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GraphDL: An Ontology for Linked Data Visualization*

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***Abstract*—Linked Data is an increasingly important source of information and contextual knowledge in Data Science, and its appropriate visualization is key to effectively exploit them. This work presents an ontology to generate graph-based visualizations of Linked Data in a flexible and efficient way. The ontology has been used to successfully visualize DrugBank and DBPedia datasets in a large visualization environment.**

***Index Terms*—Linked Data, Ontologies, Visualization, Big Data**

Aragon Open Data: A NLP-Based ontology population for Public Administration

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***Abstract*—Governments are one of the main producers of information and initiatives of making government open data are continuously gaining interest, recently. In this sense, how to provide relevant elements to improve the structuring of institutional information and deepen its standardization to make easier its access and make use of the information has become an important challenge and allows a great value to initiatives that leverage the potential of Open Data. Within this context, given the amount of unstructured information related to the Government of Aragon published on Internet at this time, with slightly or no standardization and decentralized, the need to gather it systematically to be served from a single access point in a public and structure way emerges. In this paper, an approach based on the use of web crawling, Natural Language Processing and ontology-based techniques is proposed. Experimental results based on disperse, non-homogeneous, uncontrolled and non-exploitable institutional information validate that the proposed approach improves the structuring and standardization of data that can be analyzed together, be accessible, be browsed, be exploited and offered to all interested collectives. The generated ontology is populated with institutional data, affording and securing new possibilities of generating valuable and consistent ontology-based knowledge services.**

***Index Terms*—Open Data, Ontologies, Natural Language Processing**

I. Introduction

Open Data is now a worldwide movement whose philosophy aims to provide data openness and availability to citizens. Many countries have an Open Data initiative[1]. Even in countries where that data is not yet fully open, civil society and the technology community are using government data. In Europe, Open Data has been a focus for policymakers for over a decade[2]. Today, almost all European countries have an Open Data portal, and these portals are becoming more advanced, being used more frequently and creating more benefits for citizens. As part of a national Open Data initiative, regional and provincial governments and by councils at city level have not been unresponsive to these initiatives.

Aragon Open Data is a project to open data by agreement of July 17, 2012 of the Government of Aragon, and its Internet portal[3] was presented with the objectives of creating economic within the ICT sector through the reuse of public information, increasing transparency in the Administration, promoting innovation, improving information systems of the Administration, adopting technical standards in the information society field and generating data interoperability between public sector websites. Throughout this time, there have been numerous works that allow the incorporation of new data and information available to third parties (citizens, companies, infomediary sector, developers, etc.).

In this context, on one hand, given the volume of the data that begins to exist in the Aragonese public administration, are beginning to have a special relevance all tools that help in the improvement of the structuring the information and in the standardization of data. The idea of generating a set of technical and legal rules that allow deepening in that standardization arises. On the other hand, within the line of difficulty of access and use of information, the complex casuistry presented by the regional public administration in the generation of data and information is reflected in the proliferation of a large number of websites under its root domain: `aragon.es`. These circumstances make it difficult to access and make use of information by third parties as well as public administration services of Aragon, generating the popular sense of certain lack of transparency.

This work introduces an approach to allow institutional information that is in a dispersed, non-homogeneous, non-controlled and non-exploitable way become into structured data that can be analyzed, accessible, reused, browsed, ex-

[1]Barometer Global Report, https//opendatabarometer.org, last accessed 2018/05/25

[2]The Re-use of Public Sector Information Regulations, http://www.legislation.gov.uk/uksi/2015/1415/made, last accessed 2018/09/10

[3]Aragon Open Data, http://opendata.aragon.es, last accessed 2018/09/10

ploited and served in a controlled mode under a single point. A semantic ontology has been designed and created to structure and standardize public administration information. This ontology, known as *Interoperable Information Scheme of Aragon (EI2A)*, allows modeling organizational structures, natural persons, places, territories, temporal properties of resources, events, websites, etc. In addition, a prototype has been implemented to recover open data related to the organizational chart of the Government of Aragon and all the information offered on institutional web to structure it according to EI2A ontology. Information conversion into knowledge and useful data is performed through the application of techniques and technologies such as *web crawling* or *spider*, intelligent data processing, Natural Language Processing (NLP), semantic technologies for the representation of knowledge and Big Data architecture. Specifically, the approach exploits text processing and automatic population technologies to extract knowledge from institutional content and organize it conceptually in EI2A ontology.

This paper is organized as follows: Related work on the use of semantic and NLP techniques to extract knowledge and structure it is presented in Section 2. Section 3 describes the architecture used and presents a high level description of proposed approach. EI2A ontology used is described in section 4. We discuss results in section 5 and highlight implications and of the work made. Finally, section 6 describes conclusions and discusses ideas for future work.

II. Related Work

Initiatives of making government open data are continuously gaining interest, recently. While more countries are embracing the Open Government paradigm, among the researchers working with those data there is an increasing awareness in using semantic techniques to represent them. Applying semantic web technologies enables data integration among different organization and established links to interconnect data on the Web [1]. Integration of raw data gathered from different sources, and formally and semantically represented and based on ontology, leads to opportunities for information exchange, analysis on combined datasets, simplicity in creation of mash-ups, and exploration of innovative ways to use data creatively. Enhancing with application of semantic web technologies to link data, and provide unexpected and unexplored insights into different domains and problem areas is the real value of open government data [2].

Application of semantic web technologies in government not only contributes to opening data to the community but also contributes to creating a knowledge network map that interconnects different sources that actually share data [3]. By making government data discoverable and accessible to the public, government shows that they are dedicated to the application of innovative e-services to improve accessibility, reusability and easy consumption of their data [4]. This leads to extends characteristics of publicly available data [5]. On the other hand, ontologies have become a major tool for developing semantically rich application. They provide for a standardized means of modeling, querying, and reasoning over large knowledge bases. Specialized knowledge services require tools such as [6] that can search and extract specific knowledge directly from unstructured text on the Web, guided by ontology. Other researchers have used ontology to support knowledge extraction [7], [8].

In a world in which the majority of knowledge is encoded in natural language text, automating the population of these ontologies using results obtained from the application of NLP techniques is becoming increasingly important and a major challenge [9]. The process of automatic or semi-automatic construction, enrichment, population and adaptation of ontologies is known as ontology learning. Ontology population is the task of adding new instances of concepts. Different approaches exit to export or populate results of NLP analyses into ontology such as [10], [11]. In addition, NLP techniques for term extraction and ontology population, using a combination of rule-based approaches and machine learning is described in [12]. In [13] links a knowledge-extraction tool with ontology to achieve continuous knowledge support and guide information extraction.

This paper aims to focus on the new possibilities afforded by semantic web and natural language technologies in the area of knowledge management and open government data to allow institutional information from very diverse, scattered and different sources to be structured formally and semantically to facilitate its analysis, accessibility, reuse and exploitation from a single access point in a public way.

III. Proposed Approach

The high-level architecture of the proposed approach (see Fig. 1) is primarily focused on information retrieval. Particularly, textual information of websites under `aragon.es` domain using *web crawling*, *spidering* or *spider* techniques and data related to the organizational chart of the Government of Aragon are retrieved. Secondly, the extracted textual information is analyzed/processed using NLP techniques for lowercase conversion, lemmatization, stopwords filtering, the dictionaries application, cleaning tasks, recognition and classification of concepts and summarization. Lastly, results are stored into NoSQL databases that allow the indexation of rich text and structuring information according to the EI2A ontology for later consultation through the Aragon Open Data access point.

To implement the functionalities of the proposed approach, a set of sub-processes has been developed through an own framework called *Moriarty*[4] [14]. Moriarty is and advanced Artificial Intelligence software solution framework for Big Data, developed by ITAINNOVA[5]. It is based on two basic concepts: *workitem* (class that implements an atomic function, and that can be used in multiple contexts reuse concept) and *workflow* (composed of workitems or other workflows that receive some inputs and perform transformations in them generating and returning some outputs).

[4]Moriarty, http://www.ita.es/moriarty, last accessed 2018/09/10

[5]Instituto Tecnológico de Aragón, http://www.itainnova.es, last accessed 2018/09/10

Fig. 1. High-level architecture.

