Constructing Bodies and their Qualities from Observations

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Abstract. The principle challenge for information semantics lies in the degrees of freedom to interpret symbols in terms of thoughts and experiences which leads to incompatible views on the world. Consequently, incompatible information ontologies and interpretations of the described data will remain. Even though there is usually a common experiential ground, it stays often unknown to users of semantically annotated data. This *symbol grounding problem* is a bottleneck of information semantics, which remains largely unsolved in ontological practice. In this paper, we suggest – in the spirit of Jeremy Bentham – to introduce formal primitives which are directly grounded in inter-subjective experience, and which serve to expose and construct complex qualities in information ontologies.

Keywords. Ontology of qualities, Symbol grounding, Ontology and observation

Introduction

By developing ontologies to describe and query data, members of an information community aim at reconstructing the intended interpretation in terms of their own experiences. In previous work we argued that this requires *grounding*, i.e., relating the meaning of primitives in a theory to observations [1,2]. The so-called *symbol grounding problem* [3] states that declarative semantics expressed in terms of formal symbols give rise to an infinite regress. Formal theories alone cannot account for the sources of ambiguity in semantic interpretation, like indeterminacy of empirical theories, unintended domains and indistinguishability of reference [1]. We suggest that one way out of this regress cycle is to establish a primitive operational language of reproducible observations as a social fact. Such an approach parallels the idea of *embodied semantics* [4].

In this paper, we propose to trace formal ontologies about qualities and objects back to observation processes. In this, we follow an idea of Jeremy Bentham, that *fictive (reified)* entities in a language can be explained by deconstructing them into perceptibles. We argue that, on the one hand, the arbitrariness of reifications is a major source for ambiguity and hence limited interoperability between information ontologies (Section 1.1). On the other hand, a common experiential ground is often available in terms of universal

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perceptive operations, whose existence is empirically supported (Section 1.2). We sketch a general theory for grounding objects and qualities in *reproducible observation procedures*, e.g. in order to support ontology mappings or to annotate data about qualities (in Section 2). Using a small number of perceptual primitives, we describe use cases that are commonly considered as challenging for information ontologies, the cases including *n-ary qualities*, *temporal object properties*, and the problem of how to keep track of *object identity in time* (Section 3).

Note that in discussing the problems of fictions in information ontologies, we do not suggest that they are not useful, or that the existence of fictive entities should be epistemologically questioned. Instead, we argue that for semantic engineering purposes [5], it is helpful and often possible to to relate these fictions to a common experiential ground.

1. Related Work

In this section we introduce background readings relevant for the understanding of our following argumentation.

1.1. Bentham's Fictions and the Arbitrariness of Reifications

The *Theory of Fictions* [6] published in 1815 by Jeremy Bentham is a noteworthy contribution to the problem of language semantics, which inspired Ogden in his treatment of the meaning triangle [7]. Bentham states that individual percepts, such as those of bodies, can be used to expose the meaning of *language fictions*. Language fictions are linguistic creations of the mind that cannot be directly observed, but depend on other perceivable entities. Bentham's treatment of language is a treatment of names, i.e., nouns and their compounds which denote particular entities in thought. For instance, the sentence *the color of this body is red* denotes three mental entities, a body, its color quality, and a thing called redness. According to Bentham, such entities can either be *real* or *fictitious* [6].

Real entities are the ones whose existence is non-disputable by the speakers of a language. But what does this mean in practice? This class mainly consists of *perceptibles* including *bodies* (physical entities) in the first place, as well as *individual percepts* like e.g., *pain* and *pleasure*.

In contrast, the existence of fictions is posited by a speaker because they are useful for communication. Fictions serve as language proxies for real entities and often depend on their existence. For example, redness depends on the existence of a concrete color percept and on the perceived part of the surface of a body. Without those it would not be sensible to talk about redness as an existing entity – this is related to Peirce's *Thirdness*. For Bentham, reifications of quality values are therefore fictions in the same sense as the entities denoted by the nouns *motion, cause, action* or the legal fictions *obligation* and *right*. All these existentially depend on other directly perceivable entities [6].

According to Bentham's theory, qualities are second order (unary) fictions since they can inhere in arbitrary entities – fictive or real. In principle all kinds of entities can have qualities ([6], page 27 f.). Qualities and the abstractions of their values, however, are not perceivable themselves. Abstracted quality values like redness are fictive entities, while qualities, like color, are again abstracted from them. Bentham similarly reckoned all sorts of *aggregations* (whether collections or classes) among the fictions [6]. We argue therefore that Bentham's fictions are what modern logicians such as Quine [8] would have called *reified logical entities*. Furthermore, Quine rightly suggested that such reifications can change the underlying *ontological commitment* of a theory [8], because reified entities are values of existentially quantified variables, and therefore have to be added to the domain of interpretation.

