schober (Eds.), *Proceedings of the 7th Workshop on Ontologies and Data in Life*  
13       *Sciences (ODLS 2016)*, Halle (Saale), Germany, September 29-30, 2016. CEUR Workshop Proceedings (Vol. 2692, pp.  
14       H1-H2).
- 15   Barton, A., Jansen, L. & Ethier, J.-F. (2017). A taxonomy of disposition-parthood. In A. Galton and F. Neuhaus (Eds.),  
16       *Proceedings of the 3rd Joint Ontology Workshops (JOWO 2017)*, Bozen-Bolzano, Italy, September 21-23, 2017. CEUR  
17       Workshop Proceedings (Vol. 2050, pp. 1-10).
- 18   Barton, A., Rovetto, R. & Mizoguchi, R. (2014). Newtonian forces and causation: A dispositional account. In P. Garbacz and O.  
19       Kutz (eds.), *Proceedings of the 8th International Conference on Formal Ontology in Information Systems (FOIS 2014)*,  
20       Rio de Janeiro, Brazil, September 22-25, 2014 (pp. 157-170). Amsterdam: IOS Press.
- 21   Barton, A., Toyoshima, F. & Ethier, J.-F. (2020). Approaching roles with affordances. In K. Hammar, O. Kutz, A. Dimou, T.  
22       Hahmann, R. Hoehndorf, C. Masolo and R. Vita (Eds.), *Proceedings of the 6th Joint Ontology Workshops (JOWO 2020)*,  
23       Virtual & Bozen-Bolzano, Italy, August 31st - October 7th, 2020. CEUR Workshop Proceedings (Vol. 2708, pp. 1-14).
- 24   Bateman, J. A. (2019). Ontology, language, meaning: Semiotic steps beyond the information artifact. In S. Borgo, R. Ferrario,  
25       C. Masolo and L. Vieu (Eds.), *Ontology Makes Sense: Essays in honor of Nicola Guarino* (pp. 119-135). Amsterdam: IOS  
26       Press.
- 27   Benevides, A. B. & Masolo, C. (2014). States, events, and truth-makers. In P. Garbacz and O. Kutz (Eds.), *Proceedings of the*  
28       *8th International Conference on Formal Ontology in Information Systems (FOIS 2014)*, Rio de Janeiro, Brazil, September  
29       22-25, 2014 (pp. 93-102). Amsterdam: IOS Press.
- 30   Bennett, B. (2010). Foundations for an ontology of environment and habitat. In A. Galton and R. Mizoguchi (Eds.), *Proceedings*  
31       *of the 6th International Conference on Formal Ontology in Information Systems (FOIS 2010)*, Toronto, Canada, May 11-  
32       14, 2010 (pp. 31-44). Amsterdam: IOS Press.
- 33   Bennett, B. & Cialone, C. (2014). Corpus guided sense cluster analysis: A methodology for ontology development (with  
34       examples from the spatial domain). In P. Garbacz and O. Kutz (Eds.), *Proceedings of the 8th International Conference on*  
35       *Formal Ontology in Information Systems (FOIS 2014)*, Rio de Janeiro, Brazil, September 22-25, 2014 (pp. 231-226).  
36       Amsterdam: IOS Press.
- 37   Beßler, D., Porzel, R., Pomarlan, M., Beetz, M., Malaka, R. & Bateman, J. (2020). A formal model of affordances for flexible  
38       robotic task execution. In G. De Giacomo, A. Catala, B. Dilkina, M. Milano, S. Barro, A. Bugarín and J. Lang (Eds.),  
39       *Proceedings of the 24th European Conference on Artificial Intelligence (ECAI 2020)*, Santiago de Compostela, Spain,  
40       August 29 - September 5, 2020 (pp. 2425-2432). Amsterdam: IOS Press.
- 41   Beßler, D., Porzel, R., Pomarlan, M., Vyas, A., Höffner, S., Beetz, M., Malaka, R. & Bateman, J. (2021). Foundations of the  
42       socio-physical model of activities (SOMA) for autonomous robotic agents. In F. Neuhaus and B. Brodaric (Eds.),  
43       *Proceedings of the 12th International Conference on Formal Ontology in Information Systems (FOIS 2021)*, Bozen-  
44       Bolzano, Italy, September 13-17, 2021 (pp. 159-174). Amsterdam: IOS Press.
- 45   Biccheri, L., Ferrario R. & Porello, D. (2020). Needs and intentionality - An ontological analysis and an application to public  
46       services. In B. Brodaric and F. Neuhaus (Eds.), *Proceedings of the 11th International Conference on Formal Ontology in*  
47       *Information Systems (FOIS 2020)* (pp. 125-139). Amsterdam: IOS Press.
- 48   Bird, A. (2016). Overpowering: How the powers ontology has overreached itself. *Mind*, 125(498), 341-383.