Through the execution of a periodic process, open data related to the Government of Aragon organizational chart (legislatures, entities, roles) are accessed in reusable formats (*xml*, *csv*, *json*) from Aragon Open Data portal with the aim of structuring them according to the EI2A ontology. It is initially populated with this data and is available as RDF (*Resource Description Framework*). Since web information could change regularly and new web pages may appear, a web crawling process is executed periodically (see Fig. 2), analyzing the new webs that emerge or reprocessing the webs that have changed, and thus to have the information updated. URL information of websites in an updated *csv* file is considered as the seed of this approach. *ExtractURLsFile* sub-process extracts them in order to analyze and process them. Initialized the necessary variables to carry out the entire web crawling process in *CsvToText* sub-process, a list of URLs filtered to avoid images, *css* or unauthorized links is created with the depth of analysis, the maximum number of pages to analyze and the number of crawling-threads desired in *Crawling* workitem. It uses *crawler4j*[6] library, presented as the most suitable available for the recovery of institutional information offered in websites, after a thorough analysis of the current state on research trends and technological development in relation to web crawling techniques and after developing and following a methodology with the objective of applying selection criteria.

With the aim of granting a unique identifier to the new pages instances to be processed and analyzed, *GetMaxURLID* sub-process returns the maximum identifier inserted in *Openlink Virtuoso* database. Url-to-url, *ExtractTextFromURL* sub-process extracts the text information whether it is HTML or a file (pdf, doc or docx). A series of rules are applied that allow obtaining a clean text. *CheckWebPagesChanges* is responsible for detecting if a website has changed and it is necessary to reprocess. For this purpose, a CRC *(Cyclic Redundancy Check)* code is calculated from the text. *LoadDataURL* sub-process incorporates real information to a web, subdomain or portal as RDF triplets in *Virtuoso* (e.g. *ei2a:idWebPage rdf:type ei2a:WebPage, ei2a:idWebPage rdf:type owl:NamedIndividual, ei2a:idWebPage ei2a:URL url*). In *UpdateText* sub-process, after text preprocessing, in which some common task is performed such as lowercase transformation, stemming or stopwords filtering, the main NLP techniques used on textual data involve semantic classification based on thesaurus, text summary and recognition and classification of named entities (NERC). The text summary task offers a synthesis of the textual information with the most relevant sentences by means of graph-based ranking algorithms [15]. This avoids having to read the whole web to know what it is about. The NERC task, implemented in *PredictionNerSpark* sub-process, identifies, extracts and classifies implicit information of the texts related to people, organizations and locations that are named in them. This is possible thanks to the use of neural network algorithms [16]. In this case, the neural network known as the *Multi-Layer Perceptron (MLP)* has been used. To apply the mathematical model in charge of recognizing and classifying named entities, textual information is transformed

[6]Crawler4j library, https://github.com/yasserg/crawler4j, last accessed 2018/09/10

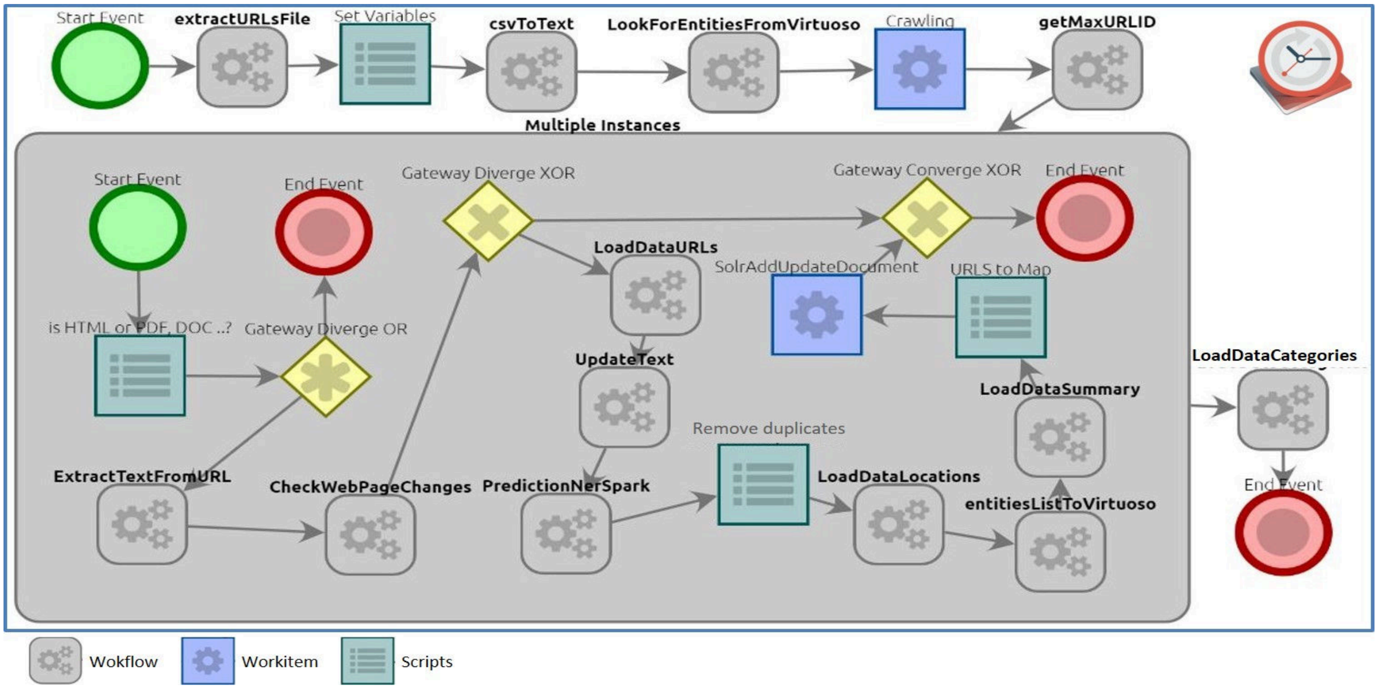

Fig. 2. Web crawling process.

into numerical representation, post-processed tasks are applied and a training set (or corpus) of formal informative type (news) has had to be built so that the model learns.

Identified the technical-legal framework applicable to the use of web crawling techniques, a methodology has been elaborated and followed for the extraction, treatment, storage, publication and reuse of institutional web information. The methodology takes into account aspects of crawling exclusion (file *robot.txt* and terms of use), intellectual property and protection of personal data. In fact, due to legal aspects, people extracted from the NERC technique, which do not belong to the organizational chart of the Government of Aragon (persons obtained through *LookForEntitiesFromVirtuoso* sub-process), is anonymized in the summary generated with asterisks. After that, extracted knowledge is stored in a structured and controlled manner in *Openlink Virtuoso* and *Solr* NoSQL databases for further exploitation. In *Openlink Virtuoso*, *LoadDataLocations* sub-process inserts through triplets all the locations previously extracted with the NERC technique, *entitiesListToVirtuoso* sub-process adds the citations, and that is, information regarding an entity (person, organization or location) is cited on a web, subdomain or portal, and *LoadDataSummary* sub-process introduces information related to the website summary. Finally, the url, CRC, categories in which a website is classified, the original text, the processed text, the current date, the summary and the persons, organizations and locations identified in the processed text, is stored in *Solr* database through the *SolrAddUpdateDocument* sub-process. Finally, the *LoadDataCategories* sub-process inserts in *Openlink Virtuoso* the data relative to the categories in which a website is classified.

IV. EI2A ONTOLOGY

In the government of Aragon an important volume of data begins to exist, and those elements such as the ontologies that contribute to the improvement of the structuring of the information and to the standardization of the data are increasingly important and relevant in the field of automation in information management systems. EI2A emerges with the main idea of generating a framework (a set of technical and legal rules) in which the open data and regional government data in general can begin to be automated in a much deeper way.

