# A Whiteheadian approach to data and knowledge

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**ABSTRACT**

**Motivation:** We live in the age of Big Data. Data are collected about everything which has a mode of existence; this can be objects, processes, pictures, verbal reports, and many other types of things. The final purpose of data is not to collect more data but to transform data into relevant applications. For this purpose, there is a need to transform data into knowledge which is the basis for a manifold of applications. The current situation of data overload is caused by a lack of methods for abstraction and interpretation of data, but also by an insufficient understanding of the relation between data and knowledge. The overall goal of our work, intended to be realized within a longstanding project, is to establish an ontological framework which may serve as a unifying theory of data and knowledge. We explore various philosophical sources, and ascertain whether they may contribute to the realization of this project. In the present paper we consider Whitehead's philosophy.

**Approach:** We explore the philosophy of Whitehead, expounded in Process and Reality, with respect to its relation to a recently developed ontology of data called GFO-Data. Whitehead's Process and Reality provides a non-formal approach to the creation of data and knowledge.

**Results:** Basic categories and relations of Whitehead's Process and Reality are analyzed and specified by axioms in FOL. We outline a representation of the informational character of a datum as a prehension. This approach needs to be completed in order to grasp the process of transforming data into knowledge in more detail.

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## 1 INTRODUCTION

In the current paper we present an approach, inspired by ideas of Whitehead's philosophy in *Process and Reality*, which supports the analysis of the categories of knowledge and data. This investigation was stimulated by the boom of Big Data and the need to gain a deeper understanding of the relation between data and knowledge. We believe that this boom precipitates, serious misinterpretations about the role of data and its expected power to generate real knowledge. From some circles of computer scientists and software engineers, but also statisticians, emanates the idea that empirical science and its methods are obsolete in the age of Big Data, because all the knowledge is in the data and can be extracted by mining algorithms and statistics (Anderson 2008).

We hold that this view is questionable and unsettled. One may ask whether it is possible to extract Einstein's General Theory of Relativity out of petabytes of physical data by methods of knowledge mining and statistics. Another example is expressed by the following quote of the statistician E. P. Box: "Essentially, all models are wrong, but some are useful" (Box 1987). We disagree, and believe that Box misunderstood the role of models and underestimates the importance of theory formation. Our detailed analysis of this topic will be published elsewhere.

Members of other communities, notably from psychology, are more aware of problems pertaining to the relation between data and knowledge. In (Mausfeld 2011) the author addresses the fundamental problem of perception theory. Mausfeld notes that in the standard model of perceptual psychology, which is basically used in computer vision, occurs an explanatory gap because this model borrows concepts, such as surfaces, shadows, boundaries or illuminations, implicitly from the output of the perceptual system. In the spirit of Whitehead, these concepts are localized in the realm of eternal objects and not directly in the raw data. The remaining problem is unsolved, namely to understand how the perceptual system integrates the sensory input with the eternal objects to create a perceptual object.

In (Albertazzi 2015) an intriguing argument is presented in favor of the usage of a natural semantics in an advanced ecological theory of perception. We hold that the same is valid for image processing, too. As Albertazzi accentuates, it is necessary to express phenomenal qualities not in an objective manner, but rather in the way they are perceived subjectively. Whiteheadian subjective forms are the key to represent how contemporary entities are perceived. Their descriptive character allows applications to not only represent appearances as dispositions, since they are capable to encode functionality and affections. Subjective forms are the result of a sense-making process and how visual data are perceived according to a perceiver.

We defend the conception that theory is needed and should be regulated as well as tested by practical applications.[1] Conveniently, the neuro-ecological model of the brain described in (Northoff 2016a) does not only withstand ontological discussion in (Northoff 2016b) but also an impressively successful comparison to empirical data. This model is based on the Whiteheadian notions of subject and object and explains how they are subsequent phases of perceiving entities. These notions will be discussed later in this paper and provide a foundation for this model in a formal guise. Such work emphasizes the important role of formal ontology as it is pointed out in (Martin 1999), which can be summarized by: *All what exists falls prey to ontology*.

