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Viewpoint

Discovering Semantic Relations between Neurodegenerative Diseases and Artistic Behaviors

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Abstract: This paper aims to introduce the value of semantics for representing knowledge related to patients with brain neurodegenerative diseases (Parkinson's, Alzheimer's, and dementia) or behavioral disorders (i.e., schizophrenia) and artistic behavior. The ultimate goal is to facilitate an effective and efficient study of neurological and behavioral changes of patients, analyzing semantically interlinked data related to neurological/behavioral conditions and artistic behaviors. By mapping the neurologically affected areas of the brain in healthy and unhealthy individuals, and by modeling their particular characteristics at the level of both behavioral and neurological expressions, it may be possible to identify semantic similarities in high-level behavioral and brain characteristics that justify correlation and causation between diseases/disorders and artistic behaviors. In this concept paper, we present our view on two key points related to proposed research on a novel framework that will (a) verify if early biomarkers of the neurogenerative diseases can be identified via artistic behavior observations, and (b) correlate patients with delayed onset of the diseases/disorders with artists, at the molecular level, or at the level of brain regions. The proposed framework is evaluated with the development of a proof-of-concept expert system based on the representation of the relevant knowledge.

Keywords: neurodegenerative diseases; artistic behaviors; ontologies; semantics

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1. Introduction

Neurodegenerative diseases (NDs) are diseases that present a progressive loss of structure or function of brain neurons. Such diseases have a biologically heterogeneous etiology and symptomatology, seriously affecting the neurons of the human brain. Neurons, the building blocks of the nervous system in the brain and spinal cord, do not reproduce; thus, their damage is permanent. Until recently, a complete recovery or reversing of the damage is not possible, although several therapies for delaying the symptoms are in trial phases. NDs are incurable diseases that lead to progressive degeneration, resulting in ataxia and dementia. Examples are Alzheimer's disease (AD), Parkinson's disease (PD), Huntington's disease (HD), multiple sclerosis (MS), and amyotrophic lateral sclerosis (ALS).

On the other hand, "artistic brains" concern the functionality and inter-connectability between cerebral hemispheres, especially of the right hemisphere, which is mostly connected with creativity, as well as with other parts of the brain such as sensory projection areas in the occipital, temporal, parietal lobes, and cerebellum. All the previous areas of the brain are involved in painting, dancing, writing, and generally, performing arts.

A few research attempts have approached the correlation of brain areas and human behaviors, mainly regarding the change in artistic style in relation to a progressive neurodegeneration, i.e., regarding artists who are affected by an ND. Other related scientific research works have studied this correlation from the therapeutic point of view, showing that art could have a positive impact on people suffering from NDs. Lastly, related research has reported the use of semantics/ontologies to develop ontology-based decision support systems for disease diagnosis.

On the basis of a literature review, our main viewpoint is that there is still a gap in the scientifically justified approach to correlating artists with neurodegenerative diseases. More specifically, to the best of our knowledge, there is no dedicated system that can efficiently compute/infer such correlations, and eventually to provide early diagnoses and/or propose related art-based treatments and disease monitoring.

Accordingly, in this concept paper, we present our viewpoint on how to work (proposed framework) to further investigate and provide answers to the following research questions:

- Could data related to different types of brain diseases be integrated with other heterogeneous data sources, e.g., artistic behaviors and skills, to develop a unified semantic data model as a knowledge base for answering scientific questions related to NDs?
- Is it possible to detect biomarkers in an early phase of NDs using an ontology-based expert system?
- Is it possible to determine common patterns and correlations between the brain mapping of artists and the brain mapping of patients with NDs?
- How is it possible to further analyze such correlations (if they exist) to identify a positive or negative impact for patients?
- Which are the most efficient methods in art-based therapy and in software development, that could eventually repair damage from NDs or delay disease development, toward improving patients' quality of life?

The proposed framework, as presented in this concept paper, in addition to the cognitive benefit of discovering the relationship between the neurodegenerative diseases and the art, aims to improve the quality of life of patients with neurodegenerative diseases either through early detection or through the beneficial effect of art. Addressing the wider challenges to the health of people, the proposed work supports the continuous need to address the global increase in neurodegenerative disorders, as well as the need for more approaches that integrate arts and sciences.

