Trait-based Module for Culturally-Competent Robots

Stefano Borgo[1] and Enrico Blanzieri[2]

(1) Laboratory for Applied Ontology (LOA), Institute of Cognitive Sciences and Technologies CNR, Trento, Italy
stefano.borgo@cnr.it
(2) Department of Information Engineering and Computer Science, University of Trento, Trento, Italy
enrico.blanzieri@unitn.it

Abstract

Robots might not act according to human expectations if they cannot anticipate how people make sense of a situation and what behavior they consider appropriate in some given circumstances. In many cases, understanding, expectations and behavior are constrained, if not driven, by culture, and a robot that knows about human culture could improve the quality level of human-robot interaction. Can we share human culture with a robot? Can we provide robots with formal representations of different cultures? In this paper we discuss the (elusive) notion of culture and propose an approach based on the notion of trait which, we argue, permits us to build formal modules suitable to represent culture (broadly understood) in a robot architecture. We distinguish the types of traits that such modules should contain, namely behavior, knowledge, rule and interpretation traits, and how they could be organized. We identify the interpretation process that maps situations to specific knowledge traits, called scenarios, as a key component of the trait-based culture module. Finally, we describe how culture modules can be integrated in an existing architecture, and discuss three use cases to exemplify the advantages of having a culture module in the robot architecture highlighting surprising potentialities.

keywords: Culture; human robot interaction; trait; ontology; interpretation; situation; scenario; culture-aware agent

1 INTRODUCTION

The relevance of culture in human-robot interaction has been proved empirically in cross-cultural studies[1, 2]. Participants of different cultures interact differently with the robots, for example in terms of proxemics[3]. Advocates of culturally-competent robotics argue that the culture of different user groups should inform the design phase[4] and that technical solutions can lead to culture-sensitive behavior of the robot. For example Dang et al.[5] modify the emotions of the robot according to culture, while Bruno et al.[6] propose to introduce cultural variables represented in fuzzy logic. This paper collocates itself among these approaches, and contributes to the comprehension and the definition of the relevant representational blocks of a culturally-competent robot.

In anthropology the term culture characterizes a complex of things like social behaviors, practices, interactions, understandings of reality and related notions. The term is traditionally associated with populations and ethnic groups but is today used more broadly to highlight specificities of communities or even of people working for an organization.

Culture is an important factor in human interactions because it codifies as default attitudes a series of behaviors and expectations allowing the agents to ignore some aspects of the interaction while concentrating on others. For this reason, human-robot interaction would improve enormously if artificial agents could comply with human culture in terms of situation understanding, expected behaviors and interaction rules. However, to comply with human culture is problematic. First, as we show below, culture is an elusive notion which is hard to characterize. For this reason, it resisted recent attempts of formalization. Second, culture is hardly a single notion and there is no guideline on how to separate different notions of culture or even to establish when similarities (of behavior or of rule) indicate a substantial overlap.

The objective of the paper is to identify a notion of culture that is: (*a*) arguably suitable for formal treatment; (*b*) conceivable as a separate knowledge-base module; and (*c*) functional to the knowledge-based perspective of artificial agents. The paper is theoretical in nature and aims to describe a modeling approach about culture in the contest of artificial agents extending our previous work[7]. It does not aim to formalize the notion or to test its practical application.

The paper is structured as follows. Section 2 reviews the definition of culture in anthropological studies, and Section 3 introduces the notions of *culture* and *trait* that we use in the paper. Section 4 discusses the different kinds of trait that are found in a culture, and section 5 how they are organized to form a trait-based culture module, which we propose as a suitable codification of culture for the robotic domain. Section 6 shows how the traits guide the interpretation of a situation marking the distinction between situation and scenario. This approach captures also the tendency among agents with the same culture to provide compatible interpretations of a given situation. In Section 7 we discuss three scenarios in the context of a retiring home to highlight how the culture module could help a robot to behave as expected. We also observe that the culture module may have important consequences even at the computational level. Section 8 compares our results with the recent literature on the use of culture in AI, robotics and related fields. Finally, Section 9 makes a few final considerations.

2 CULTURE

The concept of culture has been the subject of a fierce long-standing debate within the field of anthropology. When Kroebner and Kluckhohn[8] in 1951 listed 164 definitions of culture and the related term civilization, their goal was to establish a stronghold around the very topic, culture, that was the object of study of cultural anthropology, at the time under siege from psychology and social sciences. In particular, the authors aimed to vindicate the explanatory power of the concept, not reducible to the psychology of the individuals or to the social phenomena. Tylor[9], 80 years before, had introduced the concept in a very broad sense as “the complex whole which includes knowledge, belief, art, morals law, custom and any other capabilities and habits acquired by man as member of society.” Since then, with the work of the pioneers and founders of the field, the notion of culture has diverged. In their review, Kroebner and Kluckhohn did not provide an unifying definition but individuated a core for the concept: “Culture consists of patterns, explicit and implicit, of and for behavior acquired and transmitted by symbols [...]” (Kroebner and Kluckhohn cited in Kuper[10]).

Both the definition of Tylor and the observation of Kroebner and Kluckhohn show a deep contrast that the notion of culture struggles to resolve: culture is a whole but it has also multiple components. Once these components are described, and their characteristics, called traits, defined at least operationally, the resulting description of a culture seems to lose its unity and coherence. Although a description in terms of traits can be rather practical, it falls short in providing an account of the meaning, sense and feelings that people experience because of their culture. In fact, one of the main issues of the concept is its explanatory power or, following the critics, its lack of explanatory power. Does culture, whatever it is, really help to predict, or at least describe some behavior of agents or societies? The relevance of culture on some psychology phenomena[11] and behavior has always been controversial but there was a time when not only culture lost its explanatory power but criticism against it grew even more radical.