[1] Hamming (1997) "In science, if you know what you are doing, you should not be doing it. In engineering, if you do not know what you are doing, then you should not be doing it:"

# 2 APPROACH

## 2.1 Basics of an Ontology of Data

We use the top level ontology GFO as a reference ontology and framework for our investigation (Herre 2010; Herre et al. 2007). In GFO the existence of four ontological regions, called ontological strata, are postulated. The temporal regions include the material stratum, the stratum of societal entities, and the psychological stratum. The ideal region includes entities which are independent from space and time, including mathematical objects and universals; in Whitehead's philosophy they correspond to the eternal objects. In GFO the entities of the world are classified into categories and individuals. Categories can be instantiated; individuals are not instantiable. GFO allows for categories of higher order, i.e., there are categories whose instances are categories themselves. Spatiotemporal individuals, also called concrete individuals, are classified alongside two axes: the first one explicates the individual's relation to time and space, and the second one uses the relation of existential dependency between individuals.

Spatiotemporal individuals are classified into continuants, presentials and processes. Continuants persist through time and have a lifetime; they correspond to ordinary objects, such as cars, balls, trees etc. At any time-point of its life time, a continuant exhibits a presential, which is an entity that is wholly present at that time-point. Processes are temporally extended entities that happen in time; they can never be wholly present at a time point. Processes have temporal parts, which are processes themselves.

Concerning the second axis, attributives depend on bearers which can be objects (continuants, presentials) or processes. Situations are parts of reality which can be comprehended as a coherent whole (Barwise et al. 1983). There is a variety of types of attributives, among them qualities, roles, functions, dispositions, and structural features. Categories the instances of which are attributives are called properties. According to the different types of attributives (relational roles, qualities, structural features, individual functions, dispositions, factual, etc.) we distinguish quality properties (intrinsic properties) and role properties (extrinsic properties). The latter are classified into relational role properties (abr. relational properties), social role properties (social properties).

GFO includes a part that is GFO-Data, which is a top level ontology of data (Herre 2016). The semantics of data is captured by properties, the instances of which need a bearer. The syntax of data uses symbol structures and tokens, which can be saved on a material medium, for example a hard disc. The relation between the semantics and syntax of data is investigated in (Uciteli 2011). A similar approach is presented in (Ceusters 2015). In the following we consider the semantics of data only.

According to GFO-Data, we distinguish three levels of information: phenomenal data, factual data and propositions, whereas the term information is used informally to cover both data and knowledge. Data depend on bearers, and we assume that the bearers are concrete individuals. In GFO-Data, atomic data are covered by attributives and the corresponding properties; they are constituents for complex data.

The elementary form and the origin of phenomenal data are sense data, but also data which can be measured by instruments. These data correspond to qualities. With respect to the bearers, we distinguish between object-data and processual data. Object-data are classified into presentic object-data, and non-presentic data. At any time point of an object's life time, its object-data exhibits entities, being wholly present at this time point. This means that an individual quality of an object, say an individual red, can be wholly accessed at time points. The composition of an object with some of its qualities exhibits more complex data, called object-facts.

The bearers of processual data are processes. Processual data are classified into presentic and global. Presentic processual data are associated to process boundaries. They must be wholly accessible at time points. The isolated presentic data of process boundaries do not need any reference to a process. They can be completely reduced to object qualities. These are typically qualities of objects participating in the process. An example of a non-isolated datum of a process is the velocity of a moving body at a time-point. This datum cannot be determined and specified without a preceding process.

The global qualities of processes are the richest class of processual qualities. A systematic classification of these qualities is in its initial stage. Their main feature is that it does not make any sense to specify them at a process boundary. One type of such qualities is abstracted from time series in form of curves. Examples are electro-cardiograms or a long term blood pressure measurement. There are many other global qualities of a process which are not derived from time series. Examples are the duration of a process, its temporal extension or its occupied space. Physics provide many examples of this kind, e.g. the average velocity of moving bodies.