- 49   Bird, A. (2020). A dispositional account of causation, with some remarks on the ontology of dispositions. In A. S. Meincke (Ed.),  
50       *Dispositionalism: Perspectives from Metaphysics and the Philosophy of Science* (pp. 151-170). Dordrecht, Netherlands:  
51       Springer.
- 52   Borgo, S., Ferrario, R., Gangemi, A., Guarino, N., Masolo, C., Porello, D., Sanfilippo, E. M. & Vieu, L. (2022). DOLCE: A  
53       descriptive ontology for linguistic and cognitive engineering. *Applied Ontology*, 17(1), 45-69.
- 54   Borgo, S. & Masolo, C. (2010). Ontological foundations of DOLCE. In R. Poli, M. Healy and A. D. Kameas (Eds.), *Theory and*  
55       *Applications of Ontology: Computer Applications* (pp. 279-295). The Netherlands: Springer.
- 56   Borgo, S. and Mizoguchi, R. (2014). A first-order formalization of event, object, process, and role in YAMATO. In P. Garbacz  
57       and O. Kutz (Eds.), *Proceedings of the 8th International Conference on Formal Ontology in Information Systems (FOIS*  
58       *2014)*, Rio de Janeiro, Brazil, September 22-25, 2014 (pp. 79-92). Amsterdam: IOS Press.



- 1 Borgo, S., Porello, D. & Troquard, N. (2014). Logical operators for ontological modeling. In P. Garbacz and O. Kutz (Eds.),  
2 *Proceedings of the 8th International Conference on Formal Ontology in Information Systems (FOIS 2014)*, Rio de Janeiro,  
3 Brazil, September 22-25, 2014 (pp. 23-36). Amsterdam: IOS Press.
- 4 Bratman, M. E. (1987). *Intention, Plans, and Practical Reason*. Cambridge, MA: Harvard University Press.
- 5 Bräuner, T. & Ghilardi, S. (2007). First-order modal logic. In P. Blackburn, J. van Benthem and F. Wolter (Eds.), *Handbook of*  
6 *Modal Logic* (pp. 549-620). Amsterdam: Elsevier.
- 7 Brodaric, B. & Grüninger, M. (2018). Particular types and particular dependence. In S. Borgo, P. Hitzler and O. Kutz (Eds.),  
8 *Proceedings of the 10th International Conference on Formal Ontology in Information Systems (FOIS 2018)*, Cape Town,  
9 South Africa, September 17-21, 2018 (pp. 19-32). Amsterdam: IOS Press.
- 10 Buttigieg, P. L., Pafilis, E., Lewis, S., Schildhauer, M. P., Walls, R. L. & Mungall, C. J. (2016). The environment ontology in  
11 2016: Bridging domains with increased scope, semantic density, and interoperation. *Journal of Biomedical Semantics*, 7:57.
- 12 Casati, R. & Varzi, A. C. (1999). *Parts and Places. The Structures of Spatial Representation*. Cambridge, MA: MIT Press.
- 13 Ceusters, W. & Smith, B. (2015). Aboutness: Towards foundations for the Information Artifact Ontology. In F. M. Couto and J.  
14 Hastings (Eds.), *Proceedings of the 6th International Conference on Biomedical Ontology (ICBO 2015)*, Lisbon, Portugal,  
15 July 27-30, 2015. CEUR Workshop Proceedings (Vol. 1515, pp. 1-5).
- 16 Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology*, 15(2), 181-195.
- 17 Chemero, A. & Turvey, M. T. (2007). Gibsonian affordances for roboticists. *Adaptive Behavior*, 15(4), 473-480, 2007.
- 18 Choi, S. & Fara, M. (2021). Dispositions. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2021 ed.).  
19 <https://plato.stanford.edu/archives/spr2021/entries/dispositions/>. (Last accessed on April 13, 2022.)
- 20 Contessa, G. (2012). Do extrinsic dispositions need extrinsic causal bases? *Philosophy and Phenomenological Research*, 84(3),  
21 622-638.
- 22 Corris, A. (2020). Defining the environment in organism-environment systems. *Frontiers in Psychology*, 11:1285.
- 23 Cosentino, E. (2021). Artifacts and affordances. *Synthese*, 198, 4007-4026.
- 24 Cunha, J. M., Martins, P. & Machado, P. (2018). Using image schemas in the visual representation of concepts. In O. Kutz and  
25 M. M. Hedblom (Eds.), *Proceedings of TriCoLore 2018 - Creativity | Cognition | Computation*, Bozen-Bolzano, Italy,  
26 December 13-14, 2018. CEUR Workshop Proceedings (Vol. 2347, pp. 1-11).
- 27 Davis, E., Marcus, G. & Frazier-Logue, N. (2017). Commonsense reasoning about containers using radically incomplete  
28 information. *Artificial Intelligence*, 248, 46-84.