Similar to Bentham's suggestions how to sidestep fictions[2], Quine suggests that unnecessary (fictive) names can be avoided by introducing predicates which rephrase them as descriptions. For instance, to avoid talking of a fictive particular *Pegasus* as an existing entity, we can refer to it as *the winged horse captured by Bellerophon*. And to avoid talking of *classes or universals* as existing things, e.g., humanity, we can introduce a predicate like 'being human' which accounts for its instances.

Quine concludes that these reifications are arbitrary to a large extent [8]. Any reification or deconstruction of the sort described above is a substantial change of the theory, since the domain of discourse expands or shrinks. Consequently, such degrees of freedom in modeling the real world tend to produce non-interoperable ontologies. There cannot be one-to-one correspondence between semantic domains if the underlying ontological commitments differ. Many ontologies are affected by this arbitrariness of reification which is one reason for incompatible top level ontologies. For instance, Neuhaus et al. [9] argue for the existence of universal entities and reified quality values such as 'universal sphericity'. They introduce generic dependence relations among particulars and their instantiated universals which exactly match with Bentham's ideas of existential dependence. Additionally, they reify a layer of quality fictions orthogonal to this one, building an 'ontological square': quality values inhere in other particulars, like in *the particular red of this apple*, and instantiate quality universals like *redness*. Other ontologies such as DOLCE [10], exclude reified universals like *appleness* in their domain of discourse. In another paper, the authors demonstrate that there are many possible more or less reified formalizations of an ontology of qualities with roughly equal expressiveness [10]. In previous work we have demonstrated that 'grouping' quality values in value ranges such as 'redness' can be necessary in order to account for the complex dimensional relationships between objects and their qualities [11]: 3-dimensional rivers have a non-atomic water depth value that is a class of actual atomic water depths. Bateman thus rightly argues [12] for a flexible *layered ontological framework*, which can account for the granularities of different views on space.

Most of such ontological variations are useful and plausible by themselves. But it is their arbitrariness which puts a burden to reach semantic agreement. In their attempt to construct a linguistically and cognitively plausible theory, the authors in a way just illustrated that language and thought are indeterminate, creative, and full of (useful) fictions. But this is exactly the reason why semantic ambiguities exist in the first place.

1.2. Are there Universal Perceptive Operations?

In the following paragraphs, we review empirical evidence for the existence of appropriate human operations that are at everyone's disposal for interpreting qualities and objects. It is essential for a grounding theory that observations can be reproduced indepen-

[2]Compare pages 86 ff. in [6].

dently of who performs this interpretation. One further important requirement is that this can be done independently from other mental concepts or beliefs. The experiences have to emerge spontaneously, i.e., as a result of drawing the attention to externally triggered functions, or of performing some other simple operation, without presupposing certain conceptual or even socially influenced processing steps. In short, they must be based on some *preconceptual mechanism* which can be expected to be *universal*; compare chapter 4 in [13].

Attentional Moments We begin by stating the identity of a moment in which a human focuses his attention on a certain signal from the environment. We assume with v. Glasersfeld[3], that there is a pulsed attentional process in the human cortex that produces *discrete* mental entities on the very lowest level of conscious perception [16], and stores them in memory as a temporal sequence[4]. It is well known that the focus of attention can be shifted by an observer in a scene independently from the stimulus, and that this shift has an intermittent 'sampling' character [17,15]. We furthermore assume that each one of these stored attentional moments may or may not be *focused on some neural event* in the organism. By 'focused' we "intend no more than that an attentional pulse is made to coincide with some other signal (from the multitude that more or less continuously pervades the organism's nervous system) and thus allows it to be registered" [15]. If the pulsing attention is *focused on some external sensory-motor signal*, it produces a constant flow of *conscious experience*, into which those signals are 'encoded'. This encoded information is respresented in our theory as *perceptual relations among attentional moments*; see Section 2. Other mental operations are then available to construct abstract entities from this flow of consciousness. In a very similar way, Barsalou suggested that *perceptual symbols* on an abstract conceptual level are encoded as records of neural states in the sensory-motor regions stored in long-term memory [4].