Borrowed from philosophy, ontology is a term that refers to an explicit and formal specification of a shared conceptualization [17]. It details the concepts and relationships of a domain allowing analyzing, sharing and reusing common knowledge. Ontology populated with high-quality instantiations provides a consistent knowledge base. With the knowledge of regional public administration experts, EI2A ontology has been defined and created using a process that follows the methodological guidelines contained in [18], [19]. Based on the philosophy of the Semantic Web, well-known ontologies, schemes and vocabularies such as [20]–[25] endorsed by European directives (INSPIRE)[7] and International Consortium (W3C)[8] have been reused to model EI2A ontology.

Institutional data of common interest identified and modeled are focused on concepts related to describe organizational structures, natural persons, any places in terms of its name, address or geometry, geolocations, territories, events, temporarily and documents (including web pages). In this way,

[7]Inspire, http://www.idee.es/europeo-inspire, last accessed 2018/09/10
[8]W3C, https://www.w3.org/, last accessed 2018/09/10

the ontology provides concepts and relationships to support the representation of a very broad range of organizational structures. It is possible to describe the notion of an organization, the decomposition into sub-organizations, departments and units and the purpose and classification of organizations. In addition, membership and reporting structure with an organization: roles, posts and relationships between people and organizations. Furthermore, locations information at which organizations exist (sites or buildings) and organizational history (merger, renaming). A Government of Aragon domain-specific extension has been added to model the nature of an organic unit or office in Aragon (level of administration, public or private character, etc.). EI2A model has been enriched with aspects and metadata of DIR[9] and ENI[10]. On the other hand, motivated by the need of automatic way to extract, structure and standardize information from the huge amount of textual content available on the institutional websites, EI2A ontology provides concepts and relationships to specify semantically information related to a recognized entity (person, organization and/or location) has been cited on a web classified under a categorization of Government of Aragon themes.

V. Results

To evaluate our work of gathering, analyzing, processing, storing and keeping updated unstructured institutional information to be offered to all interested collectives from a si ngle access point in a public and structured way, 667 websites are been crawled in order to extract text content. In this section, results from a sampling of five websites (http://www.educaragon.org, http://transparencia.aragon.es, https://www.turismodearagon.com, https://www.saludinforma.es and https://inaem.aragon.es/), considered of greater relevance for the Government of Aragon and as seed of this approach, are presented as part of a larger experiment designed. The system is ready to add as websites as required. Through a periodic web crawling process, with a depth of 4 and 10 crawling-threads, 3,963 urls (HTML or a file) have been processed. Data extracted has been cleaned applying customized metadata removing rules such as headers, footnotes or indexes, and the texts have been processed (lowercase transformation, lemmatization or stopwords filtering) to prepare them for later application of NLP techniques (thesaurus-based semantic classification, named entities recognition and classification and, summarization).

To apply EI2A scheme on real data, the ontology has been populated with information from each institutional website. *Person*, *Organization*, *Site*, *Address*, *Location*, *Temporal Entity*, *WebPage* and *Citation* concepts have been populated with more than 95,978 new instances and relationships generated as triplets (subject-relation-object). Some of them provided by the NERC process. For example, information related to a recognized entity (person, organization and/or location) has been cited on a web classified under a categorization is specified semantically. In addition, data related to the url, the date of textual web content capture and the summary is added to EI2A. On the other hand, EI2A has been populated with information of the organizational chart of Government of Aragon extracted from a dataset[11] of Aragon Open Data portal. In this way, semantic information is added to indicate the nature of a person′s membership of an organization, that is to say, that a person belongs to a unit or department with a specific role in a valid time interval. Results from extracting knowledge of web textual content are stored in a structured and controlled mode into *Solr* and *Openlink Virtuoso* NoSQL databases allowing future open access and simple data exploitation. Thanks to a web interface, as a semantic search engine in which it is able to understand through natural language type questions and generate appropriate responses to the context, it is possible to search information on the generated knowledge base and to browse through the ontological model EI2A. For example, Fig. 3 shows information about where a specific person is working and on which websites is cited: 'Francisco Javier Lambán' is President of Aragon since July 4, 2015 to the present, in the department 'The presidency' that has its headquarters in Paseo María Agustín, 36. This person has been cited on a pdf document classified in the *Dependency* and *SocialCareAndDependency* categories.

Experimental results based on institutional information validate that the proposed approach improves the structuring and standardization of decentralized data that can be processed and offered to all interested collectives through the application of web crawling, NLP and ontology-based techniques. EI2A has been populated with many high-quality instantiations, affording and securing new possibilities of generating valuable and consistent ontology-based knowledge services.

VI. Conclusions and Future Work

Governments are one of the main producers of information, which, in the exercise of their functions, create, collect, treat, store, distribute and disseminate large amounts of information of different fields. How to provide relevant elements that allow improving the structuring of institutional information and deepening its standardization to make easier its access and make use of the data has become an important challenge. In this paper, an approach based on ontology and the use of NLP techniques is proposed.

Despite dealing with texts with a great diversity of domains and formats, the work carried out manages to integrate a generic system capable of fulfilling the expectations presented at the beginning. Although improvements have been identified related to define new entities according to the context, the application of a more complex text pre-processing and the generation of different mathematicians models according to the text context would also imply the improvement in the extraction of information and in the quality of the structured and stored data, results obtained are significantly satisfactory.

[9]DIR, https://administracionelectronica.gob.es/ctt/dir3, last accessed 2018/09/10

[10]ENI, https://administracionelectronica.gob.es/ctt/eni, last accessed 2018/09/10

[11]Organigram, https://opendata.aragon.es/datos/catalogo/dataset/organigrama-del-gobierno-de-aragon, last accessed 2018/09/10

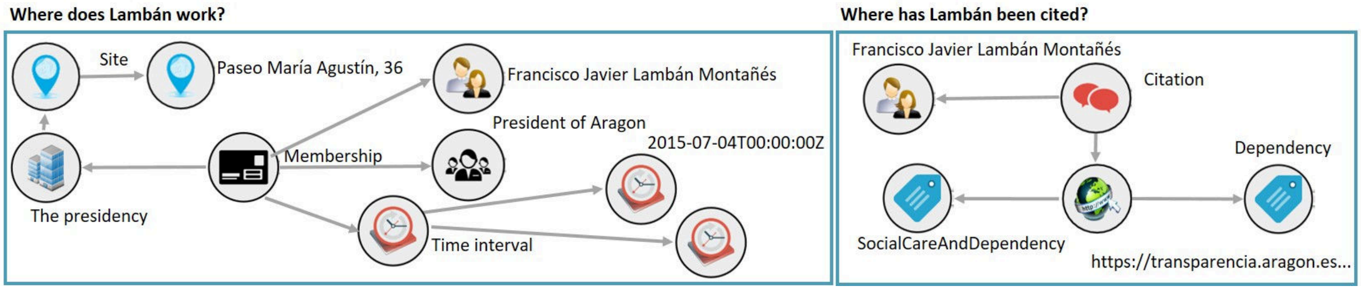

Fig. 3. Browser for EI2A ontology.

In this context, the viability of the proposed approach has been verified and new aspects have been detected in which it is necessary to continue exploring. The aim of the future work is to deploy the solution over the public Aragonese infrastructures in order to develop on top of this system new natural language recognition services with the challenge of deepening more in the understanding questions asked by a user and knowing what needs to be answered (for example, semantic search engine and assistant BOT). Moreover, to investigate new services in the line of extracting knowledge from the unstructured information that the Government of Aragon has, and to continue expanding and evolving the EI2A schema with the definition of new concepts and relationships based on the information processed as a consequence of the indicated actions.

