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1 Affordances and their ontological core

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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).

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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.

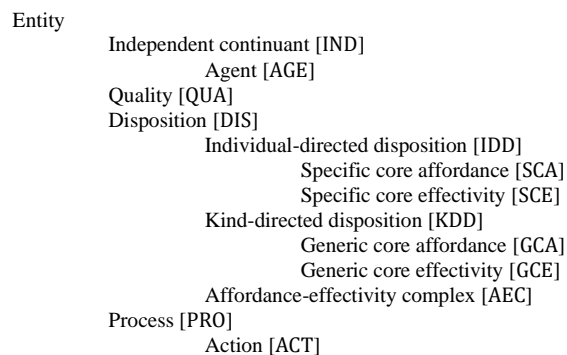


Figure 1. Taxonomy of entities and associated unary predicates.

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**₁)
 16 and a lock (say **lock**₂) such that **key**₁ opens **lock**₂. Intuitively, **key**₁ has the disposition **d**_{key1} to open **lock**₂,
 17 and **lock**₂ has the disposition **d**_{lock2} to be opened by **key**₁. Those two dispositions, **d**_{key1} and **d**_{lock2}, have
 18 something in common. That is, they have the same class of realization processes (say *lock*₂-*opening-by-*
 19 *key*₁) and they have the same class of triggering processes (say *key*₁-*pivoting-in-lock*₂) (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**_{key1}, **d**_{lock2})) 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**₂ to be opened by **key**₁ (in
11 contrast to the disposition of **lock**₂ itself to be opened by **key**₁) would be reciprocal of **d**_{lock2} (the
12 disposition of **lock**₂ to be opened by **key**₁), which would be at odds with the intended meaning of
13 reciprocal dispositions.

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

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**_{lock2} does not inhere in **key**₁, it is an external
25 basis of **d**_{key1}; and **q**_{key1} is an external basis of **d**_{lock2} (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**_{key1} and **d**_{lock2} 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**_{key1} and **d**_{lock2} are extrinsic, as whether **d**_{key1} inheres in **key**₁ depends also on its
39 external basis **q**_{lock2}, and similarly, whether **d**_{lock2} inheres in **lock**₂ depends also on its external basis **q**_{key1}.
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**_{key1} and **d**_{lock2} 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 lock_2 (in
5 particular, key_1 is an instance of Key_1) and $Lock_2$ the class of locks that can be opened by key_1 (in
6 particular, 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 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 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 key_1 to open a lock instance of $Lock_2$
- 12 ● the disposition $\mathbf{d}_{\text{lock}_2}'$ of 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 lock_2 or on any individual lock similar to lock_2 . Likewise, unlike
16 $\mathbf{d}_{\text{lock}_2}$, $\mathbf{d}_{\text{lock}_2}'$ does not depend existentially on key_1 or on any individual key similar to 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 key_1 opening another lock instance of $Lock_2$ than lock_2 . Intuitively,
22 $\mathbf{d}_{\text{key}_1}$ is a disposition that is directed at the individual 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 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 **step₀**). This concrete example
 10 will be called “CLIMB”. Let **a₀** be the climbability affordance of **step₀** and let **e₀** be **Mary**’s corresponding
 11 effectivity such that RECI (**a₀,e₀**) holds. That is to say, **a₀** and **e₀** have the same class of realizations (say
 12 *Mary-climbing-up-step₀*) (A3), they also have the same class of triggers (say *Mary-contracting-her-legs-*
 13 *on-step₀*) (A4), and they are different because their bearers do not overlap (A5). Consider now a system
 14 (say the **Mary/step₀** system) composed of **Mary** and **step₀**. 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/step₀** system will be assumed to be analyzable simply as the sum
 18 of **Mary** and **step₀**, namely an entity written **Mary+step₀** such that
 19 SUM (**Mary+step₀**, **Mary**, **step₀**) holds. According to Turvey’s (1992, p. 180) semi-formal explication,
 20 **Mary+step₀** bears neither **a₀** nor **e₀** and there is a third property instance (say **ae₀**) such that **Mary+step₀**
 21 bears **ae₀** and neither **Mary** nor **step₀** bears **ae₀**. The bearer (i.e. **Mary+step₀**) of **ae₀** is the sum of the
 22 bearers (i.e. **Mary** and **step₀**) of **a₀** and **e₀**. Accordingly, **ae₀** would be formalized as being in some sense
 23 the “sum” of **a₀** and **e₀**.

24 To formalize this third property, a ternary relation (CES) between dispositions will be introduced such
 25 that CES(**d₁,d₂,d₃**) is read as “**d₁** is a causally equivalent sum of and **d₂** and **d₃**” and e.g.
 26 CES (**ae₀,a₀,e₀**) 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(**d₁,d₂,d₃**) → DIS(**d₁**) ∧ DIS(**d₂**) ∧ DIS(**d₃**) ∧ RECI(**d₂,d₃**)

30 If **d₁** is a causally equivalent sum of **d₂** and **d₃**, then **d₁**, **d₂**, and **d₃** are dispositions and **d₂** is reciprocal
 31 with **d₃**.