Identifying Objects and Surfaces Mainstream philosophy of the mind says that *objects* (in general: particulars) are constructed from more primitive 'point-like' percepts of *qualities* using conceptual reasoning and the application of knowledge[5]. Likewise, cognitive scientists predominantly tend to think that experience is based on the projection of point-like stimuli, e.g. visual pixels on the retina, and the application of concepts, e.g. 'object-identification' predicates that were *derived from what we know* about those objects[6]. But such a view gives rise to the epistemological puzzles that concepts imply other concepts in infinite regress, and of how to explain that humans can share knowledge although concepts (especially fictions) cannot universally be expected.

A remarkable exception are Gestalt psychologists such as Wolfgang Köhler [19]. He realized that the perception of objects in its most general sense is not an epistemic issue, but the result of an unconscious, dynamic self-distributed process, which is hardwired into the system, and which spontaneously cuts out units from the signal input which correspond to circumscribed surfaces of the environment. One classical example

[3] H. v. Glasersfeld developed a 'pulse' model for the mental construction of unities, pluralities and number out of sensory raw material, see chapter 9 in [14] or [15].

[4] Although the question of whether conscious perception is discrete or not is in principle still open, there is much psychophysical evidence for its discreteness [16].

[5] See for example Strawson's influential idea of *feature-placing* [18].

[6] See for example traditional research in attentional studies [17], or the 'mental imagery' debate, chapter 4.5 in [13].

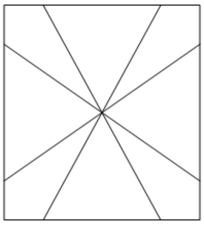


Figure 1. Slender x or thick cross? Adapted from Köhler [19].

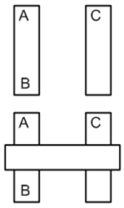


Figure 2. 'Same object advantage' in attentional spread [17].

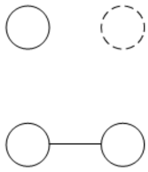


Figure 3. The effect of 'simultanagnosia', see text for details.

is depicted in Figure 1, which can either be perceived as a slender x or a thick cross – but not both at the same time, even though the information in the figure does not preclude this. Based on these insights, Gibson considered this autonomous apparatus for surface individuation an ecological constraint for the development of the visual system in the human environment [20].

There is recent empirical evidence for such a mechanism evolving from studies of object-based focal attention [17]. Same object advantages for example were demonstrated in target detection games. If attention is drawn to one end A of the bar-like object depicted in Figure 2, then *same object targets*, e.g., a sudden luminance decrement at B, can be detected faster than targets at C with exactly the same distance. The effect is stable even if the bars are partially occluded by another bar. There is an automatic spread of attention along the outlines of what humans perceive as an object, which takes into account its partial occlusion, its topological connectedness, and is symmetric and transitive. Further evidence for this mechanism is provided by the *Balint* syndrome, which is an object-based perceptual disorder that restricts attention to only one such object at a time (*Simultanagnosia*). While these patients are typically unable to see two separate discs simultaneously on a screen (see upper half of figure 3), they are perfectly able to see a single dumbbell (see lower half of figure 3), which suddenly appears when the two discs are connected by a line [17]. Pylyshyn therefore has recently [13] argued for the existence of spontaneous visual indices, called FINSTs, that are preconceptually available to refer to object surfaces, and that enable humans *to track* up to 4 such moving objects in a complex dynamic scene without any decrease in performance. This means that the same mechanism is also responsible for keeping object identity in time and under perspective change[7].

Identifying Locations, Directions and Length It is essential to understand that object and surface detection operations are crucial for all other perceptive operations that can be performed. Attentional studies show that relative mereological parts of objects as well as locations in the background environment can be identified [17]. But there is also recent evidence for a neurological mechanism underlying the construction of locations relative to the perceived object surfaces. Burgess [22] and others studied neurons in mammals, e.g., rats, that identify places (called *place cells*). These neurons fire in response to other cells (called *boundary vector cells*), that detect surfaces at a certain allocentric direc-

[7] We furthermore assume that this mechanism decides whether a strongly connected body stays the same if he loses parts, e.g. if he breaks. The mechanism therefore cannot be restricted to mere topological properties, compare [21].