The non-phenomenal data open a rich field of data, from which we select relational data only. Relational data are based on relations, which are categories (universals), the instances of which are relators. A relator, being a cognitive creation, is an attributive which is composed of (relational) roles. We consider the following expression $G :=$ "$John's\ drinking\ a\ beer$". The subterm "$drink$" denotes a relation, denoted by $Rel(drink)$. Let $p$ be an instance of $Rel(drink)$, then from this we may derive two roles, the role $q_1$ of the drinker, and the role $q_2$ of the drunken. John plays the role of the drinker and the beer plays the role of the drunken. These constituents are composed to a complex entity, a relational fact expressed by "$John`s\ drinking\ a\ beer$"; the fact, denoted by this expression $G$, is denoted by $Fact(G)$. The bearers of a relator are determined resp. specified by the players, which play the corresponding roles. The roles themselves occur as unary attributives, though they cannot be separated from the relator of which they are a part of.

Relators and roles are considered attributives, being more abstract than phenomenal data, as for example qualities. These data cannot be accessed by perception and measuring instruments. Relators can be classified with respect to the bearers; the role players may be objects or processes.

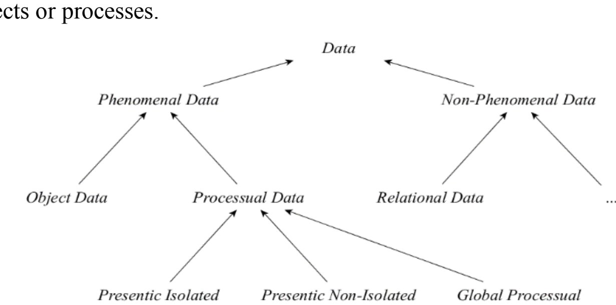


**Fig. 1** Categorical Basic structure of GFO-Data

We hold that propositions are more abstract parts of the world than facts. Elementary relational propositions correspond to relational facts. Let us consider the fact $Fact(G)$, associated to the expression $G := \text{"}John's\ drinking\ a\ beer.\text{"}$ By an operation of abstraction the mind transforms the fact $Fact(G)$ into the proposition $Prop(Fact(G)) := \text{"}John\ is\ drinking\ a\ beer.\text{"}$ The modes of existence of $Fact(G)$ and $Prop(Fact(G))$ are different: $Fact(G)$ is a part of spatiotemporal reality, whereas $Prop(Fact(G))$ is an abstract entity having an indirect relation to reality, mediated by the corresponding fact. Propositions can be satisfied or disproved, hence, they can be true or false.

We emphasize that the interface between data and knowledge occurs at the transformation from facts to propositions. Relational propositions are very simple expressions which can be used to represent small pieces of knowledge. The development of a full-fledged ontology of knowledge, which includes complex propositions, theories and knowledge fields, is an important task for the future. Figure 1 summarizes the basic categories of GFO-Data.

### 2.2 Process and Reality

The crucial part of the ontology in *Process and Reality* is the becoming of *actual entities*. These actual entities, being in space and time, are the only components reality consists of from a physicalist point of view. All other entities are abstract objects or parts of actual entities. These parts form the inner structure of each actual entity and determine its perceivable attributes. What Whitehead refers to as *process* lies in the becoming of each actual entity and plays an integral part in how the inner structure of such an entity is created. The becoming is the evaluation of the sense data which an actual entity can perceive and how the information, created out of this data, is composed. Furthermore, this information determines how the entity can be perceived by other entities.

Whitehead refers to the cycle of perceiving and being perceived as *principle of advance.* Each actual entity fulfills two tasks. Firstly, in its role as a subject, it transforms data into knowledge and secondly, in its role as an object, it provides this knowledge as data for other entities. The process itself is the transformation of data into knowledge. Data is a result of perception and no object is perceived directly, but it is grasped by its attributes. Likewise, an actual entity does not directly perceive other actual entities; it perceives its surrounding world as *prehensions* about the actual entities the world consists of. Therefore, each attribute will be reflected as a part of the prehension its carrying actual entity effects. This part is the universal the attribute instantiates.