32
 33 **A11** CES(**d₁,d₂,d₃**) ↔ CES(**d₁,d₃,d₂**)

34 The causally equivalent sum of **d₂** and **d₃** is the same as that of **d₃** and **d₂**.

35
 36 **A12** CES(**d₁,d₂,d₃**) → [REAL(**d₁,x**) ↔ REAL(**d₂,x**)]

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

38
 39 **A13** CES(**d₁,d₂,d₃**) → [TRIG(**d₁,x**) ↔ TRIG(**d₂,x**)]

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

41
 42 **T5** CES(**d₁,d₂,d₃**) → [REAL(**d₁,x**) ↔ REAL(**d₂,x**) ↔ REAL(**d₃,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(**d₁,d₂,d₃**) → [TRIG(**d₁,x**) ↔ TRIG(**d₂,x**) ↔ TRIG(**d₃,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 **step₀**) are (proper) parts of the bearer (i.e.
12 **Mary+step₀**) of \mathbf{ae}_0 .

13 (ADD-PP-REAL) If \mathbf{ae}_0 is realized in a process of **Mary** climbing up **step₀**, 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 **step₀**, 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 “**key₁/lock₂** 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 **key₁**, and $\mathbf{d}_{\text{lock}2}$ would be a
35 causal aspect of \mathbf{d}_3 , when viewed from the perspective of **lock₂**.

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, **step₀** has a general core
 7 affordance **a₀**’ to let instances of a class $Person_0$ climb **step₀**, where all instances of $Person_0$ can climb
 8 **step₀**. Relatedly, **Mary** has a general core effectivity **e₀**’ to climb instances of a class $Step_0$, where all
 9 instances of $Step_0$ 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_{key1}** relies existentially on the intrinsic disposition **d_{key1}**’ of **key₁** to open any instance (including **lock₂**)
 30 of the type $Lock_2$. 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** $SCE(x) \wedge GCE(y) \wedge REON(x,y) \wedge TRIG(x,p) \rightarrow TRIG(y,p)$

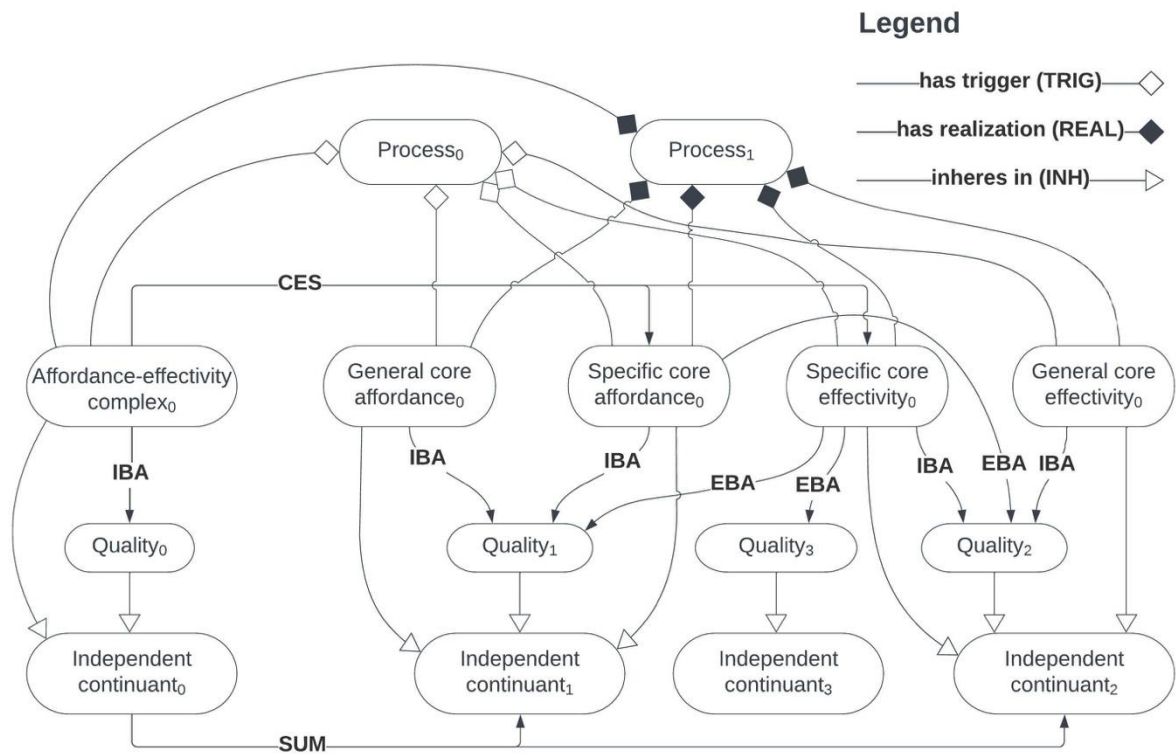
5 When a specific core effectivity is triggered, then its general core effectivity dependee is triggered
 6 by the same process.