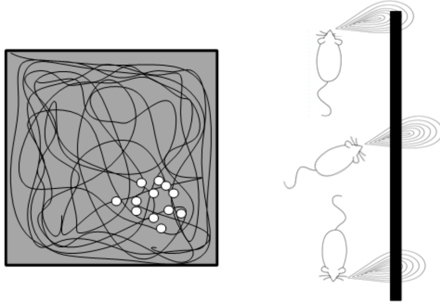
tion and distance (see Figure 4). Allocentric means that the firing of all these cells is independent of an egocentric reference frame, but depends on external landmark objects and surfaces [22]. If a rat comes across a place defined relative to the walls of a box, the cell will fire regardless of the direction of approach. In addition to these low level mechanisms, there are also those higher-level measurement operations available that we ordinarily think of when speaking about the geometry of the environment. Humans are commonly able to reproduce steps into a given direction and of a given length, which is a prerequisite for building up geographic reference systems. In this way, they are able to indicate the meaning of a location by outlining and pointing at regions relative to the environment's surface layout. Furthermore, humans have an equilibrium sense for detecting whether their body is in upright direction, and are also able to detect *verticality* of directions using any kind of physical perpendicular.

Identifying Shapes and Colors In the study of Kay and McDaniel [23], the authors suggested that there are 6 different types of color-sensitive opponent cells for detecting the primary colors blue, yellow, red, green, black and white. Each of these fire with a certain probability that can be modeled by a fuzzy membership function of measured wavelengths and intensities. By using the fuzzy set intersection, the non-primary colors orange, purple, pink, brown and grey could be derived, whereas fuzzy set union could account for broader color categories as cool and warm. Using this mechanism, the 11 so called *focal colors* and their unions can be reconstructed, which are known to be of universal significance as basic color terms in every human language. Even though the theory has been criticized and modified with regards to its claims about natural language color terms, the basic insight, that a universal neurophysiological mechanism of primary color detection exists which forms the semantic basis for most color terms of most natural languages, remains valid [24]. Although this operation is universally and autonomously available, its uncertainty is apparent because primary colors are prototypes and the color boundaries are fuzzy.

The construction of object-based qualities like shape is a more complex case which seems to involve the construction of body parts, as well as perceiving their geometric configuration using direction and distance detectors. We stick to the principle idea of Marr and Nishihara [25], that shape recognition involves a process of retrieving, storing, and comparing complex shape descriptions of bodies. These could e.g. be descriptions of oriented cylindrical body parts, consisting in the lengths of such parts and the object centered orientation angles between their natural axes (all of these can be constructed using the available operations and an extraction mechanism) [25]. The underlying operation could be physically realized as an unconscious neurological mechanism, but could also be consciously reconstructed by measurements. In either case, if such shape descriptions are compared allowing for tolerance ranges, this automatically induces equivalence classes on them, which constitute abstract shape values. Identification of shapes is also uncertain, since it depends on the shape resolution and tolerance levels which are arbitrary to a certain extent (compare the discussion in [25]).

2. Bodies and Qualities as Reifications using Perceptive Operations

In this work, we argue that one of the main problems of ontologies lies in their choice of primitives which, to a certain degree, is always arbitrary. This arbitrariness is a con-



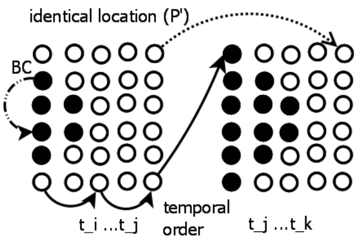


Figure 4. Place cell firing (white dots) of a rat tracked in a box (left). Principle of boundary vector cells (right). Adapted from Burgess [22], see text for details.

Figure 5. Principle of constructing temporal snapshots of bodies from foci of attention and location identifiers for two time intervals, see Section 2.4 for details.

sequence of the presence of language fictions [6]. In this section, we describe a formal theory of *personal perceptive capabilities*, which are at everyone's disposal in order to reconstruct bodies and their qualities. We begin with discussing the general idea of how to reconstruct certain kinds of fictions using identity criteria based on *equivalence relations*.

2.1. Identity Criteria for Abstract Classes, Qualities and Bodies

The importance of *identity criteria (IC)* for ontology engineering has been widely recognized [26]. In this section we argue that *identity criteria* are in fact an essential source for exhibiting the observable semantic plane of ontologies.

To state *true identity (=)* of two things in an ontology is a very fundamental semantic constraint, which influences the resolution of the described world into indistinguishable chunks, i.e., the ontology's *granularity*. This was recognized by Quine, who proposed a mechanism of *conceptual abstraction* based on indistinguishability; his *maxim of identification of indiscernibles* [27]. Quine claimed that any two-place predicate expressing an *equivalence relation* R could express identity relative to some sufficiently impoverished theory [27]. If, in this impoverished theory, two R-equivalent things become *indiscernible* with respect to the theory's terms (i.e., they satisfy Leibniz' criterion[8]), then the theory can always be *re-interpreted into a different (more abstract) domain* such that R just means $=$, and equivalent names are *identified* with one and the same thing. For example, "if one has a language in which one speaks of persons and in which persons of the same income are indistinguishable, the predicates of the language may be reinterpreted so that the predicate which previously expressed having the same income comes now to express identity. The universe of discourse now consists of income groups, not people" [29]. This is Quine's proposal of how abstract things, e.g. 'classes', but also 'objects' and 'qualities', come into being [27]. At the same time it indicates how *identity criteria* can be constructed for them: An individual in the second interpretation, an income group, is an *equivalence class* of R in the first interpretation. Similarly, suppose we have a theory about body parts containing arms, legs, and an equivalence relation R meaning 'related