- 29 Ferrario, R. & Oltramari, A. (2004). Towards a computational ontology of mind. In A. Varzi and L. Vieu (Eds.), *Proceedings of*  
30 *the 3rd International Conference on Formal Ontology in Information Systems (FOIS 2004)*, Torino, Italy, November 4-6,  
31 2004 (pp. 287-297). Amsterdam: IOS Press.
- 32 Fiebich, A. (2014). Perceiving affordances and social cognition. In M. Gallotti and J. Michael (Eds.), *Perspectives on Social*  
33 *Ontology and Social Cognition* (pp. 149-166). Studies in the Philosophy of Sociality, Vol 4. Dordrecht: Springer.
- 34 Galton, A. (2010). The formalities of affordance. In M. Bhatt, H. W. Guesgen and S. M. Hazarika (Eds.), *Spatio-Temporal*  
35 *Dynamics: 19th European Conference on Artificial Intelligence (ECAI 2010) Workshop Proceedings*, Lisbon, Portugal,  
36 August 16-20, 2010 (pp. 1-6).
- 37 Galton, A. (2018). Processes as patterns of occurrence. In R. Stout (Ed.), *Process, Action, and Experience* (pp. 41-57). Oxford:  
38 Oxford University Press.
- 39 Garbacz, P., Szady, B. & Ławrynowicz, A. (2018). Identity criteria for localities. In S. Borgo, P. Hitzler and O. Kutz (Eds.),  
40 *Proceedings of the 10th International Conference on Formal Ontology in Information Systems (FOIS 2018)*, Cape Town,  
41 South Africa, September 17-21, 2018 (pp. 47-54). Amsterdam: IOS Press.
- 42 Garbacz, P., Szady, B. & Ławrynowicz, A. (2020). Identity of historical localities in information systems. *Applied Ontology*,  
43 16(1), 55-86.
- 44 Geach P. T. (1969). *God and the Soul*. Routledge and Kegan Paul.
- 45 Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Houghton Mifflin.
- 46 Girard, J.-Y. (1987). Linear logic. *Theoretical Computer Science*, 50(1), 1-101.
- 47 Glăveanu, V. P. (2012). What can be done with an egg? Creativity, material objects, and the theory of affordances. *Journal of*  
48 *Creative Behavior*, 46(3), 192-208.
- 49 Goldfain, A., Smith, B. & Cowell, L. G. (2010). Dispositions and the infectious disease ontology. In A. Galton and R. Mizoguchi  
50 (Eds.), *Proceedings of the 6th International Conference on Formal Ontology in Information Systems (FOIS 2010)*, Toronto,  
51 Canada, May 11-14, 2010 (pp. 400-413). Amsterdam: IOS Press.
- 52 Guarino, N. (2016). BFO and DOLCE: So far, so close.... *Cosmos + Taxis*, 4(4), 10-18.
- 53 Guizzardi, G. (2005). Ontological foundations for structural conceptual models. PhD thesis, University of Twente, The  
54 Netherlands. Available online at: [https://research.utwente.nl/en/publications/ontological-foundations-for-structural-](https://research.utwente.nl/en/publications/ontological-foundations-for-structural-conceptual-models)  
55 [conceptual-models](https://research.utwente.nl/en/publications/ontological-foundations-for-structural-conceptual-models). (Last accessed on April 13, 2022.)
- 56 Guizzardi, G., Botti Benevides, A., Fonseca, C. M., Porello, D., Almeida, J. P. A. & Prince Sales, T. (2022). UFO: Unified  
57 Foundational Ontology. *Applied Ontology*, 17(1), 167-210.

- 1 Guizzardi, G., Wagner, G., Almeida, J. P. A. & Guizzardi, R. S. S. (2015). Towards ontological foundations for conceptual  
2 modeling: The unified foundational ontology (UFO) story. *Applied Ontology*, 10(3-4), 259-271.
- 3 Hampe, B. (2005). Image schemas in cognitive linguistics: Introduction. In B. Hempe (Ed.), *From Perception to Meaning: Image*  
4 *Schemas in Cognitive Linguistics* (pp. 1-12). Berlin: De Gruyter Mouton.
- 5 Hastings, J., Michie, S. & Johnston, M. (2020). Theory and ontology in behavioural science. *Nature Human Behavior*, 4, 226.
- 6 Hawke, P. (2018). Theories of aboutness. *Australasian Journal of Philosophy*, 96(4), 697-723.
- 7 Hedblom, M. M., Gromann, D. & Kutz, O. (2018). In, out and through: Formalising some dynamic aspects of the image schema  
8 Containment. In *Proceedings of the 33rd Annual ACM Symposium on Applied Computing (SAC 2018)*, Pau, France, April  
9 9-13, 2018 (pp. 918-925). New York: Association for Computing Machinery.