Whitehead calls them *eternal objects* as they are more than just object-universals. Each of them is used relative to the prehending subject, whereas an object-universal is the same for each subject. As an example we consider the situation that a dog is prehended as frightening; the eternal object, used by the subject to describe this dog, is not the object-universal *dog* only. The corresponding eternal object is a composition of the object-universal *dog* and fear as a subjective emotional component which is another eternal object. In *Process and Reality* these compositions are called *subjective forms*. These subjective forms resemble aspectual derivatives, as presented and discussed in (Herre 2013).

If an actual entity $a$ perceives the actual entities $b$ and $c$ and prehends them by means of their common attributes $X$ only, then $b$ and $c$ are perceived as a single entity $n$, because $a$ cannot distinguish them and assumes them to be the same. Whitehead calls this entity $n$ the nexus of $b$ and $c$, justified by the subjective form $x$ which is the complex eternal object having all $X$ as its parts. This nexus is not a basic datum anymore, it is already a product of $a$'s mental pole, as well as a probably unconsciously made proposition about $b$ and $c$. The creation of such mental entities mark the first step on the way to the creation of knowledge from data.

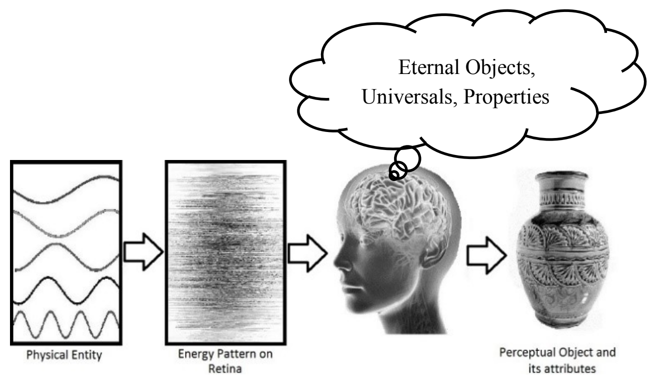


**Fig. 2** Physical entity $P$, energy pattern on the retina $R$, and the mind $M$, being dependent on the brain, are actual entities, which are connected by the prehend-relation, whereas the vase $V$ is a perceptual object which is created by the mind by integrating the input of the retina and certain eternal objects, to which $M$ has access. The perceptual object belongs to the internal structure of the mind $M$. In the picture those attributes (resp. eternal objects) of the vase are left out which refer to the tactile phenomena.

We argue that there are similarities between the Whiteheadian process ontology and the GFO-approach to an ontology of data and knowledge, as sketched in section 2.1. The justification of this claim needs a deeper analysis of the structural aspects of Whitehead's process ontology within the GFO-framework. In this paper, we focus on a partial representation of those entities types only, which Whitehead subsumes under his *Category of Existence*. In the future work, we intend to give a complete description of all these types and will define a relational structure in which they coexist to form a continuously evolving reality.

Figure 2 displays the relevant components which are associated with the perceptual system. This can be described by using the notion of actual entity, the relation of prehension, and eternal objects, which correspond to attributes being universals.

## 3 FORMAL REPRESENTATION

Whitehead's *Category of the Ultimate* specifies the principles which are presupposed in the three other categories, defined in *Process and Reality*. The so-called *Category of Existence* aggregates all types of existing entities. The subsequent *Category of Explanation* and *Category of Obligation* describe the notion of these types and their basic functional properties, as well as relations between their instances. Subsequently, we summarize how actual entities, prehensions, and eternal object must be specified to support applications in the theory of data and knowledge.

### 3.1 Data

In the Whiteheadian approach, the basic elements of the categorical scheme are actual entities, which form reality, and eternal objects that provide order and definiteness to them.

#### *3.1.1 Actual Entities*

Actual entities are defined in two different ways, depending on context. One context pertains to the evolution of developing entities, where the actual entity presents an event, whereas the other refers to an actual entity's own process of becoming as subject.