[8] *Leibniz identity* is the criterion that requires indistinguishability of properties for identical things in a theory [28].

to the same body'. If arms and legs become indistinguishable in this theory, we can reinterpret R as $=$, resulting in a more abstract theory about whole bodies. And again, the R equivalence classes of body parts provide an identity criterion for bodies. In the same way, universal quality values like 'redness' can be abstracted from individual patches of red [27]. So identical things in a more abstract (coarse-grained) theory can be expressed as *equivalence classes* in a fine-grained theory. Williamson [30] called this mechanism of identification a *two-level criterion of identity*.

It can be seen that a chain of such entities of increasing coarseness is just a special case of a reification chain in the sense of Section 1.1, namely a chain of *aggregation or quality fictions*. In this case, however, the abstractions, e.g., income levels, are expressed *on the same language level* as their constituting more concrete entities, e.g., persons, using different names. Furthermore, the identity relation on abstract entities is then *definable* in terms of equivalence classes of lower level entities. The relevance of these considerations lies in the fact that they support the following hypothesis: The primitives for conceptual construction could be *equivalence relations, denoting outputs of preconceptual perceptive operations*, that account for the identities of various more abstract concepts in question[9]. Such an enterprise is readily confronted with the standard objections to previous attempts of 'extensional abstraction of qualities', like for example Carnap's *Aufbau* [31], which was based on an abstract *resemblance relation* among percepts. But unlike such philosophical attempts, our approach is modal, since it is based on perceptual neuron states, and it is properly grounded, so philosophical puzzles about the proper specification of the resemblance relation do not arise. The problem of *coextensionality of attributes*[10] can be accounted for by assuming that the output of each operation is a *relation involving a mental entity standing for that operation itself*. For reasons of simplicity, we left this straightforward modification out of the formalism.

In order to demonstrate the usefulness of our idea, we introduce the following 8 primitive perceptive relations[11] $\leq_T$, BC, P', $=_L$, OnL, $VertAln$, $=_{Color}$ and $=_{Shape}$ in a *first-order theory*, denoting outputs of perceptive operations on a *finite domain* D. The subdomain F of this theory together with *true identity* and a *reification operator* is introduced in the next subsection. In the remainder of this section, we will step-by-step add more abstract subdomains to D that can be *reified from* F using the primitive relations above, and discuss their identity criteria in terms of equivalence classes in F.

2.2. Identity of Foci of Attention and the Reification Operator

We start with the core domain of interpretation called *foci of attention* (F), consisting of the pulsed attentional moments of a human observer explained in Section 1.2. These moments already come with a natural identity relation: Perceiving time just means to perceive a temporal partial order relation $\leq_T$ on these pulses, from which identity $=_T$ can be derived. Because we assume that attentional moments are indivisible for an observer, this relation accounts for *true identity in* F. Furthermore, since the observer has stored

[9] The reified entities standing for equivalence classes were called *unities* in ontological frameworks like in [26], but the authors did not discuss identity criteria based on them.

[10] The problem of distinguishing between two qualities that happen to inhere in the same individuals

[11] The choice of these primitives builds on the discussion in Section 1.2 and allows to deconstruct the examples in Section 3, but the list is definitely not exhaustive and may have to be supplemented for other application areas.

attentional moments in memory, he is able to perform abstraction computations on them. For this purpose, we introduce a *reification operator schema* $[x]_R^\Phi : D \rightarrow \mathit{ReifiedEntity}$, where x denotes a particular element, e.g. a single attentional focus, of a subset of the domain of interpretation D. This subset is denoted by the predicate wild-card Φ. R is any *partial equivalence relation* on D. The function produces a reified entity for that R-equivalence class in the Φ-subdomain that contains x, given that x is in the ranges of both predicates. Otherwise it throws the *default exception*, which is supposed to be a special $\mathit{ReifiedEntity}$. We will omit R or Φ if we do not restrict the reification to a particular relation or subset of the domain. The domain of our theory, D, consists of the elements of F as well as of all reified entities constructed in the following. *True identity* in this theory is then defined based on the reificiation operator and the temporal relation:

$$e_1 = e_2 \leftrightarrow \begin{cases} e_1 =_T e_2 & \text{for } e_1, e_2 \in F \\ \exists x.[x]_R^\Phi = e_1 \wedge [x]_R^\Phi = e_2 & \text{otherwise} \end{cases} \tag{1}$$