- 10 Hedblom, M. M., Kutz, O., Mossakowski, T. & Neuhaus, F. (2017). Between contact and support: Introducing a logic for image  
11 schemas and directed movement. In F. Esposito, R. Basili, S. Ferilli and F. Lisi (Eds.), *Proceedings of the XVIth*  
12 *International Conference of the Italian Association for Artificial Intelligence (AI\*IA 2017 Advances in Artificial*  
13 *Intelligence)*, Bari, Italy, November 14-17, 2017. Lecture Notes in Computer Science (Vol. 10640, pp. 256-268). Springer,  
14 Cham.
- 15 Hedblom, M. M., Kutz, O. & Neuhaus, F. (2015a). Image schemas as families of theories. In T. R. Besold, K. U. Kühnberger,  
16 M. Schorlemmer and A. Smaill (Eds.), *Proceedings of the 4th International Workshop "Computational Creativity, Concept*  
17 *Invention, and General Intelligence" (C3GI 2015)*, Istanbul, Turkey, June 25, 2015. Publications of the Institute of  
18 Cognitive Science (Vol. 2, pp. 19-33). Institute of Cognitive Science.
- 19 Hedblom, M. M., Kutz, O. & Neuhaus, F. (2015b). Choosing the right path: Image schema theory as a foundation for concept  
20 invention. *Journal of Artificial General Intelligence*, 6(1), 21-54.
- 21 Hedblom, M., Pomarlan, M., Porzel, R., Malaka, R. & Beetz, B. (2021). Dynamic action selection using image schema-based  
22 reasoning for robots. In E. M. Sanfilippo, O. Kutz, N. Troquard, T. Hahmann, C. Masolo, R. Hoehndorf and R. Vita (Eds.),  
23 *Proceedings of the 7th Joint Ontology Workshops (JOWO 2021)*, Bolzano, Italy, September 11-18, 2021. CEUR Workshop  
24 Proceedings (Vol. 2969, pp. 1-14).
- 25 Heras-Escribano, M. (2019). *The Philosophy of Affordances*. Palgrave Macmillan.
- 26 Hobbs, J. & Gordon, A. (2010). Goals in a formal theory of commonsense psychology. In A. Galton and R. Mizoguchi (Eds.),  
27 *Proceedings of the 6th International Conference on Formal Ontology in Information Systems (FOIS 2010)*, Toronto, Canada,  
28 May 11-14, 2010 (pp. 59-72). Amsterdam: IOS Press.
- 29 Horrocks, I., Patel-Schneider, P.-F., McGuinness, D. L. & Welty, C. A. (2007). OWL: A description-logic-based ontology  
30 language for the semantic web. In F. Baader, D. Calvanese, D. L. McGuinness, D. Nardi and P. F. Patel-Schneider (Eds.),  
31 *The Description Logic Handbook: Theory, Implementation and Applications* (2nd ed., pp. 458-486). Cambridge: Cambridge  
32 University Press.
- 33 Hruby, P. (2006). *Model-Driven Design Using Business Patterns*. Springer Science & Business Media.
- 34 Ioannidis, S., Livanios, V. & Psillos, S. (2021). No laws and (thin) powers in, no (governing) laws out. *European Journal for*  
35 *Philosophy of Science*, 11:6.
- 36 Jackson, D. (2012). *Software Abstractions: Logic, Language, and Analysis*. MIT press.
- 37 Jansen, L. (2018). Functions, malfunctioning, and negative causation. In A. Christian, D. Hommen, N. Retzlaff and G. Schurz  
38 (Eds.), *Philosophy of Science*. European Studies in Philosophy of Science (Vol. 9, pp. 117-135). Cham: Springer.
- 39 Johnson, M. (1987). *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. Chicago: University of  
40 Chicago Press.
- 41 Joo, J. (2013). Perception and BDI reasoning based agent model for human behavior simulation in complex system. In M. Kurosu  
42 (Ed.), *Proceedings of the 15th International Conference on Human-Computer Interaction. Towards Intelligent and Implicit*  
43 *Interaction (HCI 2013)*, Las Vegas, Nevada, U.S., July 21-26, 2013. Lecture Notes in Computer Science (Vol. 8008, pp.  
44 62-71). Berlin, Heidelberg: Springer.
- 45 Jordan, T., Raubal, M., Gartrell, B. & Egenhofer, M. J. (1998). An affordance-based model of place in GIS. In T. Poiker and N.  
46 Chrisman (Eds.), *8th International Symposium on Spatial Data Handling (SDH'98)* (pp. 98-109). Vancouver, BC: IUG.
- 47 Kaaronen, R. O. (2017). Affording sustainability: Adopting a theory of affordances as a guiding heuristic for environmental  
48 policy. *Frontiers in Psychology*, 8:1974.
- 49 Kashima, Y., McKintyre, A. & Clifford, P. (1998). The category of the mind: Folk psychology of belief, desire, and intention.  
50 *Asian Journal of Social Psychology*, 1(3), 289-313.