The notion of culture was harshly criticized in the 90s of the last century. The deconstructionism approach took its toll and culture was seen as a relative ethnocentric construct[12]. Where the western anthropologist saw a culture, there were just families and individuals pursuing their goals or simply living their life. Repeated observations led to very different accounts and the notion of culture, always slippery as a persistent explanatory description, seemed useless and even misleading. In an influential book Marcus and Fischer[13] proposed to refocus anthropology towards cultural critique, and the critique of the western culture led the discipline to militancy[14]. Globalization contributed by changing the overall frame of analysis[15] producing a stratification of heterogeneous cultural elements in the same society. Ironically, on the one hand the notion of culture was increasingly used by a broader public to promote, cope with, or contrast multiculturalism; on the other hand anthropologists risked to lose their object of study. An agent in a globalized society lives flowing between different cultures that get mixed and interact making harder and harder any attempt to isolate a single monolithic culture, assuming it exists.

Over the years, the number of definitions of culture has continued to grown and, unsurprisingly, their conceptual content to diverge. In 2012 Jaboda[16] critically reviewed some of the at-the-time recent proposals and placed them on an external-internal axis, a dimension that well signals the inherent complexity of establishing a notion of culture. The contrast between the wholeness of culture and its components combines also with the tension between society and the individual. Very recently Palecek[17] analysed literature on cultural evolution, arguing that the notion of culture can actually have an explanatory role suggesting a possible rebirth of the concept as a scientific well-founded construct.

The debate about culture should not rise the concern that the notion is too confused to be used in any practical sense. On the contrary, it shows the need to capture and represent, at least partially, the cultural component of human experience, for which there's evidence of deep psychological relevance[11]. Also Jaboda in 2012 concluded that culture is probably indispensable but its definition very hard, and, he adds, "if either for a theoretical or empirical reason clarification is essential, then the author should explain the specif manner in which she employs the term culture in that particular context"[16]. We think that the use of the concept of culture in robotics, where, as we will see below, a practical level based on traits should be combined with an abstract level based on interpretation, satisfies the premises of Jaboda's observation. The next section is devoted to clarify this intent.

3 A NOTION OF CULTURE FOR ROBOTICS

In robotics the term 'culture' has been introduced to discriminate a class of artificial agents that is capable of adapting their behavior to humans based on the cultural group to which they belong[18]. In this context, an explicit notion of culture is not yet given and the focus is on the person's cultural identity so it is understood that the modelling of culture is a particular case of personalization. Here our aim is to introduce a notion that is both well-founded in the anthropology literature and simple enough to be used in practice.

Culture is defined in terms of knowledge which is acquired and transmitted. In the definition by Peoples and Bailey: "Culture is the socially transmitted knowledge and behavior shared by some group of people" (Peoples and Bailey[19, p. 23], cited by Brumann[20]). Other authors, like Sperber[21], focus on (human) culture as mental representations widely shared within a group, where 'shared' means that people in the group have similar mental representations. Transmission is "[...] a process that may be intentional or unintentional, cooperative or non-cooperative, and which brings about a similarity of content between a mental representation in one individual and its causal descendant in another individual."[21]

Imitation and communication are two main means of cultural transmission. Sperber sees communication as a transformation process where the initial information can be lost (totally or in part), duplicated or even enriched. Similarly for imitation. From Sperber's point of view, "[...] only those representations which are repeatedly communicated and minimally transformed in the process will end up belonging to the culture"[21, p. 83], which leads to study and model cultural phenomena as the epidemiology of specific mental representations. Obviously communication as such represents just a minimal account of the complex phenomena of cultural transmission, another recent proposal[22] adopts imitation and teaching instead.

The central role of sharing and transmission is recognised by many authors but there is less agreement on what exactly is shared and transmitted in culture. We take the following examples from Brumann[20]:

- "Culture [...] refers [...] to learned, accumulated experience. A culture [...] refers to those socially transmitted patterns for behavior characteristic of a particular social group"[23, p.68].
- "The culture of any society consists of the sum total of ideas, conditioned emotional responses, and patterns of habitual behavior which the members of that society have acquired through instruction or imitation and which they share to a greater or less degree"[24].
- "A culture is the total socially acquired life-way or life-style of a group of people. It consists of the patterned, repetitive ways of thinking, feeling, and acting that are characteristic of the members of a particular society or segment of a society"[25].

These definitions concur that learning and sharing are necessary to talk of the culture of a group of agents, but the content of what is shared or learned varies. We follow Axelrod[26], see also Birukou et al.[27], in understanding the content of culture as a set of traits, which can refer to several things like behavior, knowledge facts, ideas, beliefs, norms, etc. Within this framework, given a community of agents we propose a (weak) notion of culture. The notion is clearly weak from the theoretical viewpoint but is a first step to address operative tasks:

> *Given a community of agents, the culture of the community is a selection and internally organized subset of the traits shared among those agents. The set of traits that defines the culture is such that each agent of the community has the majority of the traits in the set.*

A few observations are in need. First, we call this a notion and not a definition because it is not sufficiently qualified. For instance, nothing is said on the number and quality of traits for the notion to be acceptable. Generally speaking, traits should cover at least some typical expectations for that culture and should be interrelated to some extent. The notion does not enforce the idea of the existence of a *core culture* (traits shared by all the community members), nor that traits are somehow coherent. This should not be enforced in general though since in many cases there can be alternative behaviors and rules that are culturally acceptable. For instance, laughing and getting angry at a bad joke can be both traits characterizing a culture. Also, the general requirement that each agent has the majority of traits is not strict and should be changed depending on the sought homogeneity across the members. Finally, note that this notion of culture relies on a notion of community that has not been discussed.

