Modelling Culture with Complex, Multi-dimensional, Multi-agent Systems

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Abstract. Culture plays a significant role in human civilizations as a key determinant of relationships and organization formation, however, its role, key properties, and mechanisms are not yet fully understood. This work explores culture and cultural modelling from a complex systems, multi-dimensional, and multi-agency standpoint. The need for performing such modelling and simulation is evident since in-vivo organizational experiments are costly, not easily generalizable, and require lengthy analyses that may not be feasable in critical situations. Exploring the role and influence of culture on organizations is the aim of this chapter, whereby definitions, dimensions, and experiments have been introduced in order to show the evolution and emergence of culture as a complex, distributed, social system from a computer science perspective. This work contributes to culture studies by a) adding to the literature of culture as a complex system, b) presenting a new seven-dimensional model to describe and encapsulate culture, and c) simulating cultural interactions as a multi-agent system of high functioning agents that achieve an equilibrium of beliefs.

1 Introduction: Modelling Organizational Cultures

"No single definition of a social science construct is likely to do justice to its complexity." — Hofsteder, 2001

This work focuses on describing culture in a standard way that can be used to capture any cultural domain, and makes use of this description in an exploration of the emergence and evolution of culture in organizations. This is a first step towards future studies about the interplay and eventual integration of two or more different cultures in a shared system environment. The primary theme throughout this work is that in order to understand, discuss, and measure culture it must be recognized as a complex, multi-dimensional, and multi-agent system. These three aspects are the proposed foundation for experiments in culture starting from the level of the individual unit of an organization, and how these parts of a cultural system affect the whole system.

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Culture plays a key role in organizations, as a determinant of relationships among individual units of the organization and as a macro-level driver of its behaviour, and should be considered as one of the main points of analysis when modelling organizations (see [1], (ch. 8), for more on culture as it relates to organizations). Cultural modelling allows for incorporating knowledge about the effect and influence of culture on an organization, and predicting how the type of culture at work affects the ability of the organization to function, achieve its goals, and to ultimately survive. In order to adequately model and simulate organizational cultures there are four key components explored in this work. First, a fitting and tangible definition of culture is required. Second, a study of the key components and dimensions of culture is necessary. Third, these key dimensions must be investigated to understand the level of complexity of their interactions. Fourth, a method of simulating the organization with the defined cultural parameters is needed. These all provide the methodology, tools, and techniques for setting up and conducting experiments involving culture in organizations.

Contributions of this chapter are three-fold, namely that it a) adds to the literature of culture as a complex system, b) presents a new seven-dimensional model to describe and encapsulate culture, and c) models cultural interactions as a multi-agent system of high functioning agents that achieve a certain equilibrium in beliefs. These three details are elaborated further in the paper. Section 2 discusses individuals, organizations, cultures, and presents a working definition of culture. Section 3 describes the notions behind a complex system and makes the case for culture as such a system. Section 4 proposes a new model for culture using seven dimensions and provides the reasoning behind this approach. Section 5 describes how to measure culture with high-functioning agents. Section 6 explores both the emergence and evolution of culture and discusses the experimental results. Section 7 concludes the chapter.

2 Individual, Organization, and Culture

Human civilization consists of many layers that interact seamlessly in a distributed fashion, progressing towards different goals, with myriads of processes taking place in between, [2], (ch. 8). At the lowest levels are atoms and molecules, that organize as cellular units, which in turn form organs, in a long chain of emergence; from organs to systems, from systems to systems of organic systems, up to the level of sentient individual systems and beyond. These individually controlled units in a shared environment may be considered to be essentially an organization. An organization is a social arrangement which pursues collective goals, controls its own performance, and has a boundary separating it from its environment, [3], [4]. Although this definition of organization is an overarching definition inclusive of all other views on organizations, in this paper it is mostly used in its general meaning. Organizational modelling is a way to both describe and capture the many components of the organization as an entity consisting of various parts that also makes use of resources to achieve set goals. One key reason for such models is that they can be used to run simulations of the organization

under a host of varied conditions, allowing for large volumes of experiments to be conducted cheaply in a contained environment. To perform similar experiments in an in-vivo fashion would be considerably expensive. Furthermore, the results from organizational modelling and simulation studies allow for detailed analyses that can be useful in predicting organizational states and behaviours. This predictive capacity helps to translate simulation knowledge directly into real-world changes through policy-making and best-practices based on the model.

Organizations consist not just of varied parts and individuals, but also of the function and goals of these individuals as they perform activities over time. As cells in a multi-cellular organism operate and are distinct according to their functions, so is an organization distinguished according to its function, i.e., according to the behaviours of its individual members as governed by their beliefs, [5], (ch. 9). These behaviours *emerge* from seemingly random interactions at lower levels of order, chaos, and equilibrium, and may be described uniquely over time in a pattern governed by rules (both simple and complex) at each level. At higher levels the behaviour of individuals in an organization may be seen as a culture.