A becoming subject analyzes the data provided by the world and gains spatiotemporal extensiveness during this process. This extensiveness is effected by the resulting information of this analysis. The becoming itself has no extension on its own, but results in an actual occasion representing extensiveness. These actual occasions are a special kind of event, consisting of one unique actual entity only. We argue that these two entities are equivalent. If a reference is made to an actual entity's extensiveness, i.e. its position in time or space, we are talking about its corresponding actual occasion. Since it has no temporal extension, we argue that each becoming resembles an instantaneous change. An effected change is only to some degree specific to the actual entity, because an external determination exists.

### *3.1.2 Eternal Objects*

The determination of actual entities is provided by eternal objects. These objects are able to describe actual entities and thus, the analysis of a becoming subject results in information as a composite eternal object. The existence of such complex objects implies an ordering between all eternal objects enabling actual entities to evaluate their analysis regarding the relevance of the results. Whitehead presupposes the existence of a unique actual entity which is final; it exists initially and its internal structure implies a binary relation on the set of all eternal objects. We argue that this relation is a partial ordering; it resembles the ordering between concepts, introduced and investigated in (Herre 2007). The system of eternal objects, together with a binary relation $\leq$, is called ontology structure, and is presented by the pair $OS = (Eternal, \leq)$. We stipulate the following axioms.

$$\forall x(x \leq x) \tag{1}$$

$$\forall x, y, z(x \leq y \land y \leq z \rightarrow x \leq z) \tag{2}$$

$$\forall x, y\ (x \leq y \land y \leq x \rightarrow x = y) \tag{3}$$

For each actual entity $e$ there is a unique eternal object, called its subjective aim. This aim helps $e$ to choose valuable data during its becoming by providing the abstraction of an ideal outcome. In addition, this aim determines which eternal object $o$ is selected as a subjective form by $e$ to give meaning to a *datum*, i.e. another entity $e'$. The eventual assignment of $o$ to $e'$ is called *objectification* of $e'$ and, thus, establishes a subject-object-relationship between $e$ and $e'$. This relation characterizes $e$ as *subject* and $e'$ as *object*. $o$ provides a potential representation of $e'$ in the internal structure of $e$, as well as a valuation of $e'$, regarding the subjective aim of $e$. Thus, a subjective form is a possible composition of eternal objects, representing an objectified entity and its value for a specific subject. Since each composition of eternal objects is an eternal object, a subjective form $f$ is a complex eternal object. $f$'s role of being a subjective form existentially depends on an actual entity $s$ playing the role of a subject, and another entity $e$ playing the role of an objectified entity. This relation is a basic relation, which is denoted by $prehend(s, e, f)$.

### *3.2.2 Prehensions*

Informally, a prehension is an act of grasping something either by means of sense or mind. During the process of becoming, an actual entity creates composite entities forming its internal structure. Each of these entities is a reaction to other actual entities and to the eternal objects characterizing this reaction.

We introduce a first-order structure $KS = (W, OS, subject, datum, form)$, called knowledge structure, because it aggregates the main components taken from Whitehead's philosophy, which are crucial for the elucidation of data and knowledge. Here, $W$ denotes the universe, consisting of spatiotemporal entities, which include the set actual entities $Actual$ and the prehensions, $OS$ is an ontology structure as introduced above and $subject$, $datum$, $form$ are binary relations to be explained later. Prehensions are a special form of composite entities.