This anthropology-driven approach has some drawbacks. Representing the content of culture in terms of traits and set of traits can be an useful analysis tool[28] of material culture, however it suffers of some limitations when applied to actual behavior. For example, Qiufen[29] argues that traits do not capture the phenomena that occur in cross-cultural communication and suggests to take the perspective of Relevance Theory[30], in particular traits alone cannot give a proper account of the different interpretations arising in cross-cultural interaction. However, we argue that adopting a purely relevance-based description could lead to lose the analytical advantages of a simple traits representation.

In order to equip the representation of culture with the primitive notions that are necessary for describing interaction phenomena we propose to integrate traits with interpretations. We assume that an agent who has cultural traits has also an interpretation process that attributes cultural meaning to what the agent perceives. In particular, and crucially, the agent relies on an interpretation process to explain the observed behavior of other agents. Note that the existence of such an interpretation process is a common construct in social psychology that has characterized it in terms of attribution[31]. Research on the way one attributes to others beliefs, attitudes or motivations for explaining their behavior, has identified specific cognitive and cultural biases[32] that have consequences also, e.g., in political views[33]. Our account of the culture of a set of agents that integrates cultural traits and interpretation permits to represent relevant aspects of cultural interaction such us misunderstandings or successful cross-cultural communication.

4 TRAITS, SITUATIONS AND SCENARIOS

We have proposed to understand culture primarily in terms of traits, that is, knowledge, rules and patterns of behaviors that an agent follows or tends to manifest fairly consistently in similar circumstances. Following the definition in the previous section, an individual *has* or does not have a trait. This means that we look only at the essence of the trait, not the quality of its expression. A cultural agent may have the dancing trait for its culture even though it is a terrible dancer, an Italian may have an imprecise knowledge of how to make pizza, a Korean of the kimchi's ingredients, and a lawyer may be imprecise about a technical procedure while anyway having the corresponding trait. Also, traits do not enforce their manifestation: having a behavior trait means to have the disposition to behave according to that pattern or, in other words, to have the tendency to execute the pattern in a certain situation. After all a member of the tango culture does not need to dance every time he/she is in a milonga. It follows that behavior traits are patterns that an agent has and this implies the tendency to manifest them, not the necessity. The manifestation of a behavior trait in a specific case depends on many factors like the state of the agent and the social meaning that manifesting that trait may imply in that circumstance. Finally, we exclude from the traits the physical and biological ordinary needs like having hands and breathing. The way one walks and the way one eats soup can be cultural traits but eating and using the eyes for watching are not.

To cover the goals of our work, we first need to clarify what we mean with the terms 'situation' and 'scenario' and then to extend the types of trait listed earlier to include interpretation traits, that is, patterns for *situation interpretation* as anticipated in the previous section. From now on we use the term *environment* to mean a spatio-temporal region with all the entities in it. This notion of environment is very general, it recalls the characterization one finds in dictionaries (e.g. "the surroundings or conditions in which a person, animal, or plant lives or operates") and is independent from the observer. It should be kept apart from the use of the term in specific domains like ecology and engineering. Informally, we are interested in the spatio-temporal region and the elements in it that can potentially interact with the agent(s) at stake. We use the term *situation* to mean an environment, as just described, where we include only the entities that are potentially perceivable (and conceivable) by a type of agent of interest. In short, a situation is the best approximation of the environment that that type of agent can have. The situation captures the ideal case since the actual agent's knowledge of an environment is limited by its position (perspectival knowledge), interests (focus) and resources (sensors and computational capabilities) not including cases of detection failures or data misinterpretation. Crucially, a situation depends on the agent's type but not on the agent's culture. Finally, we use the term *scenario* to identify an interpreted situation, that is, a situation in which the different entities (or at least some of them) have a role assigned. Since the scenario includes role assignments, it is a cultural notion. It follows that an agent can behave according to a culture only if it can associate a scenario type to the situation in which it is. This means that agents that share the same culture share also some interpretation patterns with which they make sense of (usual) situations. These interpretation patterns are traits in the culture and they apply to real and to hypothetical situations alike. The underlying assumption here is that, without a shared understanding of situations, a group cannot develop the network of expectations, communications and coordination that is necessary for culture to develop and persist.

We have introduced the most general trait types of a culture: behavior, knowledge, rule and interpretation traits. While these are better described in the next section, here we clarify the distinction between interpretation traits and rule traits. These are clearly different when we look at their purpose. Rule traits are kind of regulations, they are used to provide general constraints that describe expected behaviors as well as restrictions and guidelines accepted in the culture:

what the agent is supposed to do and what the agent can expect other agents to do given a certain scenario and goals. The purpose of interpretation traits is even more fundamental: they determine when a rule is applicable and when it is not. Practically speaking, interpretation traits connect the (actual or imagined) situation to a scenario, that is, they are used to decide how the situation should be understood. For example, when entering a room, the presence of a group of individuals near a table could be interpreted as a queue for an office service. This interpretation of the situation happens under several cultural conditions: the furniture has to be of a certain type, the room layout has to follow some criteria and, depending on the culture, it might also be required that the group of individuals forms a clear row. The queue rule trait that triggers the choice of a behavior admissible in the presence of an (office) queue, is made possible because of the specific interpretation trait that links the room layout to an office, and the group of people to a queue.

5 ORGANIZING TRAITS

In order to make the trait framework applicable from a knowledge representation viewpoint, which requires the possibility to introduce, store, update and manage traits in a systematic way, traits need to be organized in a knowledge base. The organization of the traits can vary and a collection of guidelines and best practices would help the roboticists to develop stable and shareable knowledge modules. For instance, behavior traits are manifested via physical movements or actions which can be organized according to physical properties. They acquire cultural relevance when they have intentional or social meaning. By organizing them from the physical viewpoint, one looks at their physical layout: the behavior can be about an acquisition of data (e.g., watching something), a movement (e.g. walking, bending), a change of the surrounding distribution of objects (e.g., moving a chair), a physical manipulation (e.g., tearing a piece of paper), a physical interaction (e.g., holding each other hands), a production of some form of energy (e.g., emitting sound) etc. Some behaviors are obtained by combination like holding and moving hands in a coordinate way as when shaking hands.