2. Background Knowledge and Related Work

An ontology is a formal conceptualization of a domain (a conceptual model) that can be used to provide meaning and structure to data and to information exchanged across applications, services, and systems [1]. Ontologies are useful to represent, integrate, share, and infer new knowledge in a common and agreed format, between human and/or software agents.

A fuzzy ontology is an extension of the domain ontology that is used to represent uncertainty (fuzziness) in the domain knowledge, i.e., when there is a need to formally model an uncertain/fuzzy conceptualization of one or more entities and their (fuzzy) relationship in a domain of discourse [2].

Semantics is the study of meaning and truth. It is an empirical domain consisting of intuition, communication in a specific formal language, and meanings of expressions and relations [3]. Ontologies can be used for the semantic modeling of data and information, as well as for the explainability of the behavior of objects, entities, and systems.

A knowledge graph is the graphical representation of knowledge through directed network of interconnected entities and their semantics [4]. Knowledge graphs can provide embeddings of ontological models.

The main differences between crispy (not fuzzy) and fuzzy ontologies are the following [5].

- On crispy ontologies, there is certainty on the relationships between the entities. On fuzzy ontologies, the relationships between entities that are not certain can be described by a degree of membership, i.e., the value of probability to observe an entity in action under a specific event.
- Crisp ontologies have disambiguation issues when they represent multiple-located terms. On fuzzy ontologies, this issue does not occur.

- Ontology customization is not very flexible on crispy ontologies. Fuzzy ontologies make this simpler by modifying the values of entities' membership.
- Regarding fuzzy ontologies, the representation of knowledge is riven by its use, whereas, for crispy ontologies, this is driven by its structure.

As already stated, related research has been conducted to investigate the existence and form of correlation (common patterns) of brain areas and behaviors, mainly concerning the correlation of changes of artistic styles and the progressive neurodegeneration of artists who are affected by NDs. Other research works have studied this correlation from the therapeutic point of view, questioning the data showing that art could have a positive impact on people suffering from NDs. Lastly, related research concerns the use of fuzzy semantics to develop an ontology-based decision support system for NDs diagnosis.

In related work [6], it was conjectured that NDs that disrupt the interactions among the frontal, temporal, parietal, and occipital lobes or between the dominant and nondominant hemispheres can lead to artistic modifications in patients with frontotemporal dementia (FTD) [7], Alzheimer's disease (AD) [8], and Parkinson's disease (PD) [9].

Fuzzy ontologies have been used in order to resolve the uncertainty that occurs in multiple conditions for AD, at both a diagnostic and a supportive level [10]. Fuzzy ontological classes have been introduced and matched with related existing concepts using a relationship of ambiguity. As fuzzy ontologies are considered a useful technology for the representation and reasoning of crisp and fuzzy knowledge, AlzFuzzyOnto was developed, enabling the semantic representation of medical data for diagnosis and support of AD, considering uncertainties and inaccuracies associated with this disease. The main classes defined in this ontology are Doctor, Patient, Diagnosis, Enrollment, FollowUp, Test, and TestValue. In addition, the Mind ontology has been extended because there was a need to reuse its concepts for a more accurate diagnosis. The added classes regarding AD diagnosis are Questioning, Symptoms, and Entourage. The classes of Therapies, Phase, and CurrentState represent general concepts regarding AD support.

In other related work [11], from the point of view that performing arts are based on brain function and capabilities, it was stated that NDs leading in dysfunction of brain functionality could cause an alteration of performing arts by worsening and sometimes by enhancing art production. Apart from the consequences of the appearance of NDs, brain damages, depending on the area they occur, can alter the style with which people with high artistic temperaments are expressed [12]. Authors suggest that science should deal with brain damage and the differentiation of artistic expression in a field called neurosensory. A similar conjecture was found in the article "Can brain damage lead to extraordinary art?" by Jacob Silverman.