The earlier mentioned subject-object-form-relationship is crucial to the definition of prehensions. A subject *objectifies* a datum by assigning a subjective form to it. In this context, objectification means making a datum graspable by assigning abstract universals and emotions to it. Prehensions encode such objectifications, i.e. how entities generate information out of data. In the following we focus on those entities described in *Process and Reality*, which are relevant for the analysis of data; these are prehensions of actual entities, and eternal objects. These types are sufficient to describe the acquisition of data, the evaluation by the subject, and to outline the mental operations realizing the creation of data and knowledge.

$$\forall x \left(Prehension(x) :\leftrightarrow \exists u, v, w\left(subject(u, x) \land datum(w, x) \land form(w, x)\right)\right) \tag{4}$$

$$\forall x, y\left(subject(x, y) \rightarrow Actual(x) \land Prehension(y)\right) \tag{5}$$

$$\forall x, y\left(form(x, y) \rightarrow Eternal(x) \land Prehension(y)\right) \tag{6}$$

$$\forall x, y \left(datum(x, y) \rightarrow \left(Actual(x) \lor Eternal\ (x)\right) \land Prehension(y)\right) \tag{7}$$

$$\neg\exists x\ \left(Actual(x) \land Eternal(x)\right) \tag{8}$$

$$\neg\exists x\ \left(Actual(x) \land Prehension(x)\right) \tag{9}$$

$$\neg\exists x\ \left(Eternal(x) \land Prehension(x)\right) \tag{10}$$

According to the type of its datum, we distinguish between *physical* and *conceptual* prehensions. Both of them have different sources. Physical prehensions emerge from actual sense data and can be seen as raw data, whereas conceptual prehensions are products of an actual entity's mental pole which represents mental data.

$$\forall x \left(Physical(x) \colon\leftrightarrow \exists y\left(datum(y, x) \land Actual(y)\right)\right) \tag{11}$$

$$\forall x \left(Conceptual(x) \colon\leftrightarrow \exists y\left(datum(y, x) \land Eternal(y)\right)\right) \tag{12}$$

All other prehensions are called *impure*, because they integrate mental and sense data. The question arises how it is possible to ac-quire mental data. According to Whitehead's *ontological principle,* every datum has to be derived from an actual entity. Thus, there is a connection between the ontology structure $OS$ and the actual entities. The answer is given by the *Category of Conceptual Evaluation* because it states that every conceptual prehension is a reproduction of the evaluation of its corresponding physical prehension.

$$\forall x, y, z \left(Physical(y) \land subject(x, y) \land form(z, y) \rightarrow \exists u\left(subject(x, u) \land datum(z, u)\right)\right) \tag{13}$$

Let us consider an observer $o$ and a loudspeaker $l$ facing him. $l$'s emission of a soundwave $s$ is an attributive and observable as a phenomenal datum by $o$. Furthermore, assume a second loudspeaker $l'$ next to $l$ which emits the same sound wave as $l$. According to the stereo effect, $o$ will recognize the emission of a unique sound wave $s'$ as phenomenal datum. $o$ is unable to distinguish between the soundwaves of $l$ and $l'$, but, because he faces them directly, he may distinguish these concrete individuals visually, by grasping further phenomenal data provided by the loudspeakers. Applying the formalism, we define $o$, $l$ and $l'$ as actual entities and $o$ has a prehensions $p$ and $p'$ corresponding to the respective loudspeakers.