2.3. Identity of Bodies and Surfaces

What is sometimes called the *individuation of a body in time and space* in the philosophical literature, can be conceived as an equivalence class of a *partial equivalence relation* on F. The relation is called *body-connected* (BC). It practically solves the philosophical problem of *object identity in time* by detecting whether two foci of attention focus on the same surface individuated by the spontaneous unifying mechanism discussed in Section 1.2, which is itself based on spatio-temporal continuity[12]. In this way, humans are spontaneously able to 'cut out' those parts or regions in the flow of conscious experience which correspond to the same body or the same surface *irrespective of its other perceived qualities*. The underlying operation cuts out e.g. just those parts of the visual field which correspond to Gibson's [20] 'solid angles in the ambient optical array', that is the surface patches in the perceivable environment. The relation has to be a *partial* equivalence relation (so it is not reflexive), because not all foci of attention are focused parts of bodies: there are also the empty gaps of space between them, which are sometimes called the *ground* for a *figure (resp. body)*, or the *medium* for its locomotion [20]. For the individuation of media, complementary operations can be assumed based on locomotion types and *affordances*[13].

2.4. Identity of Loci of Attention and Locations

A 'place', as Bentham conceived it [6], is a space for a body that is identified with reference to another (constant) body or surface, and which can therefore -in the same way as a body- be continually identified in time[14]. The identity of places must be constructed in reference to some surface, since there is no way of determining an absolute location in

[12]This mechanism of course does not account for identity across long intervals of spatial absence, which is a limit in the present outline of the theory.

[13]Compare the approach taken in [2]. Although we do not focus on media and affordances in this paper, they are essential for grounding complex conventional categories like doors or road networks [32]

[14]Note that we use the notion 'place' only in the sense of 'location', i.e. denoting a particular identifiable part of the environment.

space and time[15]. Note that this reference can be any body surface, and that locations can be parts of bodies or the empty space between them. For example, a location could be identified as a part of a body with respect to its own surface, i.e. as a relative location on it. For reasons of simplicity, we assume that we have another primitive equivalence relation P' for identifying *locations among attentional moments* (not a partial one this time, since every element of the domain F of attentional moments is focused on some location, and therefore the relation is reflexive). P' on F gives rise to equivalence classes of foci of attention, which can be reified as *smallest perceivable locations of the environment*, e.g. as $[x]_{P'} = l$. We call these reified abstractions *loci of attention* L, so for each P'-equivalence class in F we have exactly one element in L, and P' provides an identity criterion for identity on L as defined in Equ. 1.

Every equivalence relation on F, denoted by the wild-card R, implies a corresponding equivalence relation on L by virtue of P', denoted by the definition schema $[R]_{P'}$.

$$x[R]_{P'}y \leftrightarrow \exists a, b.[a]_{P'} = x \wedge [b]_{P'} = y \wedge aRb. \tag{2}$$

$$BodyAt(x_i, x_j) = [[x_i]_{P'}]^{\lambda l.(\exists x.[x]_{P'}=l \wedge x_i \leq_T x \leq_T x_j)}_{[BC]_{P'}} \tag{3}$$

Using the relation BC in this schema, we can now reify *bodies* as entities *representing classes of loci* for each one of a sequence of time intervals $\mathit{1}, ..., i, ..., n$. The expression $BodyAt(x_i, x_j)$ produces exactly that body for the time interval i with endpoints x_i and x_j, on which the attention is focused at x_i. Now it is possible to perceive *movements of this body* by calculating the differences among the classes $\mathit{1}, ..., i, ..., n$ on L for successive time intervals, in which the attention is focused on this body (Figure 5).

Arbitrary locations G can be constructed in a very similar way as *classes in* L, giving rise to an *extensional mereology*: With a wild-card $R' : L \times L$, let us refer to *all possible equivalence relations on loci of attention* in the perceivable environment[16]. Then every relation R' partitions the loci into equivalence classes. Just call the entities reified from these classes *locations* in domain G, and define a 'part-of' relation P such that each reification has all sublocations in its class as parts. It can be shown that G together with the so defined P operator satisfy a finite atomic version of extensional mereology (compare [33])[17]. The identity criterion for identity on G is then just given as an extensionality criterion on L: All locations made of the same loci of attention are identical.

