Towards a BFO-based Ontology of Understanding in Explanatory Interactions

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Abstract

This work takes steps towards situating the concepts relevant to *explanation* and *understanding* in explanatory interactions within the scope of Basic Formal Ontology. We introduce novel ontological accounts of *understanding* and *explanation* in BFO-terms, which foster a shared conceptualization of explanations and explainee's understanding during explainer-explainee interactions. This approach also enables the tracking of different aspects of understanding and explanation through cognitive profiling of various measurable aspects under the heading of *process profile* in BFO. Additionally, we differentiate between the private mental process of understanding and *understanding displays*. Finally, we characterize the relationship between understanding displays and explanations.

Keywords

Understanding, Explanation, Explainable AI, Ontology design, BFO

1. Introduction

Explaining and understanding are two sides of the same coin [1]. To be able to give an explanation, human explainers must be able to understand the explanandum. Similarly, in order to make use of a given explanation, human explainees need to understand it. Recently, it has been argued that explanations in general are *social* [2] and that they are actually *co-constructed* by the interlocutors [3]. Both of these arguments have been made in the broader context of Explainable AI (XAI), which has traditionally focused on the explanation itself rather than the explanatory interaction. Here we are interested in explainer–explainee interactions (human–human and XAI–human), seeking, from an interdisciplinary perspective, the elements that provide us with indications of explainee's understanding, e.g., based on their linguistic and multimodal behaviour [4].

Rohlfing et al. [3] present a conceptual framework for the social design of XAI, where the explainer's task is to provide an explanation and adapt it to the current level of explainee's understanding, and the explainee's task is to provide cues that actively guide the explainer. This way, explainer and explainee, jointly help co-construct an explanation. In other words, the authors emphasize the importance of tailoring explanations to meet the needs of the explainee. Additionally, they argue that the process of explaining should not be overlooked, as social interaction is the key for producing a (socially) relevant and understandable explanation [3]. In such a 'Social XAI', multimodality, as an important property of interaction, is postulated to play a central role [3].

An underlying assumption of this paper is that ontologies and best practice principles for ontology design are helpful for social XAI. Among the many benefits that ontologies offer, one of the most concretely useful is that they provide a shared vocabulary, ideally based on rigorous definitions within a domain, thus enabling researchers to better navigate the complexity of a domain [5]. In practice,

DAO-XAI 2024: 4th International Workshop on Data meets Applied Ontologies in Explainable AI, October 19–20, 2024, Santiago de Compostela, Spain

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the shared vocabulary is not only useful for communicating about the topic, but also enables data integration, making scientific results comparable. Ontologies are also used to formally describe the entities in a domain and their relationships to each other, and can contain logical axioms. This enables automatic reasoning in technical applications and is therefore also highly relevant to the development of (social) XAI systems. We describe an effort to develop an ontology of 'understanding' in the realm of explanations. In this, we follow the general principles of ontology design as described by Arp et al. [6, p. 50], specifically *perspectivalism* and *fallibilism*.

Our ontology is based on a scientific conceptualization of *understanding*, resulting from both the concrete needs of research projects and a series of interdisciplinary synthesis workshops (happening in the context of the Collaborative Research Center SFB/Transregio 318); however, we do not seek to capture reality in its totality. We are therefore considering the principle of perspectivalism, which recognizes that there may be multiple theories that accurately represent a scientific topic, and that it may not be possible to reduce these perspectives to a single ontology. One solution would then be a modular approach, with experts in each scientific discipline maintaining a module. We also consider the notion of fallibilism, which reflects the idea that scientific statements can be revised as new evidence emerges, while at the same time being considered as candidates for expressing the truths of reality. Based on these two aspects we follow Arp et al. [6] and try to keep ontology development pragmatic: we try to strike a balance between utility and realism, developing the ontology for concrete needs in XAI research projects and grounding it in interdisciplinary scientific investigation of the concept of understanding.

On this basis, we address three fundamental research questions that arise from the social perspective on XAI [2, 3]:

- *RQ1*: How can we ontologically model explanations in Social XAI?
- *RQ2*: How can we ontologically model understanding in Social XAI?
- *RQ3*: How to track explainees' understanding in explanations?