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Participatory Design with On-line Focus Groups and Normative Systems*

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***Abstract*—Participatory design is a generally accepted practice for the construction of Ambient Assisted Living (AAL) systems. The involvement of experts and users in the conception and design of assistive solutions can lead to better systems. A common technique to involve users is called focus-group, which is mainly a moderated group meeting. Despite its benefits, it cannot be neglected the implicit cost of preparing and performing such meetings, and ensuring, later on, that the resulting assistive solution meets the requirements. A disruptive way to change this situation is the application of ICT technologies. This work contributes with a proposal for partial automation of focus-group techniques that support on-line evaluation of assistive solutions during the conception stage. Also, the paper addresses the formalization of the evaluation feedback through the use of normative systems.**

***Index Terms*—**

An analysis of the perception of intelligence by different stakeholders in the Ambient Assisted Living domain

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***Abstract*—This paper analyzes the perception of Artificial Intelligence of different stakeholders in Ambient Assisted Living creations. This perception has been widely addressed in the area of Human Robotics Interaction, but less in the Ambient Assisted Living. The study includes some insights in the industrial creation of such systems, but it focus in on a survey to Artificial Intelligence students, the future creators of these solutions; and a qualitative analysis of end-users reaction when asking about their impression about using intelligent technology. A conclusion is that early adopters tend to see AI everywhere, while industrial engineers hardly feel the need to pointing out explicitly the intelligence within. A reason for this could be the conservative stance of end-users, mostly older people, that do not understand the benefits and it may even act as deterrent. On the other hand, professionals, such as physiotherapists, are more positive towards the role of intelligence, and start imagining possible applications, just as the students in AI.**

I. Introduction

The development of Ambient Assisted Living (AAL) is a multidisciplinary one where experts from different disciplines get together in order to improve the quality of the daily living of people and, in particular, those with special needs. As researchers in this area, we have concerns about the functionality such systems ought to provide and how it is perceived by the end-users. Current approaches for developing such systems are highly driven by how end-users interact with the inventions. This is the user-centric approach that is evolving to a co-creation scenario [1]. Modeling the scenarios, as in [2], can help to foster discussion about how we want the system to be. In particular, it makes sense to wonder how intelligence is used, how it is perceived by the different stakeholders, and if it is positive or not to be explicit about the presence of intelligence in one's invention.

The stance of the paper is a social science based one, which differs from personal views of AI contributions, such as [3], or more general reviews of what is AI according to textbooks, such as [4]. When the problem is to determine what is the perception of an issue, readers should get rid of the bias of their own believes about such issue. And approaches to capture the perception of intelligence, should follow social sciences based techniques, instead.

That humans do invent intelligence and tend to assume there is some even when there is not, has been known for a while. Brooks [5] put this idea in words: the intelligence is in the eye of the beholder. Besides, the concept of intelligence changes along the years. What is considered as intelligent in the 90's may considered quite usual in the 21st century.

After all, humans are very sensible to the perception of intelligence. They are very likely to show biased opinions depending on external factors. Works in psychology have identified how we perceive different intelligence on people depending on how they dress [6], or their bodily movements [7], to cite some. It would not be a surprise if subtle changes in our systems may make others think that a behavior is more or less intelligent.

In fact, an active area in the study of human perception of intelligence is Human Robotics Interaction (HRI). Duffy [8] discusses, but not explores empirically, how, by making robots look more human (e.g. through shape or by making them execute typical human actions such as walking), robots are perceived to be more intelligent. The goal would be achieving social interaction (hand shaking, dialogues, and more complex interactions). Sabanivic [9] uses observational studies to analyze interactions with humans in the open, concluding that the physical context of the interaction matters, that gaze is part of the communication, and that robot to many interactions are needed.

HRI is not ambient intelligence, though some conclusions could be reused. Most HRI results require an embodiment of the intelligence a.k.a. the robot. In ambient intelligence, there are networks of distributed sensors and actuators, and there is not necessarily a visible body to interact with. Nevertheless, HRI results are relevant to Ambient Assisted Living, though grounding them is needed. In particular, there are misconceptions on technology related to AAL as seen by experts, practitioners, and end-users. For instance, if users think there is intelligence in an AAL facility, do they perceive the AAL system as a better one?

Needledless to say that intelligence is a word frequently occurring in the academy papers. However, industry does not share this attitude. If patent registries can be regarded as a one representative of industrial view of AAL, a likely hypothesis is that it does not care much about what is intelligence anyway in the AAL. Within this broad area, activity recognition problems are quite frequent in the AAL literature and one can find many patents about this. Classifying and recognizing activity patterns has a wide and varied use in different devices and monitoring and tracking systems [10] and is a frequent topic in ambient intelligence. Focusing in on this specific topic, a set of patents were obtained from Google Patents service looking for keywords related with "activity recognition" or "body movements", and combined with others such as "daily living" or "patient". First pages of queries were inspected looking for highly related patents to the attention of patients. This filtering led to *46 relevant patents*,though limited to european and EEUU registries. Only five patents did cite intelligence explicitly as part of the invention. In the few patents that explicitly identify artificial intelligence, there is no distinguishing characteristic with respect to other patents that perform a similar function. This is a minor revision, but it is instructive preliminary analysis of how "intelligence" becomes less a buzz word in the patent literature. For the current paper, it is a good starting point to wonder if there is a path from early practitioners towards this final situation, where functions that need to be characterized as intelligent by people,are no more extraordinary than a mathematical function when they become experienced practitioners. This justifies some groundwork on AAL to check the prejudices of early practitioners of artificial intelligence.

Similarly, technology aversion [11][12][13] plays an important role in the co-creation of AAL inventions. Some analyses from the literature produce informing evidences for understanding how intelligence is perceived. To these, this paper wants to contribute with a qualitative analysis obtained from interviews made to Parkinson patients and health professionals.

Our conclusions on both sides of the study can be summarized in a very different attitude between the early practitioners (very enthusiastic about AI) and the end-users (indifferent or with some aversion). Also between the academy (aiming to create intelligence every time) and the industry (forgetting about the intelligence itself and focusing more on the services). The work makes extensive use of social sciences methods and contributes with qualitative analysis of the results.

The paper does not contain a dedicated related work section because it has been preferred to distribute the references along the report. Section II addresses the perspective of early practitioners obtained through some surveys and short experiments. Section III reviews some interview transcripts and the literature to gain some insights in how end-users and experts perceive the intelligence. Section IV includes the conclusions of the paper.

II. Perceived intelligence by early practitioners

To address the perception of intelligence by early practitioners, a survey has been conducted to undergraduate students of the Computer Engineering Degree at Complutense University of Madrid. The survey combined open questions and scale-like questions. They have been asked about the presence of intelligence in different contexts. The survey was conducted into two different days. In the first day, 23 students were asked during a class, and then 33 undergraduate students participated in an online survey. The second day, 28 participated.

A. First day

The first day of the Smart Systems subject, 23 undergraduate students were asked to provide with an example of artificial intelligence application they knew. For this survey, a microblogging tool was used. No format was assumed, just a limitation of 170 characters. The professor graded each answer following this scoring criteria: 0 (wrong concept, badly expressed), 1 (wrong concept, but well expressed), 2 (right concept, but badly expressed) and 3 (right concept and correctly formulated). The results are presented in figure 1.

All students declared that they did not have any experience in artificial intelligence. Therefore, it is of significant meaning that 86% of students provided examples that included, at least, an understanding of artificial intelligence that the professor approves.

Thus, considering their inexperience in the area of artificial intelligence, it is evident that they should have received some kind of training or instruction from some agent of socialization, either family, peers, mass media or some kind of formal or informal education. This hypothesis could be reinforced by the fact they chose a computer science degree.

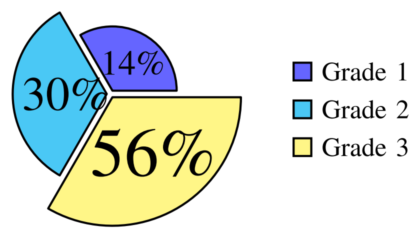

Figure 1. Grades received when suggesting an example of application of IA. The higher the grade, the better.

After the mentioned exercise of spontaneous examples of artificial intelligence, 33 students of two degree subjects, Smart Systems and Software Engineering, filled in a survey in which they were asked if they thought that six concrete devices had some artificial intelligence within. Answers followed a Likert Scale - a unidimensional scaling method that is one of the most commonly used scales in survey research [14]. For each question, the researchers formulated a statement that respondents had to evaluate: *Do you agree with the idea that Artificial Intelligence is used in the following examples?*

1) Algorithm of recommendation of a portal of films.
2) Fall detector for older adults.
3) Global Positioning System.
4) Cardiac pacemaker.

5) Controller for the body position and body movement in a video game.
6) Watch with location services for older adults.