2.5. Identity of Direction and Distance, and the Perception of Geometry

Let us call every pair of foci of attention an attentional *step*. Then we assume that there is a quaternary relation $=_L$ for perceiving equal length of two steps, e.g. $ab =_L cd$, where a, b, c, d are foci. With $[=_L]_{P'}$, we denote the reified version of this relation for the domain L. The operator realizes an equivalence relation on steps, which gives rise to the reification of *abstract lengths*: each equivalence class of steps can thus be associated with

[15]Even if we use a *spatial reference system*, this system is logically anchored in and therefore presupposes the identity of concrete places. Such an anchor place is a necessary part of a so called *geodetic datum* for a mathematical ellipsoid representing the earth surface.

[16]These are finitely many because our domain is finite.

[17]For reasons of space, we leave out the formal details here (assuming that these can be added if needed).

exactly one length. Furthermore, we have a primitive $OnL(x, y, z)$ for the perception of *collinearity* and *succession* of the two steps (x, y) and (y, z), that is, of whether both steps follow each other 'on a straight line'. Now we can define whether the length of the step x, y is smaller than that of another step q, z:

$$yx \leq_L qz \leftrightarrow \exists x'.OnL(y, x, x') \wedge yx' =_L qz \tag{4}$$

It is well known that from just these two primitives, pointless versions of a 3-dimensional Euclidean geometry can be constructed, if the domain is considered to be *continuous*[18]. Since the domain F (and likewise L) is neither *continuous* nor *dense*, but *finite*, we implicitly assume an analogous discrete 3-dimensional geometric structure in which the set of loci are 'equally spaced', like in a raster[19]. In this paper, we will not discuss any formal details of an appropriate geometry, but rather sketch the opportunities these operators offer. For example we can define a discrete notion of a *surface locus x of a body y*, following the converse idea of *isolation* in *discrete topology*, by requiring for all neighborhoods of this surface locus x, that, if they contain other loci, one of them must be not part of the body y:

$$\begin{aligned} Surface(x, y) \leftrightarrow \exists x_1, x_2.BodyAt(x_1, x_2) = y \wedge P(x, y) \wedge \\ \forall z.(z \neq x \rightarrow \exists z'.(xz'[\leq_L]_{P'} xz \wedge \neg P(z', y))) \end{aligned} \tag{5}$$

Additionally, we assume a primitive relation $VertAln(x, y)$, which detects whether the step x, y is vertically aligned with gravity.

2.6. Identity of Surface Qualities

As Gibson [20] recognized, surfaces are at the very heart of perception. They account for the individuation of bodies as well as for locating all sorts of their surface qualities. We denote the conscious operation of identifying two individual foci of attention by the universal color detection mechanism of Section 1.2 with the primitive equivalence relation $=_{Color}$. The identification of two shape descriptions (see Section 1.2), that were derived from two reified bodies for two time intervals, by the binary relation $=_{Shape}$. This last relation ranges over reified bodies, the first one over foci of attention[20].

3. Applications

The Withering Flower Representing a withering flower is a challenge for every ontology that presupposes a Leibniz-style identity criterion [28], because the flower changes all its perceivable qualities during withering very radically, e.g. shape, position, color, and odor. It might even lose some parts and still maintains its identity. The BC rela-

[18] See for example [34], and compare the approach taken in [35]. Note that many weaker geometries, e.g. topology, are definable with these primitives.

[19] The authors currently work on a discrete version of the theory about the *meaningful environment*, first outlined in [2], for this purpose. A version of such a finite space was e.g. described by Suppes [36].

[20] We suggest that each operation example stands for one of two general kinds: the first one could be called 'field-based', the second one 'object based'.

tion allows to decide whether a focused part of the flower is part of the same particular thing at another moment, regardless of any qualities. It is thus possible to individuate the flower bodies $\mathit{flower}_1 = BodyAt(x_n, x_m)$ and $\mathit{flower}_2 = BodyAt(x_i, x_j)$. If we pick out two foci x_1 and x_2 of the respective flower intervals that focus on a certain locus l on the blossom surface, i.e. $[x_1]_{P'} = [x_2]_{P'} = l$[21] with $Surface(l, \mathit{flower}_1)$ and $Surface(l, \mathit{flower}_2)$, we can check whether the perceived blossom colors are equal, $x_1 =_{Color} x_2$, that is, whether the flower has faded or not between the two time intervals. We can also express the flower's changing shape by checking $\mathit{flower}_1 =_{Shape} \mathit{flower}_2$.