We are taking steps to situate the concepts relevant to understanding and explanation within the standardized framework of Basic Formal Ontology [BFO; 7] – similar to Donohue [8]'s BFO-based Deontic Ontology. BFO is a so-called 'top-level' ontology that supports the integration of research results and enables interoperability of BFO-based domain ontologies. Following the basic types of entities in BFO [6, p. 87], we divide the concepts relevant to *understanding* and *explanation* into *continuants* (entities that continue or persist through time, such as independent objects, qualities and functions) and *occurrents* (entities that occur or happen, such as processes or events).

We will present work towards a BFO-based ontology of understanding in explanatory interactions. This endeavor is part of an ongoing larger ontology development process working towards an ontology of social explainable AI. Taken together, this paper makes three contributions:

- We provide a novel ontological account of explanations in the sense of Social XAI [2, 3] and contrast it with existing ontological accounts of explanations in XAI (Section 3).
- We provide an ontological account of understanding in explanatory interactions, which allows for capturing different measurable dimensions of understanding (Section 4).
- We provide an ontological account of how understanding is related to explanation processes in terms of understanding displays and illustrate how this matches research practices in linguistic analyses of explanatory interactions (Section 5).

2. Background

Ontologies are classification systems serving as a method for representing the structure of a specific domain by capturing the essential entities and relationships between the entities within that domain [9]. In their study, Confalonieri and Guizzardi [9] discuss multiple roles of ontologies in XAI, including reference modeling. Reference modeling involves utilizing ontologies as reference models to specify the requirements of explainable AI systems. In this capacity, ontologies can play a crucial role in the development of explainable AI systems, e.g., by helping researchers and practitioners gain a deeper understanding of human cognitive patterns and the interplay between human cognition and XAI [10].

Reference modeling for XAI aligns closely with the perspective articulated by Miller [2], who underscores that XAI can benefit from the extensive body of existing research from various areas of research, such as philosophy, psychology, sociology and cognitive science, on *"how people define, generate, select, evaluate, and present explanations."* This basically necessitates an investigation into how human actions are built. Goodwin [11] reveals answers to this question by emphasizing the importance of multi-modality. He states: *"... why multi-modality? It's a term that I don't use all that much because I think that sometimes the way people talk about multi-modality, they make it see as a side thing, [i.e.,] the core stuff is the language or the action or anything, and what I want to argue is that what we really want to look at is the core structure of the human action and that the way that human action is built is by bringing different kinds of meaning making resources together ..."*. Following Goodwin's perspective, we do not consider multi-modality as incidental when it comes to explanations.

Miller, on the other hand, discusses two accounts of *explanation*: explanation as a product and explanation as a process. He further assumes that there exists two types of processes in explanation: a *cognitive process* and a *social process*. The cognitive process is *"to determine an explanation for a given event, called the explanandum, in which the causes for the event are identified, perhaps in relation to particular counterfactual cases, and a subset of these causes is selected as the explanation (or explanans)."* [2, p. 6]. He further terms the explanation resulting from such a cognitive process as a *product*. Finally, he discusses that the social process of explanation corresponds to the knowledge transfer between explainer and explainee – a process whose main goal is to provide sufficient information for the explainee to understand the *explanandum*.

In exploring the nature of explanation as a *product* within the realm of ontologies, a parallel can be drawn to the conceptualization put forth by Chari et al. [12]. In their ontology, the authors classify *explanation* under the heading of *object*, where an object is *"an entity that is wholly identifiable at any instant of time during which it exists."* Such a definition of objects is very much in line with the concept of *continuants* within the scope of Basic Formal Ontology [6, p. 87]. Cabitza et al. [13] also propose a typology of explanation-related entities, defining explanation merely as the output of an XAI system. The authors intentionally avoid epistemological considerations and instead offer a definition of explanation that suits their practical purposes. In contrast to this, given the multimodal nature of explanations in the sense of Rohlfing et al. [3] and the account of explanations as socio-cognitive processes in the sense of Miller [2], explanations in this other facet appear to belong to the world of *occurrents*, and specifically processes. To the best of our knowledge, despite the presence of fundamental frameworks offering insights into explanation-related entities and methods [13, 14] and valuable research at the intersection of ontologies and XAI [9, 12, 15], so far, there has been no ontological account that attends to explanations as multimodal socio-cognitive processes. In the current work, we deal with such concepts using the top-level categories of BFO.