- 51 Kassel, G. (2019). Processes endure, whereas events occur. In S. Borgo, R. Ferrario, C. Masolo and L. Vieu (Eds.), *Ontology*  
52 *Makes Sense: Essays in honor of Nicola Guarino* (pp. 177-193). Amsterdam: IOS Press.
- 53 Kassel, G. (2020). Physical processes, their life and their history. *Applied Ontology*, 15(2), 109-133.
- 54 Keet, C. M. (2006). Representations of the ecological niche. In B. Klein, I. Johansson and T. Roth-Berghofer (Eds.),  
55 *Contributions to the 3rd International Workshop on Philosophy and Informatics (WSPI 2006)*, Saarbrücken, Germany, May  
56 3-4, 2006 (pp. 75-88). IFOMIS Reports.
- 57 Kistler, M. (2020). Powers, dispositions and laws of nature. In A. S. Meincke (Ed.), *Dispositionalism: Perspectives from*  
58 *Metaphysics and the Philosophy of Science* (pp. 171-188). Dordrecht, Netherlands: Springer.

- 1 Kuhn, W. (2007). An image-schematic account of spatial categories. In S. Winter, M. Duckham, L. Kulik and B. Kuipers (Eds.),  
2 *Spatial Information Theory*. Lecture Notes in Computer Science (Vol. 4736, pp. 152-168). Berlin, Heidelberg: Springer.
- 3 Kutz, O., Troquard, N., Hedblom, M. & Porello, D. (2018). The mouse and the ball: Towards a cognitively-based and  
4 ontologically-grounded logic of agency. In S. Borgo, P. Hitzler and O. Kutz (Eds.), *Proceedings of the 10th International*  
5 *Conference on Formal Ontology in Information Systems (FOIS 2018)*, Cape Town, South Africa, September 17-21, 2018  
6 (pp. 141-148). Amsterdam: IOS Press.
- 7 Lakoff, G. P. (1987). *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind*. Chicago: University of  
8 Chicago Press.
- 9 Laurier, W., Kiehn J. & Polovina, S. (2018). REA<sup>2</sup>: A unified formalisation of the Resource-Event-Agent ontology. *Applied*  
10 *Ontology*, 13(3), 201-224.
- 11 Mandler, J. M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review*, 99(4), 587-604.
- 12 Mandler, J. M. & Cánovas, C. P. (2014). On defining image schemas. *Language and Cognition*, 6(4), 510-532.
- 13 Marshall, D. & Weatherson, B. (2018). Intrinsic vs. extrinsic properties. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of*  
14 *Philosophy* (Spring 2018 ed.). <https://plato.stanford.edu/archives/spr2018/entries/intrinsic-extrinsic/>. (Last accessed on  
15 April 13, 2022.)
- 16 Martin, C. B. (2008). *The Mind in Nature*. Oxford: Oxford University Press.
- 17 Masolo, C. (2016). Observations and their explanations. In R. Ferrario and W. Kuhn (Eds.), *Proceedings of the 9th International*  
18 *Conference on Formal Ontology in Information Systems (FOIS 2016)*, Annecy, France, July 6-9, 2016 (pp. 197-210).  
19 Amsterdam: IOS Press.
- 20 Masolo, C., Benevides, A. B. & Porello, D. (2018). The interplay between models and observations. *Applied Ontology*, 13(1),  
21 41-71.
- 22 Masolo, C., Borgo, S., Gangemi, A., Guarino, N. & Oltramari, A. (2003). Wonderweb deliverable D18 - ontology library (final).  
23 Laboratory for Applied Ontology - National Research Council - Institute of Cognitive Science and Technology. Available  
24 online at: <http://wonderweb.man.ac.uk/deliverables/D18.shtml>. (Last accessed on April 13, 2022.)
- 25 Masolo, C., Vieu, L., Ferrario, R., Borgo, S. & Porello, D. (2020). Collectives, composites and pluralities. In B. Brodaric and F.  
26 Neuhaus (Eds.), *Proceedings of the 11th International Conference on Formal Ontology in Information Systems (FOIS 2020)*  
27 (pp. 186-200). Amsterdam: IOS Press.
- 28 McKittrick, J. (2003). A case for extrinsic dispositions. *Australasian Journal of Philosophy*, 81(2), 155-174.
- 29 McKittrick, J. (2018). *Dispositional Pluralism*. Oxford: Oxford University Press.
- 30 Merrell, E., Limbaugh, D., Anderson, A. & Smith, B. (2021). Mental capabilities. In A. D. Diehl, W. D. Duncan and G. Sanso  
31 (Eds.), *Proceedings of the 10th International Conference on Biomedical Ontology (ICBO 2019)*, Buffalo, New York, U.S.,  
32 July 30 - August 2, 2019. CEUR Workshop Proceedings (Vol. 2931, pp. J. 1-7).
- 33 Merrell, E. C., Limbaugh, D. G., Koch, P. M. & Smith, B. (2022). Capabilities. Unpublished manuscript. Available online at:  
34 <https://philpapers.org/archive/MERC-14.pdf>. (Last accessed on April 13, 2022.)