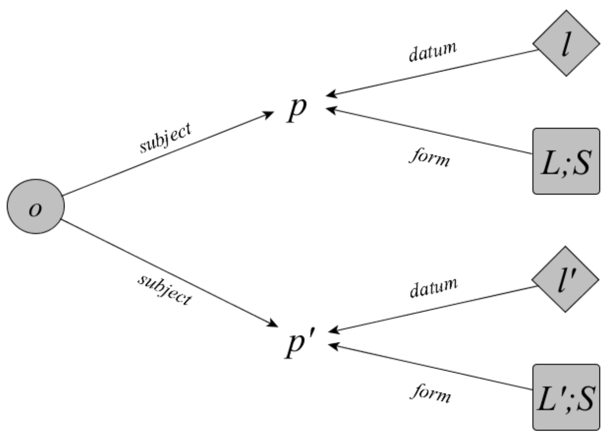


**Fig. 3** The prehensions of an observer $o$ regarding two loudspeakers $l$ and $l'$ emitting the same soundwave.

In Process and Reality this situation would be modelled far more complex, because each soundwave is composed of actual entities, and the eternal objects would resemble the laws of physics. However, we believe that the following simplification is expressive enough for most use cases. Assume the existence of the eternal objects $L$, $L'$ and $S$ representing the conceptualization of both loudspeakers and the soundwave they are emitting. Figure 3 shows both physical prehensions $o$ is perceiving. $L; S$ and $L'; S$ denote the subjective forms of $l$ and $l'$. It holds $L \leq L; S$, $S \leq L; S$, $L' \leq L'; S$ and $S \leq L'; S$. Depending on $O$ and the subjective aim of $o$ the subjective form of the conceptual evaluation of $L; S$ and $L'; S$ can be determined and define the conceptual prehensions of $o$.

There are some striking parallels between GFO-Data and *Process and Reality*. The physical prehension $p$ resembles the bundle $b$ of all phenomenal data inhered by $l$, i.e. a set of object facts, and thereby each quality $o$ is able to perceive from them. $p$'s subjective form $L; S$ is the fusion of all categories instantiated by the elements of $b$ as an eternal object. To perceive an individual quality of $l$, $o$ has to divide $p$ into atomic parts to create more granular prehensions. The prehensions $p_1, p_2, \dots, p_n$ of $x$ are inherited by $o$ as $p'_1, p'_2, \dots, p'_n$ with modified subjective forms. There has to be a prehension $p_i$ in $l$ that is inherited by $o$ that effects its sound emission instantiating the universal $sound\ emission$ corresponding to $S$. Thus, $p'_i$'s subjective form has $S$ as a part. Let us extend the inheritance to contain a historical way from the loudspeaker over the ears and cochlear nerves up to $o$'s brain, which is able to prehend sound emissions consciously. An analysis of $p_i$ and this historical way will enable us to analyze the principles of perception further. We plan to embed this procedural concept into GFO-Data to show how phenomenal data is acquired similar to the process shown in Figure 2.

## 3.2 Knowledge

If we want to capture the notion of knowledge, we have to bear in mind that knowledge is represented in prehensions whose objects are propositions. Since we have seen that data is the direct sensing of another actual entity resp. its conceptual evaluation, propositions are what we called impure prehensions. Knowledge arises if mental and sense data are mixed to create propositions about the contemporary world of a subject.

Let us reconsider the example of the observer and the two loudspeakers and take away the light. $o$ is able to perceive the sound emission such that the perceivable attributives of $l$ and $l'$ are the same. The activity of perceiving two concrete individuals as one entity yields a special type instantiated by the abstract individual $s'$ that exists for $o'$ only as shown in Figure 4. In *Process and Reality*, individuals like $s'$ are called *nexūs* which are similar to relators in GFO. Their purpose is to provide an abstraction from an exhaustive granularity or express missing differentiation between individuals. To formalize this notion, we need an alternative axiomatization of knowledge structures with the following axiom allowing us to define nexūs. An extended signature needs to contain the binary relation $\in$ denoting that an actual entity is included in a nexus. Nexūs are used to describe the mereological fusion of a set of actual entities to a complex entity, according to their common prehensions. The complex eternal object, which is the common part of the subjective forms of these prehensions, is called the common element of form.

$$\forall x, y, z, u, v \Big( Actual(x) \land subject(y,z) \land datum(x,z) \land form(v,z) \land\ u \leq v \rightarrow \forall r, s, t\big(Actual(r) \land datum(r,s) \land subject(y,s) \land form(t,s)\ \land u \leq t \leftrightarrow \exists m, n(datum(m,n) \land subject(y,n) \land r \in m)\big)\Big) \tag{14}$$

Nexūs are the logical objects of propositions, and provide an abstraction from the atomic view at the expense of accuracy. Propositions are statements about groups of entities abstracted to a nexūs. They consist of two parts, the earlier mentioned logical subject and a logical predicate. This predicate is a subjective evaluation about the logical subject and hence a complex eternal object. Some of the created knowledge is chosen to constitute the internal structure of this entity, since not every conceivable piece of knowledge is correct or consistent with other propositions. In order to reach this distinction, an actual entity distinguishes *positive* and *negative* prehensions. The datum of a negative prehensions has no relevance for the subject, while the datum of a positive prehension resp. *feeling* has relevance.