As discussed, explanation and understanding are tied together. Considering the previously mentioned research, it is clear that new approaches to explanation focus on the needs of the explainee and adapting the explanation to explainee's current level of understanding. Accordingly, for an XAI system to effectively model an explanation process, it must be capable of assessing understanding while interacting with humans. This necessitates addressing fundamental questions: *What is understanding?* and *What is it that we want to measure accordingly?*

A relevant avenue of investigation is the field of discursive psychology, which examines how private, inner, mental processes manifest in social interactions. Deppermann [16] explores how *understanding in interaction* is informed by *temporality* and *retrospection*. He asserts that "Understanding is a temporally extended, sequentially organized *process*. Temporality, namely, the sequential relationship of turn positions, equips participants with default mechanisms to display understandings and to expect such displays" [16, p. 57]. He further discusses that understanding is a private mental process, which is not available to others. Moreover, one can neither check understanding nor react to it. Consequently, in discursive psychology, understanding is 'respecified' by examining *"how it becomes relevant, observable* *and treatable for participants in the interaction itself.”*

Within the realm of philosophy, Grimm and Hannon [17] argue that “Understanding is a kind of *cognitive accomplishment*, and the objects of understanding [...] are strikingly varied.” Speaking of ‘accomplishment’ immediately points us to a classic typology which distinguishes four types of *events* – *accomplishment*, *activity*, *state*, and *achievement* [18]:

> An *activity*, such as Anita’s walking uphill, is a homogeneous event: its sub-events satisfy the same description as the activity itself, which has no natural finishing point or culmination. An *accomplishment*, such as Anita’s climbing the mountain, may have a culmination, but is never homogeneous. An *achievement*, such as Anita’s reaching the top, is a culminating event (and is therefore always instantaneous). And a *state*, such as Anita’s knowing the shortest way, is homogeneous and may extend over time, but it makes no sense to ask how long it took or whether it culminated. [18]

Casati and Varzi [18] discuss that sometimes *achievements* are considered as events in the strict sense and all other types of events are classified as *processes* (i.e., temporally extended entities). This speaks of the fact that viewing understanding as a cognitive ‘accomplishment’ emphasizes its nature as a process.

The BFO account of processes extends Zemach’s concept of *‘events’*. According to Smith [20], *event* in the sense of Zemach [19] refers to the whole content of a spatiotemporal region. Yet, in BFO terms, multiple processes can *occupy* the same spatiotemporal region, e.g. *“when a process of your running down the street is co-located with a process of your getting warmer”* [20, p. 473].

Smith further refers to these measurable dimensions of processes as *streamiform structures* [21], and introduces the top-level category of *process profile* into BFO (although this is not part of the BFO ISO-standard [7] yet). Discerning streamiform structures within a complex process allows for studying these structures in isolation, while also acknowledging the complexity of the phenomena and leaving space for studying the impact of combination of these structures as a whole.

3. On the Nature of Explanation

The accounts of explanation proposed by Miller [2] and the framework proposed for social XAI by Rohlfing et al. [3] are not grounded in any ontological or philosophical theories of processes, such as Smith [20] or Guarino and Guizzardi [22]. Consequently, we recognize the need to formalize such accounts of explanations. In alignment with Miller’s perspective on explanation as both a socio-cognitive process and a product [2], we conceptualize explanations as both an occurrent entity and a continuant entity, respectively.

Within the scope of our ontology, we use the term *‘explanation’* to denote the occurrent facet of explanation, while reserving the term *‘explanans’* to refer to the continuant facet of explanation, which we will explore in future work.

We therefore put forth the thesis that explanation is an occurrent entity in BFO terms, precisely categorized under *BFO:process*. Derived from the inherent attributes of BFO:process [6, p. 89], we can subsequently deduce the following implications for explanations:

- Explanations unfold in successive temporal parts or phases.
- Because no two distinct phases exist simultaneously, there is no point in time at which an explanation exists as a whole.
- An explanation exists at any given point in time only in some correspondingly short-lived stage or slice.

Note that the dialogue participants that take the role of explainer or explainee are the material entities that participate in the explanation.