This physical classification of behaviors is distinct from the one arising when we take into account the context in which the mere physical movement happens and, in our view, it should be part of the basic knowledge of the robot. When a behavior is interpreted, like bending to bow or mutually holding and moving hands to handshake, it acquires a cultural meaning and it should be organized in the trait-based culture module, culture module for short. Note that the meaning of physical behaviors can be stratified depending on the context: a handshaking can be a greetings when the agents meet, a farewell if performed when they depart and a promise when marking an agreement. Cultural agents may decide to manifest or hide a physical behavior which is culturally associated with a situation to imply or prevent its cultural reading. For example, an Italian person can voluntary inhibits her own gestures language, or a Polish migrant in contemporary Great Britain decides to speak, or not to speak, Polish in public[34]. To use the physical behavior traits according to their social meaning, the culture module should include a classification of what are usually mentioned as social contexts, e.g., based on institutions and networks as originally discussed already in the 1970s[35], and of the cultural reading(s) that a physical behavior acquires in those contexts.

Given the role of knowledge traits, their organization may follow the standard subdivision in topics and domains, as they are most often retrieved depending on the topic of the situation or application domain. Some knowledge is also used to generate analogies, like myths and stereotypes (e.g. the Prometheus myth and the Oedipus complex) or to record shared interpretations of facts, like the narrative about a war (which is notoriously culture dependent) or the context that motivates a special law. It is important to capture this form of meta-knowledge (e.g. via knowledge relationships across traits) and we will give some pointers to existing efforts in the discussion section. A type of knowledge traits that deserves particular attention since it has a special role in our modeling of culture is the scenario type. We will discuss this in the next section.

The need to introduce relationships across traits applies also to rule traits. Generally speaking, these are prescriptive patterns associated with scenarios and sometimes with principles. (Scenarios and principles are both knowledge traits.) The organization of rules can be scenario-based, possibly including preferences within the scenario, or principle-based when the rule is driven by a general principle and is independent from the scenarios, e.g., in some culture the rule 'never hurt a human being' is scenario independent.

Finally, the interpretation traits are a special type of rules (and guidelines) used to associate situations, or better parts of a situation, with a scenario type, that is, to interpret situations from a cultural viewpoint. Our earlier example of the queue at the office highlights this role of interpretation traits. The process that leads to associate a situation with a scenario is here called an *interpretation process*. The purpose of the interpretation process is to identify the best match between the known situation (that is, what the agent believes about the situation at stake) and the available scenarios, the latter being knowledge traits. The interpretation process and the relationship between scenario types and interpretation traits are discussed in the next section.

6 SITUATIONS AND SCENARIOS IN CULTURAL AGENTS

In the interaction between cultural agents the interpretation of the situation in which one is, plays a major role. Differences in situation interpretation provide a key factor for subtle distinctions like between intentional and non-intentional collaborations as well as misunderstanding. The interpretation process can be seen as a function and is quite complex; in this section we look at some of its features like its input and output. The understanding of this process sheds light on its genuine cultural nature as well as on the role of interpretation traits.

First, let us face some basic objections. One could argue that interpretation traits are not cultural, and thus do not belong to the trait-based culture module, for two opposite reasons:

1. interpretation traits are actually the result of an interpretation process that an agent has because of its nature, that is, they are not cultural since not learned;

2. interpretation traits are private and not shareable, thus not cultural.

These views are too extreme since each focuses on a restricted component of the interpretation process. One could think that the interpretation process is the same for every agent of a certain type as all these agents detect similar things in a situation (after all, they have similar sensors and capabilities). This is the point of the first claim. However, this means that misunderstandings between two agents can be only the result of errors in processing stimuli from the environment. This is not the case: two agents may have different interpretations of a situation like, when seeing a person running and a dog after her, one agent can think that the person is running away from the dog and another that the dog is simply following her owner which is doing sprint workouts. It is true that agents of a certain type recognize similar things in a situation (e.g. objects, colors, shapes, positions etc.) and that this is not based on culture, but the interpretation process must also indicate whether these objects have specific roles and purposes, this latter information is not determined by the agent's type.

Should we conclude that interpretation traits are private? If it were so, it would be impossible to explain how complex cultures arise as every non-trivial situation could be understood differently by different agents. An interpretation process must model the tendency of agents with the same culture to develop similar interpretations of (what they perceive of) a given situation. Taking the interpretation process to be a general pattern matching system, different interpretations within the same culture are possible (depending on how one combines interpretation traits and the subtleties of scenarios available in that culture) but are rare compared to the case of agents that belong to different cultures since these may have different scenario traits at their disposal.

As said, the interpretation process is what assigns meaning to the perceived situation. We have seen that the process itself is likely complex comprising components that are universal within an agent type (e.g. all human agents attributes a positive value to the perceived warmth and competence of others[36]), components that are cultural, and even components that are personal (e.g. an agent attributes personal meaning to melodies). Our modeling view makes possible to identify, represent and control the parts of the interpretation process that depend on culture (e.g. the ability to recognize that a hand shaking movement is a handshake, namely a behavior trait of a culture). This is the role of the interpretation traits and the scenario traits, both shared in a culture, since they are the guidelines and the candidates for the process and, as such, realize the tendency of two cultural agents to select the same meaning for the same situation. The interpretation process can be thought of as a function from what is known (or believed) of a situation to the scenario traits. The scenario trait that gets associated with a situation provides the cultural meaning of that situation. Theoretically (due to the variety of scenario traits) and practically (for computational reasons), we should not assume that traits that are not classified as scenario traits, can be candidates to provide cultural meaning to situations.