- 35 Michaels, C. F. (2003). Affordances: Four points of debate. *Ecological Psychology*, 15(2), 135-148.
- 36 Michie, S., Thomas, J., Johnston, M., Aonghusa, P. M., Shawe-Taylor, J., Kelly, M. P., Deleris, L. A., Finnerty, A. N., Marques,  
37 M. M., Norris, E., O'Mara-Eves, A., & West, R. (2017). The Human Behaviour-Change Project: Harnessing the power of  
38 artificial intelligence and machine learning for evidence synthesis and interpretation. *Implementation Science*, 12(1), 121.
- 39 Min, H., Yi, C., Luo, R., Zhu, J. & Bi, S. (2016). Affordance research in developmental robotics: A survey. *IEEE Transactions*  
40 *on Cognitive and Developmental Systems*, 8(4), 237-255.
- 41 Miranda, G. M., Almeida, J. P. A., Azevedo, C. L. B. & Guizzardi, G. (2016). An ontological analysis of capability modeling in  
42 defense enterprise architecture frameworks. In *Proceedings of the 8th Brazilian Symposium on Ontology Research*  
43 *(ONTOBRAS 2016)*, Curitiba-PR, Brazil, October 3-6, 2016 (pp. 11-22).
- 44 Moralez, L. A. (2016). Affordance ontology: Towards a unified description of affordances as events. *Res Cogitans*, 7(1), 35-45.
- 45 Nagy, P. & Neff, G. (2015). Imagined affordance: Reconstructing a keyword for communication theory. *Social Media + Society*,  
46 pp. 1-9. <https://doi.org/10.1177/2056305115603385>.
- 47 Norman, D. A. (1999). Affordance, conventions, and design. *Interactions*, 6(3), 38-43.
- 48 Oakley, T. (2010). Image schema. In D. Geeraerts and H. Cuyckens (Eds.), *The Oxford Handbook of Cognitive Linguistics* (pp.  
49 214-235). Oxford: Oxford University Press.
- 50 Oliver, M. (2005). The problem with affordance. *E-Learning*, 2(4), 402-413.
- 51 Ortmann, J., De Felice, G., Wang, D. and Daniel, D. (2014). An egocentric semantic reference system for affordances. *Semantic*  
52 *Web journal*, 5, 449-472.
- 53 Ortmann, J. & Kuhn, W. (2010). Affordances as qualities. In A. Galton and R. Mizoguchi (Eds.), *Proceedings of the 6th*  
54 *International Conference on Formal Ontology in Information Systems (FOIS 2010)*, Toronto, Canada, May 11-14, 2010  
55 (pp. 117-130). Amsterdam: IOS Press.
- 56 Ortmann, J. & Kuhn, W. (2012). Afforded actions. Unpublished manuscript. Available online at:  
57 [https://www.academia.edu/13187216/Afforded\\_Actions](https://www.academia.edu/13187216/Afforded_Actions). (Last accessed on April 13, 2022.)

- 1 Ortmann J. & Michels, H. (2011) Modelling Umwelten. In S. Geertman, W. Reinhardt and F. Toppen (Eds.), *Advancing*  
2 *Geoinformation Science for a Changing World*. Lecture Notes in Geoinformation and Cartography (Vol. 1, pp. 293-316).  
3 Berlin, Heidelberg: Springer.
- 4 Otte, J. N., Beverley, J. & Ruttenberg, A. (2022). BFO: Basic Formal Ontology. *Applied Ontology*, 17(1), 17-43.
- 5 Peirce, C. S. (1998). *The Essential Peirce*. Vol. 2. Peirce edition Project. Bloomington I.N.: Indiana University Press.
- 6 Pomarlan, M. & Bateman, J. A. (2020). Embodied functional relations: A formal account combining abstract logical theory with  
7 grounding in simulation. In B. Brodaric and F. Neuhaus (Eds.), *Proceedings of the 11th International Conference on Formal*  
8 *Ontology in Information Systems (FOIS 2020)* (pp. 155-168). Amsterdam: IOS Press.
- 9 Prior, E., Pargetter, R. & Jackson, F. (1982). Three theses about dispositions. *American Philosophical Quarterly*, 19(3), 251-  
10 257.
- 11 Reed, E. S. (1982). An outline of a theory of action systems. *Journal of Motor Behavior*, 14(2), 98-134.
- 12 Reed, E. S. (1996). *Encountering the World: Toward an Ecological Psychology*. Oxford: Oxford University Press.
- 13 Röhl, J. (2012). Mechanisms in biomedical ontology. *Journal of Biomedical Semantics*, 3(Suppl 2):S9.