Given the nature of explanations as processes, the acknowledgment that *“the way human action is built is by bringing different kinds of meaning-making resources together”* [11] (possibly via different modalities), emphasizes the existence of distinct dimensions of qualitative change (e.g., through a focus on particular modalities) within a broader conglomerate of processes. Accordingly, different dimensions of distinctive qualitative change can therefore be discerned, such as alterations in the cognitive mode of engagement [23] of explainer and explainee, shifts in their facial expressions, changes in their eye gaze [24], adaptations in the types of speech acts they utilize [25], and alterations in prosody they employ [11]. These are in fact the streamiform structures, i.e., *process profiles* that we can cognitively profile within the complex explanation process.

To elucidate this line of thinking, let us characterize explanations as dialogues in which explainee and explainer take turns to advance the explanation process. There exists approaches [26, 27] that analyze the single contributions and intentions of explainees or explainers as *speech/dialogue acts* [28, 25], within explanatory dialogues. From our point of view, these methods look at a specific *streamiform* structure of reality in the explanation process, which is the sequence of speech acts produced by the explainer and the explainee during the course of an explanation. By characterizing the series of speech acts as a *streamiform* structure of reality, we highlight the examination of a *thinner* process (in the sense of Smith [21]), representing a meaningful structure within the *broader* process of explanation. Simultaneously, we recognize that explanation, as a process, may involve various modalities (i.e., process profiles) beyond speech acts, depending on the communication medium [29].

In the above-mentioned example, a speech act produced by explainer or explainee is a *proper_occurrent_part_of* an explanation process.

4. On the Nature of Understanding

Similar to Deppermann's concept of *understanding in interaction* [16] and drawing inspiration from Grimm and Hannon's perspective [17], we view *understanding* as a process. However, we aim to provide a more comprehensive account of understanding by utilizing the theory of processes from Basic Formal Ontology [20, 30].

We propose categorizing *understanding* under the heading of *BFO:process* and the measurable dimensions of understanding under the heading of *BFO:process profile.*

In a first attempt for conceptualizing different dimensions of understanding within the scope of social XAI, we employ different cognitive dimensions of the Bloom's taxonomy [31] – i.e., *Knowledge*, *Comprehension*, *Application*, *Analysis*, *Synthesis*, and *Evaluation* – as heuristics for different measurable dimensions of understanding.

As an example, we illustrate potential process profiles of understanding processes in terms of cognitive dimensions of Bloom's taxonomy with the following equation:

$$y_i = 0.5 + \log_{m_i}(t+2)\left(1 + 0.1\sin\left(\frac{n_i \pi t}{10}\right)\right)$$

where:

- i denotes the i-th level of Bloom's taxonomy and ranges from 1 to 6 (1: *Knowledge*, 2: *Comprehension*, 3: *Application*, 4: *Analysis*, 5: *Synthesis*, and 6: *Evaluation*)
- y_i denotes the corresponding instance of process profile for the i-th level of Bloom's taxonomy.
- $(m_i, n_i) \in \{(2,0),(3,2),(5,4),(7,6),(11,8),(13,10)\}$ where m_i are the bases of the logarithm and n_i are the frequencies of the sinusoidal term.
- t is a variable denoting time.

Note that the equation primarily serves illustrative purposes rather than precise modeling. It is designed to represent the understanding processes of an explainee with low to medium skill levels regarding some specific explanandum, with the constant term 0.5 vertically shifting the function to accommodate this. The logarithmic term $\log_{m_i}(t+2)$ captures the growth in cognitive gains over time. Periodic fluctuations in cognitive performance are modeled by the sinusoidal modulation $\left(1 + 0.1\sin\left(\frac{n_i \pi t}{10}\right)\right)$, which introduces oscillations around a general trend. Figure 1 illustrates these functions within an