Ideally, the culture-dependent interpretation function, that we call $\mathcal{I}_{\mathcal{C}}$, outputs a single scenario and can be presented as follows:

$$\begin{array}{rccc} \mathcal{I}_{\mathcal{C}}: & \mathcal{P} \times \mathcal{M} \times \mathcal{C} \times \mathcal{A} & \rightarrow & \mathcal{S} \\ & (p, \ m, \ c, \ a) & \mapsto & c' \end{array} \tag{1}$$

where $\mathcal{P}$ (perception), $\mathcal{M}$ (memory), $\mathcal{C}$ (culture), and $\mathcal{A}$ (agent) are distinct input spaces while $\mathcal{S}$ is the set of scenarios in the agent's culture module.

More precisely, $\mathcal{P}$ is the input relative to the situation. Since the agent has only a perspectival view of the situation, $\mathcal{P}$ is the space of the agent's perception of the situation. It comprises the knowledge or belief of the agent relatively to the following aspects of the considered situation:

($\mathcal{P}$.1) Region of space;

($\mathcal{P}$.2) Time information;

($\mathcal{P}$.3) Objects present in the situation (including their location and qualities like color, size, shape etc.);

($\mathcal{P}$.4) Relationships of, and across objects and locations e.g. of mereological, geometrical, qualitative and quantitative nature.

Note that $\mathcal{P}$ provides information about the situation based on the agent's type. For instance it says what are the objects that this kind of agents detects according to its perception characteristics, and perhaps the related affordance. It does not provide any cultural meaning, for instance, here what we usually call a traffic light is seen as an object that has lights of different colors which go on and off following a fixed pattern.

The space $\mathcal{M}$ provides the information about the recent situations, scenarios and their evolution. These are the situations, scenarios and changes that are still considered active or relevant by the agent:

($\mathcal{M}$.1) Recent situations, associated scenarios and their evolution. (This information can be partial depending on the agent capabilities.)

($\mathcal{M}$.2) Situation that recently have been considered relevant or were related to the actual according to the agent.

Obviously, the culture of the agent is itself a key factor for the interpretation function. The information provided by the space $\mathcal{C}$ is quite articulated:

($\mathcal{C}$.1) Active scenarios (the scenario to which the agent previously committed as the actual one);

($\mathcal{C}$.2) Expected scenarios' evolution (this can be the result of an estimation based on knowledge about the physical world and culture; it takes into account behaviors and rules relevant to the active scenario, e.g., if one is given a waiting number at the restaurant, she expects that at some point the number will be called);

($\mathcal{C}$.3) Interpretation traits (e.g. the link that, taken a spatio-temporal region with a red light on the side of a long stripe of asphalt, labels 'road' the stripe of asphalt and 'stop traffic sign' the red light);

($\mathcal{C}$.4) Cultural but scenario-independent rules like myths and taboo that trigger a reaction even before selecting a scenario (e.g. strike back when hit, or turn around when suddenly seeing someone naked).

Finally, the state of the agent has also an impact on the interpretation of the actual situation:

($\mathcal{A}$.1) Agent's type (e.g. being optimistic or pessimistic influence how the situation is interpreted) and actual state (e.g. emotional state).

Although a full characterization of function $\mathcal{I}_{\mathcal{C}}$ is complex and is part of the cultural model itself, one core requirement is that $\mathcal{I}_{\mathcal{C}}$ tends to preserve role attribution in the input scenario provided by ($\mathcal{C}$.1) as long as there is a sufficiently compatible interpretation of the ongoing situation.

Agents can interact reducing the possibility of misunderstanding when using the same interpretation traits which fosters an alignment of the situation interpretation. However, this does not rule out other possible misunderstandings. One can image cases where the mismatch is due to different knowledge traits, behavior traits, rules traits, or any combination of these. Also, the structural organization of the traits can be a factor leading to misunderstanding since different traits may be associated (directly or indirectly) with the same scenario.

At this point we can introduce the distinction between cultural agents and the culture-aware agents. We call *cultural agent* an agent that is equipped with a culture module, that is, a module (largely shared by a community) that organizes the different kinds of traits and is capable of performing the interpretation process described above. A cultural agent that has several culture modules is called an *inter-cultural* agent. Finally, a *culture-aware agent* is a cultural agent that can learn new culture modules by duplicating and modifying the module(s) it already has via observing and interacting with other agents. The development of new culture modules requires specific functionalities paired with suitable observation capacities and learning techniques. It is interesting to note that it is exactly the cultural nature of the interpretation traits (the fact that they can be learned) that permits them to be shared across cultures from which the possible existence of culture-aware agents.

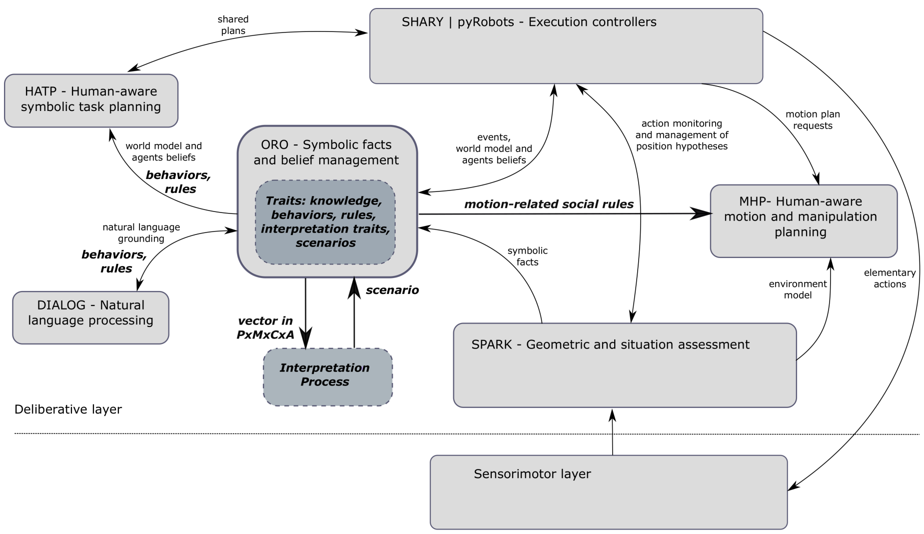

Figure 1: Overview of an implemented architecture[37] enriched with the culture module: the "Trait" submodule extends the ORO (OpenRobots Ontology) module and the "Interpretation process" submodule is added as a new functionality. Changes in the information flows are shown in italics. The trait module corresponds to one culture, the interpretation process is the same across cultures. Different cultures may also share parts of their trait module.