In [13], it was stated that deep understanding of the neural circuit during the artistic expression and the neural connectivity during an ND has shown that artistic expressions could lead in a targeted modulation and stimulation at the related brain map regions, improving the cognitive or the motor functions. Furthermore, the authors believed that, within a growing scientific context overflowing with data in different forms, ontologies can be the most appropriate data engineering environment for the homogenization and integration of different types of data concerning the same subject of study. They studied the ontologies of AD in order to retrieve and standardize information as part of a single study subject. Another very interesting approach in this work was the investigation of the possibility of visual creativity and artistic productivity to be used for both diagnosis and therapeutic innovations in brain disorders. It also supports the possibility that the altered neurotransmission in NDs is maybe connected with observable behavioral changes and, therefore, could be a marker for early diagnosis. An example of how music can be beneficial to subjects with NDs is the use of music that could be protective against age-related cognitive decline. For instance, PD patients treated with dopaminergic agonists/replacement therapy were observed to increase quantity or production and changes in the technical attribute such as more vibrant colors or a trend toward abstraction.

Previous studies have examined domain-specific mechanisms of creativity performance, but the knowledge in this field is still not at highly understandable levels. One study applied an activation likelihood estimation meta-analysis to identify brain activation; for that purpose, the authors synthesized functional neuroimaging studies across the artistic creativities such as music improvisation, drawing, and literary creativity [14]. In addition, the rare phenomenon of de novo artistic abilities appearing for patients with traumatic brain injury was noted [15].

Lastly, in another related work [16], researchers aimed to discover the links between painting and neurology by mapping the location and the nature of neural damages, and then correlating them with changes in the artistic style.

3. Correlating Art and Science for NDs

As presented in Section 2, related works have not fully investigated the correlations and changes in the artistic or kinesiological behaviors of patients. Furthermore, they have not emphasized the use of ontologies for analyzing the behavior of artistic brains suffering from NDs. On the other hand, it can be conjectured that the existence of a connection between NDs and artistic brains is already known. Having said that, the appearance of degeneration in kinesiology occurs mainly in advanced stages of the disease; therefore, the artistic incapacity begins to become more and more obvious. Thus, the interesting questions are related to (a) if and how an artist affected by NDs changes their artistic style, (b) if a non-artist person with the onset of an ND can participate in artistic tasks (music playing, or painting) as a means of communication, expression, and creativity, (c) if an artist can be diagnosed with early symptoms of NDs by looking only at changes in their artistic style, (d) if artists and non-artists, patients suffering from NDs, have the same severity and progression of the disease, and (e) if an artistic brain can develop different neuron synapses to compensate for neurodegeneration.

To answer such questions, the collection, integration, and processing of voluminous and heterogeneous data related to NDs and artists is necessary. For instance, neuroimages of brains suffering from NDs and neuroimages of artistic brains are only two of the related datasets required in this research. Another dataset concerns sensor data gathered from observations of ND patients in their daily tasks, compared to observations recorded during artistic tasks that they are given in a random or controlled manner, e.g., drawing while listening to their favorite music.

To be able to represent the related knowledge and semantically annotate the available data toward an integrated unified view, the use of ontologies is necessary. Ontologies that represent knowledge of NDs (Parkinson's and Alzheimer's) have already been proposed: a fuzzy ontology for Alzheimer's disease [10], the Alzheimer Disease Map ontology from National Center for Biomedical Ontology (NCBO) BioPortal [17], the PDON Parkinson's disease ontology for the representation and modeling of the PD knowledge domain [18], the Human Disease Ontology from NCBO [19], and others. However, this is not the case for the artistic behavior domain. Since there is no well-understood and well-defined relation between patients affected by NDs and artistic behavior, and since there are many subjective and fuzzy observations such as those changing the artistic behavior related to the presence of NDs, there is a real need to apply well-defined formal semantics.

For this reason, we propose the use of fuzzy ontologies, consisting of well-defined formal semantics for the domain of NDs and artistic behavior, integrating a hierarchical description of fuzzy concepts, along with the description of their fuzzy attributes. For instance, according to the example demonstrated in [10], a patient who is 73 years old is considered as an old patient with a degree of membership equal to 0.4. He is also considered as very old patient with a degree of membership equal to 0.6, but he is not considered as an elderly patient. In this model, the patient concept is identified as a fuzzy class depending on age. Since it is important to know the degree of old age of the patient for a more reliable diagnosis and support, the patient class is fuzzified into the three fuzzy classes above.