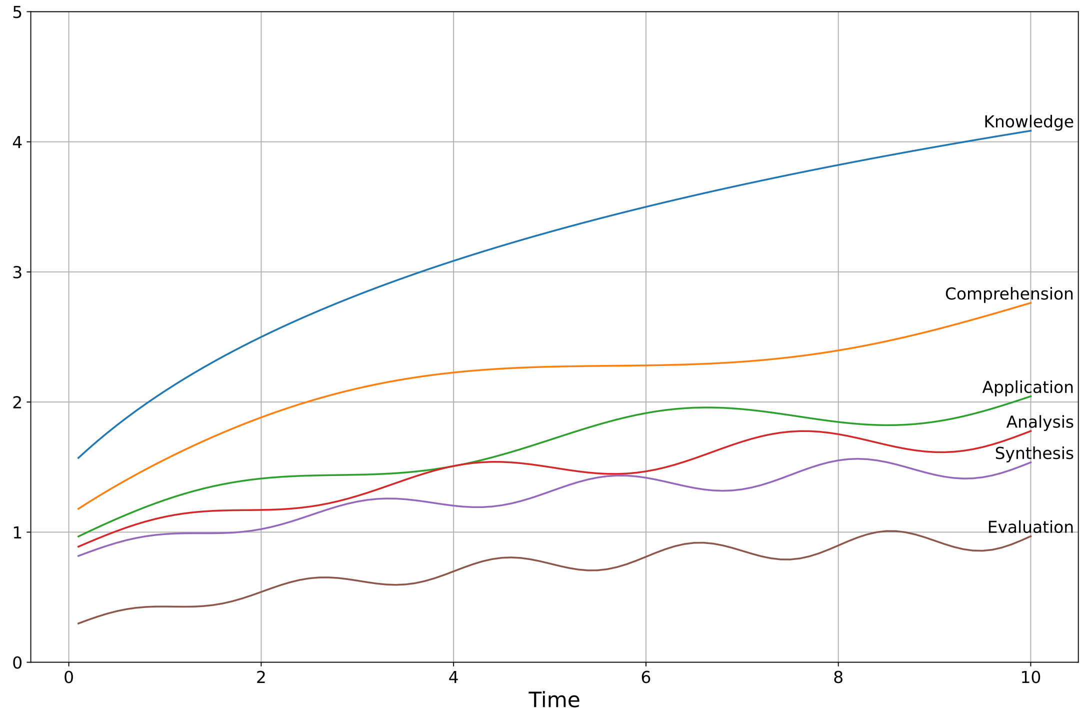

Figure 1: Illustrative modeling of understanding processes of an explainee over 10 units of time with low to medium skills regarding some specific explanandum at the beginning of the explanation process. Each curve represents an instance of a process profile.

explanation process over a period of 10 time units. As time increases, the curves demonstrate how understanding deepens across any of the six cognitive dimensions. Each curve represents an instance of a process profile.

A further category that we can introduce to our ontology of understanding is *understanding achievement*. We assume that the understanding process has culmination points (think of 'Aha-moments', 'Huh?-moments', etc.). We categorize these culmination points as 'understanding achievement'. An achievement is instantaneous and can be categorized as an occurrent entity, specifically under the heading of *BFO:process boundary*. In BFO, beginnings, endings and thresholds in processes, that are in fact infinitesimal or of zero length, are categorized under *BFO:process boundary*.

5. Understanding Displays

As mentioned in Section 2, understanding is considered a private process and thus not available to others [16]. However, in dialogical interaction generally, and explanatory interactions specifically, addressees multimodally communicate their (private [16] and subjective [4, §2.1.3]) mental state of understanding to speakers, and speakers monitor addressees for understanding [32]. Such 'understanding displays' can take many forms and play an important role in dialogue by enabling speakers to attribute mental states of understanding [4] to addressees and thus to incrementally adapt their ongoing speech production to addressees' needs – a process called recipient or audience design [33]. In explanatory interactions, these processes of monitoring and adaptation (or 'scaffolding', to use a term from educational and developmental research) are thought to be crucial for co-constructing explanations by explainers and explainees [3].