As a proof of concept we show in Figure 1 how the culture module could be inserted into a robot architecture. The reference robot architecture we extend is due to Leimagnan and colleagues [37] which is here reproduced with solid lines and text in normal font. We omit the internal details of the modules that the reader can fully appreciate in the original publication where the authors also report about several cases in which the architecture was implemented and evaluated. The architecture is organized into a sensorimotor layer devoted to perception and actuation and a deliberative layer articulated in several modules: SPARK, SHARY—PYROBOTS, MHP, HATP, DIALOGS, and ORO. SPARK is in charge of the sensory fusion process using input from the underlying layer and producing symbolic facts and environment models. It also interacts with the execution controllers in SHARY—PYROBOTS. MHP and HATP are both human-aware planning modules: one is devoted to motion and manipulation and the other to planning at the symbolic level. DIALOGS is a natural language process component and finally ORO contains symbolic knowledge in terms of ontologies and manages symbolic facts and beliefs. The overall flow of information and computation over the original architectures permits to encompass different levels of complexity of behavior from fine sensory-motor control to the adoption of shared plans with humans[37].

In Figure 1 the culture module is depicted with a dashed boundary and its outputs are in italics. They fit in the original architecture by Leimagnan and colleagues allowing for the robot to interact in a culture-dependent way. The culture module is composed of a trait module (comprising knowledge, behaviors, rules, scenarios and interpretation traits) and an interpretation process module. The traits fit nicely in the knowledge-representation ORO module whereas the interpretation process needs a separate new module. However, the change in the architecture has a limited impact on the flow of information. In fact the information that the interpretation process needs (perception, memory, culture, agent) is already available in the ORO module in terms of symbolic facts, agent beliefs and knowledge. The output of the interpretation process, namely the scenario, is then sent back and stored among the beliefs in the ORO module. In this way, the interpretation module interacts with the ORO module only. Once the scenario has been stored as a belief its content can be made available to the other modules. In particular, along the flow lines already present in the original architecture, the scenario information can be helpful to the modules HATP and DIALOG in terms of behaviors and rules. Moreover, motion-related social rules present in the scenario can be made available to the MHP module along a flow line that was not present in the original architecture. Clearly, several different cultural modules can fit in the ORO module and the inference mechanism inside the module can decide which one to activate. The implementation of the original architecture reports that ORO is a central server and we take advantage of this circumstance. In fact, a natural way of implementing the interpretation process is by means of a neural network model that learns how to map situations (and related information) to scenarios. The model could be trained offline and deployed in the interpretation process module of the robot itself.

The advantages of the presence of a culture module into a robot architecture are both functional and computational. From the functional point of view, as we all see in the example, the presence of such module permits the robot to distinguish and react differently depending on the culture. From the computational point of view the information of the scenario, in terms of behavior and rules, can be used by other modules to cut the search space or the decision space.

7 THE ROLE OF THE CULTURE MODULE: THREE SCENARIOS

In this section we show how the trait culture module helps a robot to recognize a scenario and to behave as expected from a cultural viewpoint. We consider the case of a retiring home, that is, a multi-residence housing facility intended for the elderly. In studies about the application of robots for the elderly, robots are often exploited to verbally interact with people and to identify unusual situations. Activities include greeting retirees and their guests, engage retirees in conversation and check if something unusual happens, e.g., if a retiree is not seen for a period of time during the day. To make clear the impact of culture in the discussed cases, we assume that the facility hosts several people from different countries, each with his/her expectations and attitude related to their culture.

Let us consider an inter-cultural humanoid robot, that we call ICHA (the acronym of Inter-Cultural Humanoid Agent) employed in the facility. There are three cases we want to describe focusing on ICHA's decisions and behavior: greeting someone for the first time in the morning; opening a door when someone inside is not answering; and encountering someone on the wrong lane in the hallway. The first case is a standard scenario in robot studies. The other two are based on a recent report by Li and colleagues[38] which classifies the preferences in robots' normative behavior expressed in a survey by participants from U.S.A. and China.

The first case is about ICHA meeting John, and later Mun-Hee, for the first time in the morning. ICHA knows John and Mun-Hee from previous experiences. Also ICHA, having access to the facility database, knows that John has the western culture and Mun-Hee the asian culture.[1]

As John approaches, ICHA's sensorimotor layer feeds the SPARK layer which, in turn, sends a situation description (detected facts in symbolic terms) to the ORO layer providing the following high-level information: location, detected object with geometric and dynamic properties (e.g. moving closer). The ORO layer matches the object's data with `John` and activates the culture module correspoinding to his culture. This data augmented with the recent history about

[1] We have not discussed how to divide cultures or identify subcultures. Because of this the terms "western" and "asian" should be seen as placeholders correspoinding to an intended simplification.

interactions with John, is sent to the interpretation process which returns the 'first meeting of the day' scenario. At this point, ORO sends to the HATP task planner the scenario with the specific goal (greeting) including the western rules and behavior for the scenario, e.g. greetings by speaking, greetings by speaking and hand waiving, greetings by speaking and hand shaking. The chosen option is then matched in ORO with a description of the expected scenario evolution. ORO also sends to the MHP layer the rules for geometric behavior (expected speed of movement, relative hand positioning, proxemics guidelines[39, 40, 3] and so on) including expectations about how the person should behave in the interaction. Similarly, ICHA's behavior complies with Mun-Hee expectations when they meet later as the flow of data from SPARK to ORO is described as before but, since this time Mun-Hee is identified as having asian culture, ORO correctly selects the appropriate set of rules and behavior (bowing, stopping at the expected distance, avoiding physical contact, perhaps making a small chat) and pass the scenario with these rules to the task and geometric planners. It is important to note that ICHA, having cultural knowledge about the expected scenario evolution, can verify whether the person, John or Mun-Hee, reacts to the greetings in one of the culturally acceptable variants. In the case of unusual behavior, ICHA can send an alert to the facility system triggering other services (e.g., a request that a caregiver visits the person).