The question aimed to explore the perception of the implicit AI in different devices, most of them directly related with AAL applications. Second and fifth devices were written thinking about sensors used to identify bodily positions in different contexts (gaming vs fall detection). Third and sixth devices used location services in general (just thinking about GPS) and in a AAL context (location services for older people). Fourth question was a control one. Since it was assumed a cardiac pacemaker ought not to involve a relevant amount of AI in general, respondents were expected to disagree. The first question was a control one too, but a positive control this time. It was intended to provide a positive answer about the use of AI in a classical film streaming service used at home.

It was expected that an expert would strongly agree to the presence of AI in the first, second, fifth, and have concerns about the sixth (a watch with location services can have multiple uses); and disagree/strongly disagree in the fourth case. The students' performance was different. In general, the students, see figure 2, identified correctly the objective presence of AI in the positive examples. In the case of the algorithm of recommendation, there is a 75.8% expressed partial or strong agreement while none of them selected strong disagreement. The percentage of right answers in the fall detector is even higher (84.9%). In the last of the objective AI examples, the controller of the body position and movement of a video game, there is a 15.2% of partial disagreement, but right questions are still considerably higher with 78.8%.

These positive results were lower in effectiveness than the results obtained from the open question from figure 1. Our conclusion is that students have a correct knowledge of success cases of AI techniques. However, when asked to evaluate a particular case, such as the chosen devices, some of them still fail to recognize the presence of AI.

Control questions returned unexpected results, as shown in figure 3. The GPS device received the same amount of votes to the agreement (total & partial agreement) with 39.4% and disagreement (total & partial) with 39.4%. The cardiac pacemaker is less evident, but it showed anyway a 51.5% of agreement (total & partial) and a 36.4% disagreement (total & partial). In the watch device, the votes are mostly positive (45.4% of votes) though there is a surprising uncertainty of 27.3 & of votes.

It is natural to have doubts when answering the last question about the role of AI in a watch. However, the variety of answers for the GPS or pacemaker cases was unexpected. Even though respondents were not questioned about the reason why they had chosen this answer, we elaborated an hypothesis: students were biased to think there was AI. The specific application to the health or medical area or its appearance in the context of an AI survey, as well as other intervening variables that are out of researchers' control, may have fostered those false positives. This could be the case of the watch locator for older adults, associating it with other smartwatches' characteristics that were not mentioned in the survey statement, such as emergency help or activity recognition. Something similar could have happened to students in the GPS case. Some students may have thought of driving or city map applications and how they guide them, which could be regarded as an intelligent behavior. Other possible explanation is that they think about GPS just as the satellite network.

In either case, many students decided there was AI in those devices, almost as many as the ones deciding there is not. Whatever the reason, we interpret these false positives as a tendency to observe AI in any case. This would fit the theory that our perception of intelligence can be affected by the context and other variables, as in the effect of how we are perceived differently depending on how we dress [6].

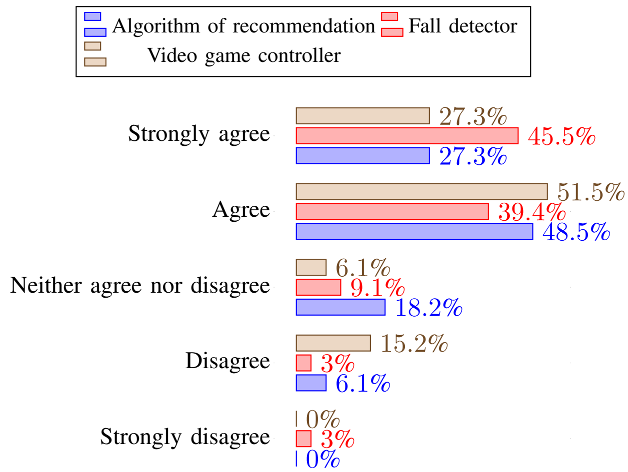

Figure 2. Expected positive cases in perception of AI presence.

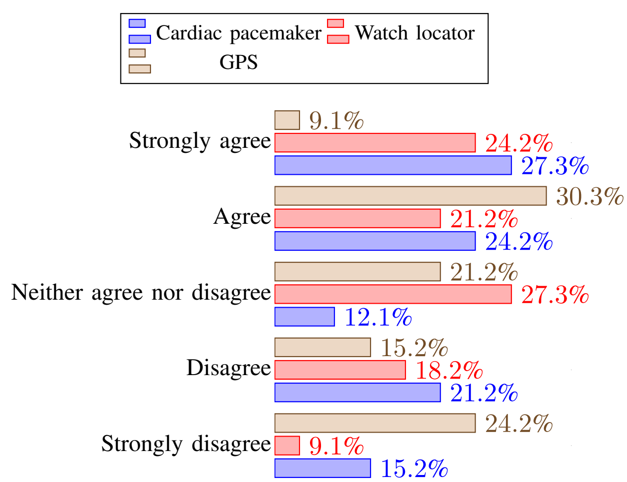

Figure 3. Expected negative cases in perception of AI presence.

B. Second day

While the first day the effort was focused on text based questions, this time a visual/auditive stimulus was used. This experiment aims to proof that a system providing the same functionality may convince observers to involve more or less or more AI depending on how it is presented.

The experiment subjects were a group of 28 students of the Smart Systems subject, most were from 20 to 25 years old. They were shown the same video twice, though the second time it involved additional voice tracks. The students were informed about what the videos were about. Both videos depicts a case of midnight sleep disorder which may happen to those developing Alzheimer's disease. In both cases, the informing text is the following: *A person wakes up in the middle of the night. When he/she gets up, the lights turn on as this person moves from one place to another. It is decided that he/she may not be aware of what is doing and the person is asked if he/she is disoriented.*

Students were asked "Do you agree with the idea that Artificial Intelligence is applied in this scene?". Students watched the first video and answered the question. Then, the second video was presented followed by the same question again.

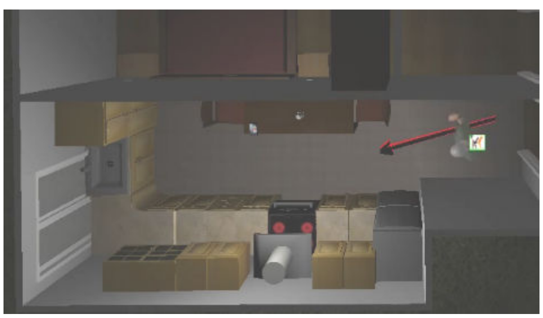

Figure 4. Fragment of the video used for the experiment.

Both videos represented the same course of action and, visually, were identical and looked like the figure 4. The differences between the first and the second video where the background dialog as follows:

- Video 1: Opening text: "The patient wakes up"
  - Audio: (after a time) "It seems that you are disoriented"
- Video 2. Opening text: "The patient wakes up"
  - Audio 1: "Let me turn on the light of this room"
  - Audio 2: "I turn on the light of the bathroom"
  - Audio 3: "You are wandering and it is 3 a.m."
  - Audio 4: "It seems that you are disoriented"

The answers are presented in figure 5. It should be remarked that the video depicted exactly the same scene. Only the second added three more audio tracks providing hints on what was being done. For instance, if the lights in the first video just lighted on, the extra audio indicated in the second video that lights were going to be lighted on.

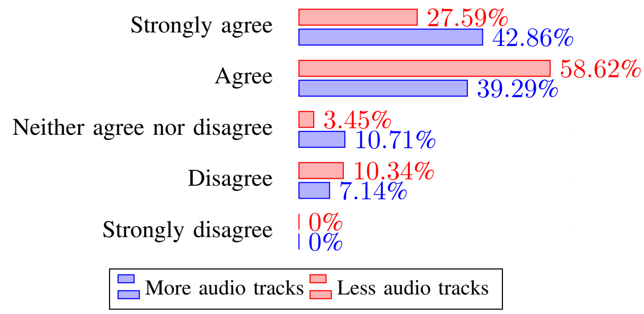

Figure 5. Perception of AI using videos with textual and audio information. 28 participating students.

The sum of those students who strongly agree that there is AI in the video plus those that only agree is roughly the same (86.21% first video against 82.15% in the second). However, the decisiveness in strongly assessing the presence of AI technology, changes remarkably, from a 27.6% in the first video to a 42.9 % in the second one.