Similarly, a fuzzy relation is defined as a fuzzy set. Thus, its instances have varying degrees of membership with a value in the interval (0,1). These degrees are calculated according to the membership function defined for the relation. For instance, according to the example demonstrated in [10], a property "InPhase" is identified as a fuzzy relation since it is difficult to determine the exact phase of the AD for the patient; tests on a patient may give approximate results of the disease severity degree, and a patient may be about to change from one phase to another, whereby they can belong to two phases at the same time. Therefore, a property such as "InPhase" can be fuzzified in four fuzzy relations (inPhase1, inPhase2, inPhase3, inPhase4) where each relation has its own membership function.

It is our aim to use fuzzy semantics, as in the examples provided above, in order to model the required knowledge for both the NDs and the artistic behaviors. Moreover, such an approach would be more effective if applied for the representation of the interconnections between the two domains, i.e., for introducing fuzzy relations that represent dependencies of NDs symptoms and artistic behavior characteristics, e.g., fuzzifying the relation of hand tremor observation in a PD patient with a painting (drawing direct lines) to ability observation (scaling between dependency values such as low values express low dependency). For the implementation of such semantics, we can investigate fuzzy semantics technology such as the OWL Fuzzy 2 [20].

Going beyond the current state of the art in approaches for correlating art and science for NDs, considering our viewpoint on the problem as presented in this concept paper, we propose a novel framework for the exploration of common mechanisms between patients and healthy people, with a view to the early detection of NDs and the discovery of correlations between artists and brain diseases/disorders. As such, we present the proposed framework for the use of semantic models based on fuzzy ontologies, aiming at the integrated representation of biological and artistic knowledge. Such a framework can be realized by the development and evaluation of an ontology-based interlinking and decision support system, emphasizing fuzzy semantics and biomedical data. Figure 1 depicts a high-level design of such a system. Data and fuzzy semantics (on the left) are provided as input for semantic annotation, interlinking, enrichment, and analysis, toward providing support for decisions related to (a) the discovery/identification of ND and artistic behavior interrelations, and (b) identification of preliminary ND biomarkers (on the right).

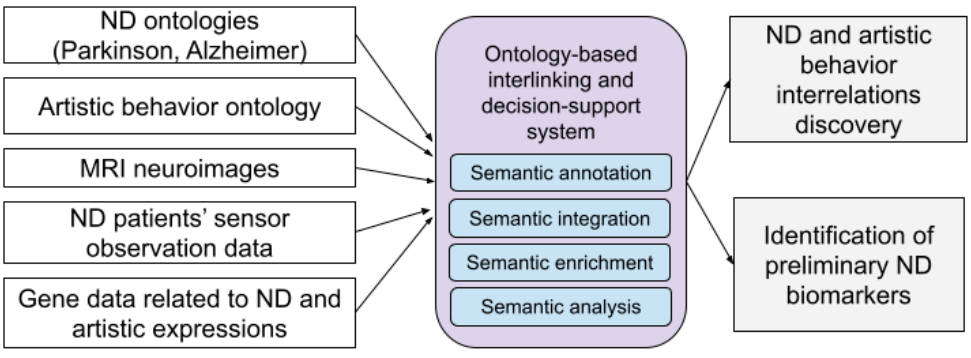


Figure 1. High-level design of a system realizing the proposed framework.

More specifically, the *semantic annotation module* concerns the use of fuzzy ontologies for a semantic description of the available data. The *semantic integration module* concerns the transformation of the semantically annotated data into a common data model and its interlinking using standards such as RDF and Linked Data. The *semantic enrichment module* concerns the enrichment of the integrated data with additional (external) data that may be discovered in other data sources such as the Web. Lastly, the *semantic analysis module* concerns the use of reasoning engines and rule languages for inferring new knowledge from the asserted one.

4. Conclusions

In this paper, we presented our view on key points related to proposed research on a novel approach for correlating art and science in the ND domain. Our future research plans include the implementation and validation of a system that could reveal the functional and structural relation between artists and patients suffering from NDs. Fuzzy ontologies will be used for the representation of knowledge concerning NDs and the specific characteristics of the brains of people who exhibit artistic behavior and skills. The development and evaluation of an ontology-based data/information interlinking and decision-support system, emphasizing fuzzy semantics and heterogeneous biomedical data, introduce a new era of revealing common mechanisms of neurobiological processes, addressing the wider challenges to the health of people.

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