For sake of comparison let us discuss the simple scenario presented above considering a culture-oblivious agent instead of a inter-cultural agent. The culture-oblivious agent could be based on the same architecture of Lemaignan and colleagues[37], namely that of Fig.1 without the trait submodule, the interpretation process and the information flow described in italics. In this agent, the ORO module passes to the HATP planner generic rules about the greeting goal and would need *ad hoc* information to adapt its behavior to the two agents. Further *ad hoc* information is needed if we want this agent to report whether the person behaves as expected depending on his/her culture. (This observation is general, for instance it applies also to the knowledge-based architecture used by Borgo and colleagues[41].) Without cultural information, an agent cannot discriminate when extra services are required. Given the need for this kind of information as shown by the case study, we argue that it is better to store it in culture modules where it can be reused in strict connection with scenario identification, and it can be exploited in task and geometric planning as we described.

Note that the possibility that some action might be physically possible but socially or culturally unacceptable may determine the quality of the service and even the well-being of the retirees in the facility. Let us consider the case in which ICHA has to decide what to do "when an emergency (pipe burst/fire) arises while you are in the bathroom"[38]. The study by Li and colleagues shows that among the two provided options, namely 'to barge in to save the person' vs 'to knock on the door before entering' (a choice between safety and privacy), people in the U.S.A. tend to opt for the first choice while people in China for the second. In the description of the meeting case we saw that the enriched flow of information, due to the culture module, provides a more suitable set of rules for the given case. This also indicates the robot what action is most acceptable by the interested person. This is particularly useful in the emergence scenario, provided the culture of the person in the room is known, since the culture module avoids the risk to choose the culturally unacceptable action, action that might trigger an extremely negative reaction by the person to help. Since in this case the culture module acts by limiting the search space, the consequence is that the culture module, while increasing the information dealt with in the knowledge base (the ORO module), it reduces the search space and the computational effort at the planner level. Furthermore, since the inter-cultural agent knows if the chosen actions comply with the culture, it can take this factor into account when choosing an action not fitting the traits, for instance by stating publicly its intention (and motivations) in order to make the other person(s) in the interaction aware of its plan of action before performing it. Finally, when detecting an unusual behavior by the retiree, e.g., the person is laying on the floor or is unresponsive, the mismatch between the detected situation and the activated scenario allows the interpretation process to change scenario. This is different, for instance, than the case in which the opening of the door fails due to the door to be locked. A failure in the plan and a mismatch in the scenario must lead to different types of reactions from ICHA.

The final case we describe is about how to react to slightly unusual human behavior. The scenario here is that of ICHA moving down the hallway on its right side as instructed and meeting an (elderly/disabled) person walking towards it on the same side. Li and colleagues[38] claim that western and asian people disagree on which action the robot should take among these options: (1) Stay to the right-hand side of the hallway to obey social rules; (2) Move out of the way to the left-hand side of the hallway to maintain the safety of the human; and (3) Move out of the way to the left-hand side of the hallway to accommodate the human's behavior. Here we do not discuss the scenario in terms of the flow of information, which is similar to the previous cases. The interesting aspect here is that these studies can give further indication about how the robot should behave in other cases. As Li and colleagues point out, the study of this scenario tells us that "although safety is the major concern in this scenario, Chinese participants would prefer the robot to obey social rules, while [U.S.A.] participants would prefer the robot to accommodate the person even if the person is violating a social norm". We can take this cultural rule (assumed it is confirmed in further studies), as a general cultural rule to help ICHA deciding how to act even in situations that are unexpected or in scenarios that are only partially characterized in the knowledge base.

8 RELATED WORK AND DISCUSSION

The concept of (human) culture has been used for more than a century in anthropology and, more recently, has become central in organizational science spreading also across related fields. The modeling of culture via traits reminds in part the cultural schema theory[42] and has been addressed in AI by, e.g., Birukou et al.[27] who formally defined culture as a set of traits shared by a group of agents and satisfying certain properties. A basic distinction between knowledge and behavior traits was adopted elsewhere[27] but a characterization of trait and of trait organization was not attempted. In this paper we built over these approaches by distinguishing new kinds of traits, in particular rules and interpretation traits, and by proposing a general trait framework. Effective use of traits to model social phenomena can be found in the study of cultural transmission from an economic point of view[43, 44].

In the previous sections we have proposed to equip an artificial agent with a trait-based representation of culture to be organized into a culture module and we have argued how this solution can contribute to an architectural solution for robots that interact with users of different cultures. The traits included in the culture module comprise knowledge traits (which include the scenario traits), behavioral traits, rules traits and interpretation traits. In order to delineate how such a module can be built in practice one should specify the way the information is represented and the way the culture module can be populated. It is beyond the scope of this paper to present a complete and working solution, however we can delineate and discuss the general way this can be achieved.