The set of propositions of every actual entity in $KS$ is its judgement about data in $KS$. This implies that the truth of each proposition depends on its prehending subject, i.e. if it is a feeling, i.e. true for the actual entity creating it, but this does not imply universal truth. To describe this relation, an extended interpretation of the concepts as theories approach, described in GFO-Data, has to be applied because this approach makes the same assumption about truth of propositions. We intend to evaluate these Whiteheadian notions of knowledge, i.e. nexus and proposition, regarding a usage in GFO.

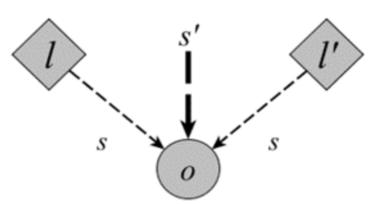


**Fig. 4** An observer $o$ with two loudspeakers $l$ and $l'$ facing him. The emission of the equivalent soundwaves $s$ is perceived as the singular soundwave $s'$.

## 4 RELATED WORK

The process-ontological ideas of Whitehead's *Process and Reality* are well-recognized by many scientists of various disciplines beyond philosophy. To the best of our knowledge, there are not many applications of it in computer science. Additionally, none of these are similar to the work presented here.

The work in (Palomäki et al. 2010) copes with the application of Whiteheadian philosophy in software engineering. The proposed process ontology is a framework that will augment existing models by embedding them into it. In contrast to our work, they use connectivity of events as a causal relation between them. Our approach considered prehensions, which are the foundation of each becoming event. In later works, we plan to define our own definition of causality based on events and temporality. Without considering prehensions, the becoming of entities is limited to the final result and no temporal relations can be derived formally.

The extensive abstraction of events is the foundation of Whitehead's point-free geometry. This kind of geometry is highly influential in the research area of Qualitative Spatial Reasoning. An extension of these approaches is investigated in (Vakarelov 2010). Vakarelov creates a dynamic mereotopology by incorporating the epochal theory of time into contact algebras. In contrast to a mere consideration of the spatiotemporal representation of reality, our work used an interpretation of actual events, how they obtain prehensions as well as their final concrescence which forms reality.

A use case to apply an ontology of perception is given in (Galton et al. 2015). They emphasize the processual nature of relations inherent in the processing of histological images. The reduction of information immanent in these processes allows a qualitative conceptualization of data items. This reduction closely resembles how nexūs are created to abstract from exhaustive granularity. Although the terminology is rather technical, their ontological layers can be mapped easily to layers of perception as shown in Figure 2. However, we argue that a formal ontology can be regarded as foundation of computer vision and image processing only if is based on human perception rather than a technical substitute.

## 5 CONCLUSION

In this paper we investigated interrelations between GFO-Data and Whitehead's philosophy, expounded in *Process and Reality*. This investigation is intended to gain a deeper insight in the categories of data and knowledge, and how they occur in the network of actual entities. It turns out that the relation of prehension is a basic relation, the ontology of which is compatible with the integrative realism, as introduced in the top level ontology GFO.

Furthermore, we presented an axiomatization of various binary relations and classes of basic entities, occurring in *Process and Reality*. These axioms are specified by formulas in First Order Logic, and they exhibit the first version of a formal ontology associated with Whitehead's philosophy. In further studies, we want to investigate in more detail the relation of prehension, and ascertain whether these ideas can be applied to various fields, in particular in the field of computer vision and cognitive psychology.

The next step of our work is the design of a detailed research program aiming at an ontologically-based unifying theory of data and knowledge. The boundary between data and knowledge can be localized at that place, where facts are transformed into propositions. In our examples these propositions are very simple; they present only small pieces of knowledge. For the development of a full-fledged ontology of knowledge we will use ideas in (Herre 2013), where a bridge between formal ontology and knowledge organization was established.

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