It could be concluded that a 15% of the undergraduate students were deceived by the voice audio of the second video, or more if the transference of votes from disagree to neither both is accounted. The same functionality, when explained by an artificial voice, led the students to believe the AI was more relevant in the second video than in the first.

III. End-users attitudes towards intelligence in AAL

The end-users for AAL can be just anyone, but it is frequent that engineers focus on older people. This is a concern because the attitude of older people is more sensible towards technology and we expect Artificial Intelligence to be specially challenging to understand and to welcome.

A first analysis (section III-A) has been made reusing interviews obtained from project (Name omitted for the sake of blind review). This provides an insight on the reaction towards the intelligence on behalf end-users.

Then, a second analysis (section III-B) focused on the literature was made. There is an relevant amount of results on technology aversion in the literature. However, the specific topic of intelligence, its perception and reaction towards it, is not so common.

A. Analyzing interviews

In a past project about AAL that involved Parkinson's patients and other end-users (SociAAL Social Ambient Assisted Living, TIN2011-28335-C02-01)[15][16], 27 in-depth interviews were conducted to gather qualitative data about the Parkinson's disease. Some interviews involved more than one individual, but, in total, there were 5 Parkinson's disease experts (two neurologists, two psychologists and one physiotherapist), 13 Parkinson's patients (stages 3 and 4 of the Hoehn and Yahr scale) and 9 caregivers [17]. Those semi-structured, in-depth interviews included questions about the daily lives, main symptoms and limitations, activities of the caregivers and the perception of Ambient Assisted Living technologies. The youngest interviewed individual patient was 59 and the eldest one was 75. Half of them were male and half were female. All patients and caregivers lived in the Community of Madrid (Spain) with different social and cultural backgrounds.

For the present paper, we have analyzed in greater depth the transcriptions of these interviews to know of their stance towards intelligence. Interviewers were social scientists who were involved in the project, so they had knowledge that intelligence played an important role in the systems to be developed. The interviews were semi-structured ones, with a script oriented towards knowing more of their needs and how technology could aid them. Sometimes, the interviewer asked directly the interviewed about the role of some intelligent technology.

The transcriptions were reviewed looking for mentions of "intelligence" and "intelligent". These terms were used in 10 of the 27 interviews (6 interviews with patients/caregivers and 4 interviews with professionals, one of them with two professionals at the same time). None of the patients or caregivers brought this topic in, and, in all cases it was the interviewer who do did it. When talking with the experts, the result was the opposite in two of the three cases. Once the topic appeared, the reactions were different.

Patients or caregivers do not answer using those terms "intelligent" or "intelligence" when they are suggested by interviewers. All of them belong to either lower middle class or upper middle class. Furthermore, if the topic of artificial intelligence was addressed, some patients and caregivers associated it with high cost ("That's for people that have a lot of money", "But that is not accessible to all", "Nobody would give financial help for that"), distant future ("It sounds like a house of the future") and other personal circumstances ("I can't be left on my own"). Nevertheless, a patient maintained that he agreed with all ways to keep up-to-date and a caregiver -a patient's wife- claimed she would be capable of getting used to such a system.

When considering experts, three of five had reactions towards the term "intelligence". Two used pro-actively the word "intelligent" without being questioned, and one was asked about the "intelligence" directly.

The interviewer asked a physiotherapist about the interest of an intelligent system. The physiotherapist answered that it was a great idea, but then she questioned to what extent it was useful, for instance, to perform activities instead of the patient, because it was good for the patient to exercise themselves. However, the assistance oriented towards monitoring and to actively remind the patient was more positively received. In one case, the therapist started playing with the idea and imagining things an *intelligent house* could do.

A psychologist used the word "intelligent" but was reluctant to elaborate and immediately grounded the term to things done within projects this psychologist was involved into (identify patient's situation to recommend physical exercises, handwriting analysis, cognitive training). She knew of the subject and the necessary technology. A neurologist also used the word "intelligent" when referring to adaptability (amount of medicine an intelligent pump system has to supply, or apps with smart-phones that have access to multiple sensors). In both cases, the question was a generic one about their prior knowledge on relevant technologies for AAL, like domotics.

The first conclusion is that words like "intelligence" or "intelligent" are not likely used by patients or caregivers, but by interviewers and experts. Also, that experts can be already familiar with the term and that it is inherently associated with technology. They do not elaborate too much about it, but, with the exception of the physiotherapist, the neurologist and the psychologist seem more aware of what it really can do. They identify specific functions and catalog them as intelligent ones because of the presence of capabilities like adaptiveness, handwriting recognition, or sensor processing capabilities, to cite some.

Patient and caregivers are less receptive to words like "intelligence" or "intelligent". As it has been shown, they do not use it despite the social class they belong to. They tend to think it is something expensive and do not elaborate much about what they can do with it. This may be related with the technology aversion which will be analyzed in section III-B .

B. *Analyzing the literature*

It is hard to evaluate how much intelligence contribute to the technology aversion identified by the literature. The factors and barriers for the acceptance of technology for Ambient Assisted Living that were collected in the interviews to Parkinson's patients coincided with the results of previous researchers [11][12][13].

Among the scientific literature gathered, Peek et al. [13] carried out a systematic review of 16 articles, obtaining as a result 27 factors of acceptance in the pre-implementation stage of technology for aging at home. These factors are summarized by the authors in six items [13]: "concerns regarding technology (like cost, privacy and usability); expected benefits of technology (like safety and perceived usefulness); need for technology (e.g., perceived need and subjective health status); alternatives to technology (e.g., help by family or spouse), social influence (e.g., influence of family, friends and professional caregivers); and characteristics of older adults (e.g., desire to age in place)".

Intelligence requires data obtained from the user contexts. Jaschinski and Allouch's [12] study expounds on these technological concerns related to privacy for personal information, security, possible intrusion of too visible devices or constant surveillance. Other barrier that is gathered by the authors is the lack of user control reinforced by elderly people's technological inexperience that leads to technology anxiety. Finally, and according to this compilation, intelligent technologies "cannot and should not replace human assistance and human interaction", especially in aspects related to personal care tasks, leisure activities and most health related tasks [18].

IV. Conclusions

Addressing the role of intelligence in a area like Ambient Assisted Living ought to be a concern in a development. This work has contributed with an analysis of the perception of intelligence from two perspectives: as it is perceived by the future creators of AI technologies, and as it is perceived by other stakeholders of these systems (end-users and experts). This research was made within the context of Ambient Assisted Living systems, i.e., systems that aim to assist users to improve the quality of their daily living.

The end-users have shown unemotional reaction when someone uses the word "intelligent". They have assumed it is expensive and do not incorporate that word into their responses. Being people of 59 and older, this may seem natural. The experts' opinion is more positive and in two of the cases the experts pro-actively brought the topic of intelligence in a very accurate way. In these cases, experts had prior knowledge because they were working in similar areas.

This stance contrasts with the new practitioners and engineers, that enthusiastically tend to see intelligence everywhere. However, the industry, when registering inventions, do not highlight the intelligence they incorporate in the devices. They prefer most of the time to focus on the capability without concern of whether this brings intelligence or not.

From the social sciences view, the population of this study is a minimal one. Despite the size, the results are still better that one's intuition about the problem and can be of some value when addressing an AI related project. They can foster additional thinking about this issue so that engineers do not assume different stakeholders (developers, end-users, and experts) share the same view on AI. More results are still needed, but these are inspiring enough to continue this research.

Acknowledgment

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Computational machines, free will and human reason

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***Abstract*—David Hume, the Scottish philosopher, conceives reason as the slave of the passions, which implies that human reason has predetermined objectives it cannot question. An essential element of an algorithm running on a computational machine (or Logical Computing Machine, as Alan Turing calls it) is its having a predetermined purpose: an algorithm cannot question its purpose, because it would cease to be an algorithm. Therefore, if self-determination is essential to human intelligence, then human beings are neither Humean robots, nor computational machines.**

Keywords—human nature; free will; self-determination; algorithm; computational machine; goal and strategy selection

I. Introduction

In this paper we want to show the connection between Hume's conception of human nature and the modern conception of robots. Even if, quite possibly, the concept of 'robot' would have proved deeply strange to Hume, the truth is that his conception of reason as 'the slave of the passions' anticipated the modern concept of computing machine: we call his conception a *Humean robot*, that is, an instrumental intelligence at the service of predetermined objectives, or passions. In fact, if for us humans of the 21st century, it is tempting to consider ourselves complicated biological robots, it is only because we have previously accepted the Humean paradigm of reason as the slave of the passions. We are prone to believe that we are robots, because we have first accepted that reason neither chooses nor prioritizes its ends.