Some of the traits, namely knowledge, behavior and rules, are rather standard concepts to be represented and so state-of-the-art representation techniques can be used. For example, the knowledge traits could be classified using Dewey Decimal Classification and the automatic tools that have more recently appeared[45] for short texts. Alternative methods to acquire and maintain meta-knowledge and meta-data are also available in particular in the context of knowledge fusion[46]. The behaviors can be represented with one of the work aimed to build ontologies of actions like IMAGACT[47]. Finally, rules have an important role in so-called rule-based systems, which are well studied in the literature, see, for example, a recent proposal for reasoning in a personalization context[48].

Since long ago knowledge bases, representing also behaviours and rules, have been included in robot architectures[49]. However, they have been mostly used to represent the world in a robot-centric way: rules are instrumental to the robot physical actions, the knowledge is limited to what it needs for its tasks, the behaviors to what it can perform, and the rules to what it has to apply. In some cases the robot incorporates a user model, however this tends to be focused on modeling an individual user in order to achieve a requirement of personalized interaction. Although surveys on user modeling in robotics may still fail to mention the cultural aspects among the research gaps[50], the relevance of these is vindicated by recent advancements[18].

The acquisition of the information about knowledge, behaviour and rules can also be achieved in standard ways, considering that this can be acquired offline and deployed to the robot. The recent shift towards data-driven machine learning computation, caused by the success of Deep Learning, makes the choice to lean towards automated techniques of information extraction from heterogeneous data. In fact, if not already available, ontologies of relevant knowledge, behavior and rules can be extracted by text and videos or more directly from language-oriented rescuers such as VerbNet[51]. Moreover, the single robot could also access the information organized in a shared structure available online[52].

A specific attention must be devoted to the acquisition of interpretation and scenario traits. In Sect. 4 we assumed the existence of interpretation traits needed to associate scenario traits with what is perceived by the agent. This view leads to understand an interpretation trait as an ability, thus a kind of trait. This view of traits has some similarity with a proposal in knowledge representation to see concepts as the ability to recognize certain instances[53] (moving away from the extensional view of concepts as classes of objects). The interpreted situation, namely the scenario, can be represented by recruiting the long-standing concept of frame with resources like Framenet[54].

The interpretation function that realizes the interpretation process could quite naturally be implemented by means of a classifier with structured output based on machine learning techniques. For example, the data could be obtained by combining gamification and crowdsourcing approaches[55], and the model learned with techniques based on deep learning for structured outputs[56]. Like in case of the other traits the interpretation function can be learned offline and deployed to the robots on demand.

The definition of culture that we gave in Section 3 states that a trait is considered to be part of a culture if the number of agents that have that trait exceeds a threshold that we set, in a rather arbitrary way, to the majority of the agents of the group. Here we discuss the arbitrarity of that choice and what it means for an agent to *have* a trait. Both issues are better understood if we consider them in the perspective of cultural evolutionary models (see Lehmann et al.[57] for an example), whose research paradigm aims to study the distribution of cultural traits using statistical methods also used in phylogenetics or epidemiology. In that perspective the number of agents having a trait varies as a consequence of complex dynamics of transmission and acceptance, moreover the models can distinguish between carrying a trait and expressing a trait, distinction that is overlooked when one, as we did on purpose in Section 3, mentions just a far more generic *having* a trait. Our definition obeys to the need of giving a simple, operative and practical characterization of the concept of culture. However, more complex choices are possible and there is an accumulating literature[58] that provides alternative characterizations.

Finally it is worth to note that a cultural model can be useful, not only for guiding the robot actions with the interpretation of the situations, but also to realize other important requirements, like performing explainable actions or being emotionally-aware. In Section 3 we have motivated some of our choices referring to attribution theory, interestingly Tim Miller cites the very same theory as a research result relevant for explainable artificial intelligence[59]. The interpretation process that we propose in Section 6 is based on the same phenomenon that social psychology identifies in people. Morever, the role of culture in emotions has been recently reasserted[60]. Although the statement here is purely speculative, it is intriguing to argue that a robot that incorporates a culture module could effectively use scenario information for providing satisfactory explanations of its own behavior and improving its emotional competence.

9 CONCLUSIONS

Culture is a notion hard to characterize and we need practical ways to model it if we want to develop agents that are aware of our way of thinking and behaving. By accepting the idea of traits, we can make the notion of culture suitable for formalization via a structured system of traits, that we called trait-based culture module. It is important to recognize that culture is not just a set of traits, let them be rules, knowledge, expected and accepted behaviors, and scenarios. Culture is also a precise organization of these traits and of their interrelationships.

Based on our experience in ontological modeling, we proposed to organize the culture module according to general principles (highlighting what the trait represents and how it should be used) and described the role it can play in the knowledge flow internal to an (autonomous) agent. The envisioned structure helps to smooth some bottlenecks in the traditional knowledge-base view of artificial agents.

Although the discussion has stopped at the theoretical level and much more work is needed to develop a culture module in some formal language suitable for simulations, it should be clear that the introduction of structure and rules dedicated to model the cultural level does not increase the complexity level of a knowledge-based agent as we know them. On the contrary, the new information could even help to reduce the computational limitations found in more traditional architectures. Moreover, representation of culture information can establish a workable solution to the culture-dependency of expected human-robot interactions that is emerging in empirical studies.

We traced a distinction between cultural, inter-cultural and culture-aware agents discussing the presence of one or more culture modules that, in our proposal, include also an interpretation process whose function is to determine the current scenario. We argued that a robot architecture equipped with traits and interpretation process can provide functional and computational advantages. In particular, we explored a possible architecture and information flow of an agent, called Inter-Cultural Humanoid Robot, that we imagined operating in three realistic scenarios of culture-dependent interaction in the realm of robotics for the elderly.

Further research is needed in order to empirically validate the approach. In the future, we aim to provide guidelines on how to conceive and build culture modules for culturally-competent agents, and to verify in practice how these modules can be embedded in the traditional knowledge-based agents for interpretation and reasoning purposes.

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