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 **step₀** 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 **step₀** by dint of
9 its disposition **a₀** to move **Mary** upward and its disposition (say **a₀***) to move **Mary** downward. This
10 more general, specific core affordance (say **a₀+a₀***) of **step₀** 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. **step₀**) of **a₀+a₀*** is an improper part of the bearers (i.e. **step₀**) of **a₀** and
14 **a₀***.
15 (MOD-PP-REAL) **a₀+a₀*** is realized in a process of **Mary** moving using **step₀** if and only if at
16 least one of its proper mod-parts (i.e. **a₀** or **a₀***) is realized in this process.
17 (MOD-PP-TRIG) **a₀+a₀*** is triggered by a process of **Mary** positioning her feet on **step₀** if and
18 only if at least one of its proper mod-parts (i.e. **a₀** or **a₀***) 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 =_{def.} 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 =_{def.} 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 **step₀**. In particular, she contracted her
23 muscles adequately in an effort to climb up **step₀**. However, a gust of wind blew so strongly that **Mary**
24 failed to climb up **step₀**. Following Williams (2019, 2020), a dilemma can arise as to whether the specific
25 core affordance **a₀** (which is a sure-fire disposition) of **step₀** was realized or not. On the first horn of the
26 dilemma, if **a₀** was realized, then a whole process of **Mary** climbing up **step₀** must have occurred. On the
27 second horn, if **a₀** was not realized, then it contradicts the fact that **a₀** was indeed triggered by a process
28 of **Mary** contracting her legs on **step₀**.

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 **a₀** (namely, a process of **Mary** climbing up **step₀**) 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 **soa₁**) of **Mary** being on **step₀**, but **soa₁** 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**₀)
10 that are successfully (i.e. with no interruption) brought about by affordances (e.g. **a**₀), 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 =_{def.} 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 \mathbf{step}_0 would not be Reedian because
25 \mathbf{step}_0 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- ϕ (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 **step₀** 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.

1
2 Further axioms can also be added to specify the relationality of Chemeran affordances with connection
3 with general core affordances:

$$4 \quad \text{GCA}(x) \rightarrow \exists y \text{CAF}(x,y)$$

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

$$9 \quad \text{GCE}(y) \rightarrow \exists x \text{CAF}(x,y)$$

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

12 4.3. Observer perspective

13 Finally, the observer perspective “is used when the interaction of an agent with the environment is
14 observed by a third party” and “one must also have the capability of taking the observer perspective when
15 perceiving affordances, at least for the agents of the same species as the observer” (Şahin et al., 2007, p.
16 457). Şahin et al. (2007) argue for the relevance of the observer perspective to affordance-based robot
17 control. Although not being referred to in their argument, examples to illustrate the observer perspective
18 may include Ortmann & Kuhn’s (2010, 2012) extension of their ontology of observation to Turvey’s
19 (1992) dispositional account of affordances and its application to what Ortmann et al. (2014) call an
20 “egocentric semantic reference system for affordances”; as well as Beßler et al.’s (2020) definition of
21 affordances as “descriptions of dispositions” (rather than as dispositions themselves) in ameliorating
22 autonomous robot control (Beßler et al., 2021).

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

34 5. Application

35 This section discusses, from the viewpoint of core affordances, three entities that are closely
36 intertwined with affordances: the environment (Section 5.1), image schemas (Section 5.2), and intentions
37 (Section 5.3). Since these notions each merit careful investigation, the goal of this section is not to provide
38 a full ontological analysis of them, but rather to demonstrate that the theory of core affordances developed
39 above has the potential to serve as a solid basis for their ontologies. Note that an affordance-based
40 approach (to appear below) to the environment, image schemas, and intentions is preliminarily considered
41 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

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

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, **step₀**) of
 28 the climbability specific core affordance (namely, **a₀**). 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 “ CON_{John} ”). Assuming that a gap is a kind of container,
 2 several affordances and effectivities can be considered to explicate CON_{John} : first, the specific core
 3 affordance \mathbf{a}_1 of a gap (say 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 gap_1 ; second, the general core affordance \mathbf{a}_1' of gap_1 to contain any
 5 instance (e.g. **John**) of a general class Agent_1 (namely, the class of agents with the appropriate dimensions
 6 to be contained in gap_1) and the general core effectivity \mathbf{e}_1' of **John** to be contained in any instance (e.g.
 7 gap_1) of a general class Gap_1 (namely, the class of gaps with the appropriate dimensions to contain **John**).
 8 Since CON_{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 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 CON_{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 CON_{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, CON_{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 **step₀** is a disposition to be realized in a process of **Mary** climbing up **step₀** (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 **step₀** is the process of **Mary**'s climbing and this process is
 19 also the realization of **Mary**'s effectivity **e₀** (and so is the realization of its reciprocal affordance **a₀**
 20 of **step₀** 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).

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