- 14 Röhl, J. & Jansen, L. (2011). Representing dispositions. *Journal of Biomedical Semantics*, 2(Suppl 4):S4.
- 15 Röhl, J. & Jansen, L. (2014). Why functions are not special dispositions: an improved classification of realizable for top-level  
16 ontologies. *Journal of Biomedical Semantics*, 5:27.
- 17 Ryle, G. (1949). *The Concept of Mind*. London: Routledge.
- 18 Şahin, E., Çakmak, M., Dögar, M. R., Uğur, E. & Üçoluk, G. (2007). To afford or not to afford: A new formalization of  
19 affordances toward affordance-based robot control. *Adaptive Behavior*, 15(4), 447-472.
- 20 Sanders, J. T. (1997). An ontology of affordances. *Ecological Psychology*, 9(1), 97-112.
- 21 Sanfilippo, E. M. (2021). Ontologies for information entities: State of the art and open challenges. *Applied ontology*, 16(2). 11-  
22 135.
- 23 Sanfilippo, E. M., Terkaj, W. & Borgo, S. (2019). Resources in manufacturing. In A. Barton, S. Seppälä and D. Porello (Eds.),  
24 *Proceedings of the 5th Joint Ontology Workshops (JOWO 2019)*, Graz, Austria, September 23-25, 2019. CEUR Workshop  
25 Proceedings (Vol. 2518, pp. 1-12).
- 26 Scheider, S. & Janowicz, K. (2014). Place reference systems: A constructive activity model of reference to places. *Applied*  
27 *Ontology*, 9(2), 97-127.
- 28 Schulz, S., Martínez-Costa, C., Karlsson, D., Cornet, R., Brochhausen, M. & Rector, A. (2014). An ontological analysis of  
29 reference in health record statements. In P. Garbacz and O. Kutz (Eds.), *Proceedings of the 8th International Conference*  
30 *on Formal Ontology in Information Systems (FOIS 2014)*, Rio de Janeiro, Brazil, September 22-25, 2014 (pp. 289-302).  
31 Amsterdam: IOS Press.
- 32 Seppälä, S., Ruttenberg, A. and Smith, B. (2016). The functions of definitions in ontologies. In R. Ferrario and W. Kuhn (Eds.),  
33 *Proceedings of the 9th International Conference on Formal Ontology in Information Systems (FOIS 2016)*, Annecy, France,  
34 July 6-9, 2016 (pp. 37-50). Amsterdam: IOS Press.
- 35 Shoemaker, S. (1980). Causality and properties. In P. van Inwagen (Ed.), *Time and Cause* (pp. 109-135). Reidel, Dordrecht.
- 36 Smith, B. (2008). New desiderata for biomedical ontologies. In K. Munn and B. Smith (Eds.), *Applied Ontology: An Introduction*  
37 (pp. 84-107). Frankfurt: Ontos Verlag.
- 38 Smith, B. (2009). Toward a realistic science of environments. *Ecological Psychology*, 21(2), 121-130.
- 39 Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W., Ceusters, W., Goldberg, L. J., Eilbeck, K., Ireland, A., Mungall, C. J.,  
40 OBI Consortium, Leontis, N., Rocca-Serra, P., Ruttenberg, A., Sansone, S. A., Scheuermann, R. H., Shah, N., Whetzel, P.  
41 L. & Lewis, S. (2007). The OBO Foundry: Coordinated evolution of ontologies to support biomedical data  
42 integration. *Nature biotechnology*, 25(11), 1251-1255.
- 43 Smith, B. & Varzi, A. C. (1999). The Niche. *Noûs*, 33(2), 198-222.
- 44 Sowa, J. F. (2015). Signs and reality. *Applied Ontology*, 10(3-4), 273-284.
- 45 Spear, A. D., Ceusters, W. & Smith, B. (2016). Functions in Basic Formal Ontology. *Applied Ontology*, 11(2), 103-128.
- 46 Steedman, M. (2002). Formalizing affordance. In W. D. Gray and C. D. Schunn (Eds.), *Proceedings of the 24th Annual Meeting*  
47 *of the Cognitive Science Society (CogSci 2002)*, Fairfax, Virginia, U.S., August 7-10, 2002 (pp. 834-839). Mahwah, New  
48 Jersey: Lawrence Erlbaum Associates Inc.
- 49 Stoffregen, T. A. (2003). Affordances as properties of the animal-environment system. *Ecological Psychology*, 15(2), 115-134.
- 50 Tenenboim-Weinblatt, K. & Neiger, M. (2018). Temporal affordances in the news. *Journalism*, 19(1), 37-55.