The Far Side of The Moon Since the far side of the moon is always occluded from the viewpoint of the earth surface, the general layout of the moon surface was unknown until the Lunik 3 satellite managed to orbit around it and took the first photographs in 1959. Before 1959, the surface quality of the moon (e.g. its color and texture) in an astronomic ontology would have had no groundable meaning. Also, from a logical point of view, the far side could not be identified by its properties, and therefore the common Leibniz-identity criterion fails again. Observers are sure to photograph the moon only if they realize a continuous movement of the satellite to the far side. This movement is an interval in F, during which observers (or the engineers calculating the orbiting curve) must be able to constantly keep the identity of the moon surface while traveling in space. This can only be done by an independent mechanism like BC.

Distances vs. Widths of two Bodies Suppose we have to decide whether an armchair c fits between two cupboards cb_1 and cb_2. The width of the armchair is a unary quality inhering in an object, which is ordinarily dealt with in information ontologies. But the distance between the cupboards is a binary quality which inheres in two objects, and therefore cannot be attributed to one object. We first have to construct an operation $Horiz(x, y)$ which denotes horizontal steps, definable from the primitive $VertAln$ and the geometry of Section 2.5 [22]. Then we can define the width quality of the armchair c by the length of the largest horizontal attentional step that starts and ends at the armchair's surface:

$$Diam(x, y, c) \leftrightarrow Horiz(x, y) \wedge Surface([x]_L, c) \wedge Surface([y]_L, c) \tag{6}$$

$$Width(c) = (x, y) \leftrightarrow Diam(x, y, c) \wedge (\forall w, z.Diam(w, z, c) \rightarrow xy \geq_L wz) \tag{7}$$

Similarly, the distance between the cupboards cb_1 and cb_2 is the length of the smallest step connecting their surfaces:

$$Range(x, y, cb_1, cb_2) \leftrightarrow Horiz(x, y) \wedge Surface([x]_L, cb_1) \wedge Surface([y]_L, cb_2) \tag{8}$$

$$\begin{aligned} Dist(cb_1, cb_2) = (x, y) \leftrightarrow Range(x, y, cb_1, cb_2) \wedge \\ (\forall w, z.Range(w, z, cb_1, cb_2) \rightarrow wz \geq_L xy) \end{aligned} \tag{9}$$

It is now possible to check whether $Dist(cb_1, cb_2) \geq_L Width(chair)$.

[21] P' is used here to identify equivalent parts of the flower *relative to its own body*.

[22] For this purpose, we need to fix a *reference vertical*, i.e. a series of vertically aligned foci, for example at one edge of a cupboard. On each focus of this vertical we can construct a plane which lies perpendicular to the vertical. We can then assert $Horiz(x, y)$ if x and y lie in one of these planes.

4. Conclusion

In this work, we introduced a list of primitives for a logical theory that can be used to ground ontologies and datasets about objects and qualities in universal perceptive operations. We demonstrated that the mechanism of logical reification of fictive entities using identity criteria (based on equivalence classes evolving from these primitives) helps to deal with some examples that are commonly concerned as challenging for ontologies. We have also provided empirical support for the view that these primitives are based on preconceptual, concept independent and universal mechanisms, being at the disposal of most human beings, and therefore enabling a common semantic plane.

As our approach is in an early stage, several questions remain open. First, universality in a physiological or ecological sense, i.e., in the sense of sharing common dispositions for the proposed operations, is only a necessary prerequisite in order to reach semantic agreement. The principal challenge for semantic engineering is how to adequately coordinate personal semantic interpretations of symbols [1]. What is missing, is a way of enabling that the individual semantic interpretation process, e.g., the naming and construction of perceivable bodies and qualities, can be coordinated in a group, given that constructing operators is creative or even fuzzy. The authors believe that such a process could rely on demonstrative acts like ostension or on an underlying mirror neuron mechanism. Second, the proposed formalism needs a full exposure. Defendable axioms have to be introduced (the authors have discussed a continuous version of an axiomatized theory in previous work [2]). Meta-logical properties, like expressivity, satisfiability, and reasoning capabilities of an appropriate finite first-order theory have to be discussed. And third, real application examples, e.g. for road network data [32] and hydrological qualities, will require extensions of the theory.

Acknowledgements

This manuscript owes much to the detailed comments of the anonymous reviewers. Our work is funded by the Semantic Reference Systems II project (DFG KU 1368/4-2) and the International Research Training Group on *Semantic Integration of Geospatial Information* (DFG GRK 1498).

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