This paper is a summary of the one published in the Journal of Experimental & Theoretical Artificial Intelligence (Jan 2018) with the title *Are Human Beings Humean Robots?* [2].

II. David Hume: reason is the slave of the passions

David Hume (1711-1776) wrote in *A Treatise of Human Nature*, under the section devoted to the influencing motives of the will, that "reason is, and ought only to be the slave of the passions, and can never pretend to any other office than to serve and obey them" [6]. Hume wanted to understand the human mind as Isaac Newton had understood the cosmos, by adopting a mechanistic approach to human intelligence. Human beings are attracted by passions, and moving towards a concrete passion can be resisted only with aid of a stronger and opposite passion, much in the same way as physical forces operate on bodies. In this conception of human nature, *the role of reason is to elaborate a strategy* to best fulfill the set of passions; but reason neither questions nor chooses the passions it has to serve. We think Hume proposes a suggestive account of instrumental reason that anticipates and prepares a modern algorithmic model of intelligence, aimed at optimizing the achievement of its predetermined objectives (i.e. passions).

In Hume's sentimentalist approach to ethics, happiness is achieved when passions are satisfied. In this model, *reason is understood primarily as an optimization tool* (technical or instrumental reason, therefore), used to calculate the behavior that better satisfies the passions involved and that demands less effort from the subject. *Reason is the slave of the passions*: it does not question those passions that are irresistibly imposed upon it, nor their objectives, nor the strength of their attracting force; passions and objectives are pre-rational or meta-rational.

If Reason is integrated into the realm of passions, or goals, as an algorithmic calculation, Will cannot be anything but automatic: once the optimal path is known, all that is left is to start out, give the order, but not properly 'decide'. What is implied here is *a radical denial of human freedom* in the usual sense of the term, to which we will refer later.

III. Alan Turing: what is a computational machine

A robot is usually defined as a mechanical device that is controlled by a computer running a program; a robot is, in this sense, an algorithmic or computational machine. An algorithm can be preliminary defined as a rule-based procedure that obtains a desired result in a finite number of steps. Alan Turing laid the foundations of the modern notion of algorithm, establishing that a computation method is *effective* (a.k.a. mechanical) if it can be carried out by a Turing Machine [8], or, as Turing himself calls it, a Logical Computing Machine [9]. This is the substance of the Church-Turing thesis [1].

However, and perhaps surprisingly, there is a lack of satisfactory consensus on the definition of algorithm [10]. A recent study by Hill [4] examines existing approaches to the notion of algorithm, from semi-formal definitions like the one by Donald Knuth, "an algorithm is a finite set of rules that gives a sequence of operations for solving a specific type of problem" [7], to more formal ones.

After some analysis, Hill offers a definition: "An algorithm is a finite, abstract, effective, compound control structure, imperatively given, *accomplishing a given purpose* under given provisions." The italics manifest the *intentionality* of algorithms. This sense of utility or purposefulness is shared by machines in general. It is the success or failure in accomplishing its function that permits us to tell whether the machine works properly or not. Thus, *a machine cannot be defined and accounted for without reference to its purpose* [3].

Take for example a game playing machine, designed to play against a human. Initially, the machine has the goal to win the game. If the game is very simple (like Tic-Tac-Toe), designing a strategy (an algorithm) to win, or at least not to lose, is rather easy. In the case of chess, the complexity of the game has not permitted, until now, an infallible strategy, even though, with current technology, most of human players will lose against a rather common artificial chess player.

A somewhat different kind of chess machine might include a certain degree of randomness in its 'decisions', or it might be able to self-limit the effectiveness of its strategy in order to configure an affordable level of difficulty, so that the human player still enjoys the game and does not throw in the towel too soon. These two kinds of chess machines have slightly different objectives: either winning the game, or else having the human player learn how to play better and enjoy the learning process. Nevertheless, in each case the machine has a well determined purpose or function that defines it. What we do not expect from a chess machine of the first kind (i.e. designed to win) is that it chooses to lose the game… *It can fail to achieve its goal, but it cannot change its goal*. Of course, there can be algorithms with different levels of goal selection and prioritization. However, those *dynamic goal-selection algorithms* are in fact obeying higher-order goals (meta-goals) to select convenient sub-goals and strategies.

We think Turing himself acknowledged this *lack of freedom* was essential in his conception of a computational machine, even if implemented by humans performing calculations: "A man provided with paper, pencil, and rubber, and *subject to strict discipline*, is in effect a universal machine" [9] (our italics). Notably, it happened exactly in this way in the internal organization of Bletchley Park labor groups set up by Turing and others to decipher German codes during World War Two [5]. Being 'subject to strict discipline' means not questioning at all the rules and purposes of the procedure, i.e. the computation.

IV. Determination, indetermination, self-determination

Mechanism in philosophy is the view that all beings, whether lifeless or alive, are like complicated machines. Mechanism is closely linked to determinism, since the scientific and technological revolution of the 17th century made some philosophers –Hume among them– believe that all phenomena could eventually be explained in terms of 'mechanical laws', i.e. natural laws governing the motion and collision of matter under the influence of physical forces. Modern mechanistic views of living beings, including humans, comprise mechanical *information processing* as an essential element of the 'living machine', for example in behaviorist stimulus-response theories. We distinguish three ways of relationship between mechanistic determination and the behavior of humans and computational machines.

1. **Hetero-determination.** The behavior is fully determined by the received stimuli and the computational or neurological processing these stimuli undergo to produce a response, according to more or less complex programs and evaluation systems.
2. **Indetermination.** This view complements the previous one by adding a certain degree of uncertainty. However, indeterminism does not add anything essentially different to the Humean conception of human nature. In fact, these two views, hetero-determination and indetermination, agree in their radical negation of human freedom.
3. **Self-determination.** In this position the previous two are rejected. If human freedom, in its usual sense, is not an illusion, then it is not true that human behavior is determined (even only statistically) just by the material aspects of the body and the phenomena that occur in it. On the contrary, being truly free means that human beings self-determine in their actions.

V. Summary of the argument

David Hume conceives reason as the slave of the passions, which implies that human reason has predetermined objectives it cannot question. On the other hand, an essential element of an algorithm running on a computational machine is its predefined purpose: an algorithm cannot question its purpose, because it would cease to be an algorithm. We have reached a critical point for the Humean-computational view of human beings, since self-determination is not an algorithmically programmable function: *purpose is the prerequisite of an algorithm, not its result*. Therefore, if self-determination is the true essence of human freedom, then human beings are neither Humean robots, nor algorithmic machines.

We have *not* demonstrated that human beings are truly free (self-determined). We have only demonstrated that *if* humans are free, *then* they cannot be algorithmic machines; *then* human intelligence cannot be properly defined as an algorithmic process; and *then* human behavior cannot be perfectly emulated by algorithmic robots. Whether we, in some uncertain future, can produce in our laboratories a kind of non-algorithmic robots that can be properly called free, and whether they still can be called 'robots', will be the subject of further research.

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Bireducts with tolerance relations

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***Abstract*—Reducing the number of attributes by preventing the occurrence of incompatibilities and eliminating existing noise in the original data is an important goal in different frameworks, such as in those focused on modelling and processing incomplete information in information systems. Bireducts were introduced in Rough Set Theory (RST) as one successful solution for achieving a balance between the elimination of attributes and the characterization of objects that the remaining attributes can still distinguish. This paper considers bireducts in a general framework in which attributes induce tolerance relations over the available objects. In order to compute the new reducts and bireducts a characterization based on a general discernibility function is given.**

***Index Terms*—Attributes reduction, tolerance relations, discernibility function, information bireducts.**

I. Introduction

Two complementary approaches to treat imperfect knowledge are Fuzzy Set Theory (FST) introduced by Zadeh [11] and Rough Set Theory (RST) proposed by Pawlak [9]. In FST, the elements belong to a set considering a certain degree of truth. On the other hand, RST computes approximations of concepts from incomplete information.