- 51 Toyoshima, F. (2018). Modeling affordances with dispositions. In L. Jansen, D. P. Radicioni and D. Gromann (Eds.),  
52 *Proceedings of the 4th Joint Ontology Workshops (JOWO 2018)*, Cape Town, South Africa, September 17-18, 2018. CEUR  
53 Workshop Proceedings (Vol. 2205, pp. 1-6).
- 54 Toyoshima, F. (2019). How do processes work? In A. Barton, S. Seppälä and D. Porello (Eds.), *Proceedings of the 5th Joint*  
55 *Ontology Workshops (JOWO 2019)*, Graz, Austria, September 23-25, 2019. CEUR Workshop Proceedings (Vol. 2518, pp.  
56 1-10).

- 1 Toyoshima, F. & Barton, A. (2019a). A formal representation of affordances as reciprocal dispositions. In O. Kutz and M. M.  
2 Hedblom (Eds.), *Proceedings of TriCoLore 2018 - Creativity | Cognition | Computation*, Bozen-Bolzano, Italy, December  
3 13-14, 2018. CEUR Workshop Proceedings (Vol. 2347, pp. 1-14).
- 4 Toyoshima, F. & Barton, A. (2019b). Linking image schemas with affordances: An ontological approach. In A. Barton, S.  
5 Seppälä and D. Porello (Eds.), *Proceedings of the 5th Joint Ontology Workshops (JOWO 2019)*, Graz, Austria, September  
6 23-25, 2019. CEUR Workshop Proceedings (Vol. 2518, pp. 1-10).
- 7 Toyoshima, F. (2020a). Natural necessity: An introductory guide for ontologists. *Applied Ontology*, 15(1), 61-89.
- 8 Toyoshima, F. (2020b). Foundations for ontology of persistence: Beyond talk of temporal parts. In B. Brodaric and F. Neuhaus  
9 (Eds.), *Proceedings of the 11th International Conference on Formal Ontology in Information Systems (FOIS 2020)* (pp. 17-  
10 31). Amsterdam: IOS Press.
- 11 Toyoshima, F. (2021). Roles and their three facets: A foundational perspective. *Applied Ontology*, 16(2), 161-192.
- 12 Toyoshima, F., Barton, A. and Grenier, O. (2020). Foundations for an ontology of belief, desire and intention. In B. Brodaric  
13 and F. Neuhaus (Eds.), *Proceedings of the 11th International Conference on Formal Ontology in Information Systems*  
14 *(FOIS 2020)* (pp. 140-154). Amsterdam: IOS Press.
- 15 Toyoshima, F., Barton, A., Jansen, L. & Ethier, J.-F. (2021). Towards a unified dispositional framework for realizable entities.  
16 In F. Neuhaus and B. Brodaric (Eds.), *Proceedings of the 12th International Conference on Formal Ontology in Information*  
17 *Systems (FOIS 2021)*, Bozen-Bolzano, Italy, September 13-17, 2021 (pp. 64-78). Amsterdam: IOS Press.
- 18 Trypuz, R. (2007). Formal ontology of action: A unifying approach. PhD thesis, University of Trento, Italy. Available online at:  
19 <https://www.researchgate.net/publication/233990262>. (Last accessed on April 13, 2022.)
- 20 Tseng, M.-U. (2007). Exploring image schemas as a critical concept: Toward a critical-cognitive linguistic account of image-  
21 schematic interactions. *Journal of Literary Semantics*, 36(2), 135-157.
- 22 Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological Psychology*, 4(3), 173-187.
- 23 Vetter, B. (2015). *Potentiality: From Dispositions to Modality*. Oxford: Oxford University Press.
- 24 Vetter, B. (2018). Perceiving potentiality: A metaphysics for affordances. *Topoi*, 39, 1177-1191.
- 25 Vetter, B. (2019). Are abilities dispositions? *Synthese*, 196, 201-220.
- 26 Vetter, B. & Jaster, R. (2017). Dispositional accounts of abilities. *Philosophy Compass*, 12(8), e12432.
- 27 Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology*, 105(5),  
28 683-703.
- 29 Williams, N. E. (2019). *The Powers Metaphysic*. Oxford: Oxford University Press.
- 30 Williams, N. E. (2020). What are manifestations? In A. S. Meincke (Ed.), *Dispositionalism: Perspectives from Metaphysics and*  
31 *the Philosophy of Science* (pp. 67-87). Dordrecht, Netherlands: Springer.
- 32 Withagen, R. & van der Kamp, J. (2018). An ecological approach to creativity in making. *New Ideas in Psychology*, 49, 1-6.
- 33 Wooldridge, M. J. (2000). *Reasoning about Rational Agents*. Cambridge, MA: MIT Press.
- 34 Yablo, S. (2014). *Aboutness*. Princeton: Princeton University Press.
- 35 Yamanobe, N., Wan, W., Ramirez-Alpizar, I. G., Petit, D., Tsuji, T., Akizuki, S., Hashimoto, M., Nagata, K., & Harada, K.  
36 (2017). A brief review of affordance in robotic manipulation research. *Advanced Robotics*, 31(19-20), 1086-1101.