The most important examples for understanding displays in verbal explanations are the explanatory moves [26]. Some of these moves explicitly serve the purpose of providing evidence of understanding of the interlocutors utterance, or lack thereof, specifically the moves *acknowledge*, *(non-lexical) backchannel*, *completion*, *signal-understanding/non-understanding*. Other moves might serve similar functions when

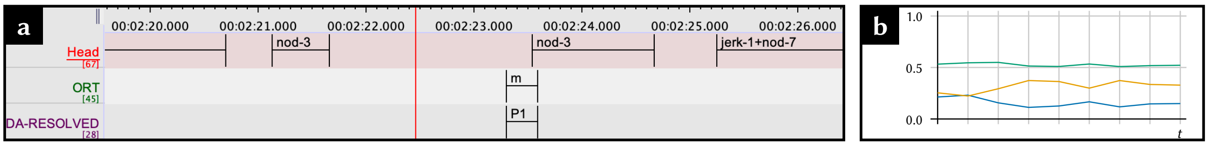

Figure 2: (a) Multimodal understanding displays of an interlocutor in dialogue annotated on three layers: head gesture, utterance, dialogue act (from the ALICO corpus [36]). (b) Computationally tracked belief state of the mental state of understanding attributed to a listener over the course of the dialogue (x-axis), colors represent degree of understanding (blue: low, green: medium, yellow: orange; [adapted from 4, fig. 5.13]).

produced in response to feedback elicitation requests by explainers (e.g., to *test understanding questions*), or more generally (e.g., explainees asking a relevant *question* may implicitly display their understanding). In multimodal face-to-face explanatory dialogues, explainees' mental states of understanding are often displayed in embodied ways [34] through head gestures (e.g., nods), facial expressions (e.g., eyebrow raise), eye blinks, and gaze behaviour. Being expressed in other modalities than speech, these embodied understanding displays can happen simultaneously (and potentially continuously) to the explainer's verbal explanation, enabling immediate adaptation [32] without the need to respect the turn-taking system [35].

We consider an understanding display as a *proper_occurrent_part_of* an explanation process. Understanding displays are integral sub-*processes* of explanatory dialogues [20] central to the co-construction of explanations. We thus categorize understanding displays under the heading of *BFO:process*. Their contribution to explanations being that they make 'understanding' – generally not available to others during explanatory dialogues – indirectly measurable through interpretation, thus informing the measurable dimension of understanding (*BFO:process profile*). That understanding displays fit well with profiling of understanding, is evident from research practice in linguistics as well as in computational modeling of listener understanding.

In linguistic annotation, understanding displays in the form of multimodal listener behaviors are annotated in time-aligned ways (illustrated with the example in Figure 2a), allowing for time-aligned interpretation and attribution of understanding. In computational work, multimodal feedback behaviour can be interpreted by an artificial conversational agent and modeled as a dynamic belief state of a state of understanding attributed to the interaction partner over time (illustrated in Figure 2b).

6. Final Considerations

In this work we have focused on three research questions, inspired by the framework of 'social XAI' – an account of XAI which focuses on explainer-explainee interactions and their co-construction of an explanation [3].

Concerning *RQ1* and *RQ2*, which address the ontological modeling of explanation and understanding in social XAI, respectively, we have introduced novel ontological accounts in BFO terms. This effort aims to remedy the current lack of formalization of explanation and understanding in social XAI. We classify both explanation and understanding under the heading of *BFO:process*. Such a treatment allows for capturing different measurable dimensions of both understanding and explanation through *process profiles* [20]. To the best of our knowledge, these ontological accounts are the first that model the concepts specific to 'social XAI' in which temporality is considered as a key dimension.

Such a treatment of explanation and understanding also necessitates an extension in the existing theories that characterize their relationship with explanation being treated as a *continuant*. For instance, Grimm [37] discusses one of these theories that holds: *"Something E is an explanation of why Q only if someone who possesses E understands why Q."*

Regarding *RQ2*, for the sake of illustrative modeling, we have also described how different dimensions of understanding can be conceptualized in terms of cognitive dimensions of the Bloom's taxonomy.

Regarding *RQ3*, which focuses on the tracking of explainee's understanding in explanations, we have described how understanding can be displayed through different explanatory moves in verbal explanations or other modalities than speech. Finally, we have characterized the relationship between understanding displays and explanations, where we consider an understanding display to be a *proper_occurrent_part_of* an explanation process.

Taken together, we hope that the ontological accounts that we have provided for *explanation* and *understanding* in explanatory interactions can contribute to the endowment of explainable AI systems.

Acknowledgments

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation): TRR 318/1 2021 – 438445824, Projects INF ("Toward a framework for assessing explanation quality") and A02 ("Monitoring the understanding of explanations").

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