One of the main goal is to reduce databases keeping the same information. To this end, the reducts, minimal subsets of attributes preserving the original information, were studied in [3], [6], [8].

In this paper, we also consider bireducts, which are an extension the notion of reduct, that is, a subset of attributes and a subset of objects that prevent the occurrence of incompatibilities and eliminating existing noise in the original data.

Throughout the paper, we work with information reducts and information bireducts, as well as with decision reducts and decision bireducts. We also take into consideration similarity and tolerance relations in order to provide a natural relationship of distance among the elements of the universe. In some cases, a tolerance relation can be more appropriate since, for instance, the transitivity constraints imposed by similarity relations may produce conflicts with user's specifications or the exclusive use of similarity relations may cause wrong modeling of vague information. The notions and results obtained considering this framework is deeply studied in [2].

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II. (Bi)Reducts in Information System

In this section we are going to present the notions of reduct and bireduct of an information system. First of all, we recall the idea of tolerance relation.

If we consider an information system $\mathbb{A} = (U, \mathcal{A})$, a fuzzy tolerance relation family $\{E_a \colon V_a \times V_a \to [0,1] \mid a \in \mathcal{A}\}$ and a family of values $\Delta = \{\delta_a \in [0,1] \mid a \in \mathcal{A} \cup \{d\}\}$, we can define, for each $a \in \mathcal{A}$, the relations T_{a,δ_a} as:

$$T_{a,\delta_a} = \{(v, w) \in V_a \times V_a \mid \delta_a \leq E_a(v, w)\} \qquad (1)$$

Note that each relation T_{a,δ_a} is straightforwardly a tolerance relation. Moreover, in the general environment of an information system or decision system, each attribute can have different nature and so, different thresholds could be assumed for each attribute. For further information about tolerance relations see [7]. For some examples on how to employ tolerance relations in rough set mechanisms of attribute reduction see, e.g. [10].

Based on a family of tolerance relations $\mathcal{E} = \{R_a \subseteq V_a \times V_a \mid a \in \mathcal{A}\}$, the notion of discernibility is generalized as follows.

Definition 1: Given an information system $\mathbb{A} = (U, \mathcal{A})$, a subset $B \subseteq \mathcal{A}$ and a tolerance relation family $\mathcal{E} = \{R_a \subseteq V_a \times V_a \mid a \in \mathcal{A}\}$, we say that objects $x, y \in U$ are $\mathcal{E}_B$-*similar* if for all $a \in B$ we have

$$(a(x), a(y)) \in R_a$$

Otherwise, we say that objects $x, y \in U$ are $\mathcal{E}_B$-*discordant*, that is, if the following holds

$$\{a \in B \mid (a(x), a(y)) \notin R_a\} \neq \varnothing$$

In the following definition, we present the notion of $\mathcal{E}$-information reduct, the generalization of reduct considering tolerance relations.

Definition 2: The set $B \subseteq \mathcal{A}$ is called $\mathcal{E}$-*information reduct* if B satisfies that every pair $x, y \in U$, which is $\mathcal{E}$-discordant, is also $\mathcal{E}_B$-discordant, and B is irreducible with respect to this property, that is, there is no $C \subsetneq B$ such that all pairs $x, y \in U$ are $\mathcal{E}_C$-discordant.

Analogously, we generalize the notion of information bireduct.

Definition 3: Let $\mathbb{A} = (U, \mathcal{A})$ be an information system. The pair (X, B), where $X \subseteq U$ and $B \subseteq \mathcal{A}$, is called $\mathcal{E}$-*information bireduct* if and only if all pairs $x, y \in X$ are $\mathcal{E}_B$-discordant and, B is irreducible and X is inextensible with respect to this property.

III. (BI)REDUCT IN DECISION SYSTEM

In this section, we will present the notions and result needed in order to study the knowledge of a decision system. We generalize the notion of decision reduct. Throughout this section, we consider a decision system $\mathbb{A} = (U, \mathcal{A} \cup d)$, that is, a set of objects, a set of attributes and a decision attribute.

Definition 4: Let $\mathbb{A} = (U, \mathcal{A} \cup d)$ a decision system. A subset $B \subseteq \mathcal{A}$ is called $\mathcal{E}$-*decision reduct* if B satisfies that every $x, y \in U$, which is $\mathcal{E}_d$-discordant and $\mathcal{E}$-discordant, is also $\mathcal{E}_B$-discordant, and B is irreducible with respect to this property.

In order to compute the reducts, we are going to use the generalization of the unidimensional discernibility function.

Definition 5: The *unidimensional $\mathcal{E}$-discernibility function of* $\mathbb{A}$, is defined as the following conjunctive normal form (CNF):

$$\tau_{\mathbb{A}}^{\text{uni}} = \bigwedge \Big\{ \bigvee \{a \in \mathcal{A} \mid (a(x), a(y)) \notin R_a\} \mid x, y \in U, \\ (d(x), d(y)) \notin R_d \Big\}$$

where the elements of $\mathcal{A}$ are the propositional symbols of the language.

The following result presents a mechanism to compute the reducts, using the reduced disjunctive normal form associated with the unidimensional $\mathcal{E}$-discernibility function.

Theorem 1: An arbitrary set B, where $B \subseteq \mathcal{A}$, is a $\mathcal{E}$-decision reduct of $\mathbb{A}$ if and only if the cube $\bigwedge_{b \in B} b$ is a cube in the RDNF of $\tau_{\mathbb{A}}^{\text{uni}}$.

Also, we can define the decision bireduct considering a tolerance relation.

Definition 6: A $(\mathcal{E}, U)$-*decision bireduct* is a pair (X, B), where $X \subseteq U$ and $B \subseteq \mathcal{A}$, and satisfy that all $x \in X$ and $y \in U$, with $(d(x), d(y)) \notin R_d$, are $\mathcal{E}_B$-discordant and, B is irreducible and X is inextensible with respect to this property.

The following definition presents the conjunctive normal form with which the bidimensional $\mathcal{E}$-discernibility function is defined.

Definition 7: The conjunctive normal form

$$\tau_{\mathbb{A}}^{bi} = \bigwedge \Big\{ x \vee y \vee \bigvee \{a \in \mathcal{A} \mid (a(x), a(y)) \notin R_a\} \mid x, y \in U, \\ x < y,\ (d(x), d(y)) \notin R_d \Big\}$$

where the elements of U and $\mathcal{A}$ are the propositional symbols of the language, is called the *bidimensional $\mathcal{E}$-discernibility function of* $\mathbb{A}$.

This bidimensional $\mathcal{E}$-discernibility function is used in order to characterize the computation of $\mathcal{E}$-decision bireducts.

Theorem 2: An arbitrary pair (X, B), where $X \subseteq U$ and $B \subseteq \mathcal{A}$, is a $\mathcal{E}$-decision bireduct if and only if the cube $\bigwedge_{b \in B} b \wedge \bigwedge_{x \notin X} x$ is a cube in the RDNF of $\tau_{\mathbb{A}}^{bi}$.

IV. CONCLUSIONS AND FUTURE WORK

We have considered tolerance relations in order to study the reducts and bireducts in the classical environment of RST. We have generalized the classical notion of discernibility function, from which we have characterized the reducts and bireducts in these environments.

The consideration of tolerance relations within this theory provides a great flexibility in different environments and the range of possible applications increase dramatically, for example, considering fuzzy tolerance relations with thresholds.

In the future, we will consider the theory developed throughout this paper in order to provide a new reduction method in fuzzy FCA. In addition, the (bi)reduction proposed for FCA will be compared with other reduction mechanisms, which reduce the size of the concept lattice considering similarities [1], [5].

Furthermore, we will extend our approach to obtain bireducts in fuzzy environments, such as in fuzzy rough sets [3], [4] and we will apply the theory developed in both theories to practical cases.

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