2.1 A Working Definition of Culture

Traditionally, culture is defined as a "set of shared attitudes, values, goals, and practices that [both] characterizes an institution, organization, or group", as well as emerges from and sets the behaviour of a group, [6]. It has also been considered by social scientists, [1], (ch. 1), to be the "collective programming of the mind." In this work culture is envisioned as an open system, [7]; that is, as an entity standing in a state of equilibrium within a specific environment. Additionally, a unique working definition of culture is proposed as *the holistic interaction among n agents, across seven distinct dimensions, that causes stabilization of beliefs within these interacting agents over time.* This definition targets interaction at the level of the individual, and leads to shared beliefs over time as new individuals are added to or removed from the environment. This type of definition allows us to consider both the community of individuals as a whole (e.g. a country or an institution), as well as distinct parts (e.g. a province or a department in an organization) with their distinctive characteristics. Thus one can eventually extend the domain of discourse from a mono-cultural context to a multi-cultural one (while at the same time shaping culture into a multi-agent systems modelling problem).

3 Culture as a Complex System

This section promotes the view of culture as a complex system, and makes the case that complex systems theory provides strong tools to capture and delineate culture. This is important because culture has been studied in many works and contexts over a wide range of literature domains, and may be considered as one of the "fuzzy" human-factors which are well known, but largely intangible. The view of culture as a system promotes a focus on the emergence of culture from

its tangible components, and how the relationships between these components openly affect the macro-level culture, as defined previously, and also how that macro-level culture in turn impacts and influences the behaviours of the micro-level components themselves. The complexity of the dimensions of interaction within culture and their impacts are difficult to capture in a systematic and testable fashion, but may be obtained if standard tools from complex systems research are used. These tools allow for the definition of fuzzy concepts in a concrete language, and for the study of these on multiple levels. For instance, a top-down picture of culture could be obtained through the use of system dynamics causal loop and stocks and flows diagrams to show how the parts of culture relate, while a bottom-up picture of the culture system may be obtained from using collective emergence of agent interactions in a multi-agent system. This work focuses on the bottom-up interactions of the cultural system and uses the agent-based modelling approach to elucidate the complexity of culture.

3.1 Complex Systems

There are many classes of complex systems, ranging from those composed of simple inorganic components interacting according to very precise rules, to those made up of macro-organisms that interact according to loose and imprecise rules of behaviour, [2], (ch. 0). In describing a complex system it may be defined according to "the amount of information needed in order to fully describe the system," [2], (ch. 8). This description of the system includes the discussion of the system states, as well as its interactions. The state of the system includes the combined macro-level state of the global system, as well as the micro-level state of the system components, as both are important. While there are many factors to describe a complex system, for this work the focus is on a) emergence, b) evolution, and c) equilibrium.

Emergence is the notion that "the whole is more than the sum of parts...that constitutive characteristics are not explainable from the characteristics of isolated parts...[but] appear as 'new' or 'emergent'," [7], (ch. 3). Hence culture, once it has emerged is something more than its elements. Evolution may be considered as the accumulation and advancement of macro-level changes in a system over a period of time. This accumulation of changes may occur across any significant property of the system, in any direction, as trends. In terms of culture, evolution is seen as the global trends of beliefs changing in both its macro and micro elements, across any of its dimensions over time. Equilibrium is the balance, or "centeredness" within a system, [7], that stems from not just interactions within the system, but also the strength of those interactions. This equilibrium emerges from the lowest levels of the system. For culture, an equilibrium is considered at the micro-level to be the centeredness of the belief system of each agent in the system, and at a macro-level as the strength (resistance to change) of beliefs over all agents in a system of high-functioning, belief-based agents.

As defined in, [2], (ch. 0), any complex system may be described according to its elements, interactions, formation (and operation), diversity (and variability), environment, and activities. For culture, as defined above, the system

components are as follows: Elements are Individuals within a system that are autonomous, and for this work, belief-based. Interactions between these are through social communication, both verbal (spoken or written) and non-verbal (social or emotional cues, or levels of influence) channels. Formation and operation of culture is the emergent activity based on viewing the system as a whole, formed at the moment an individual unit (agent) encounters a new unit. Diversity and variability also arise as emergent activity based on viewing the system as a whole, that comes about as a result of specific properties of an individual unit (agent). The Environment is important and represents the physical location and sub-locations containing the individuals within the system, as a host where interactions are conducted. Finally, Activities of culture may be seen as emergent based on viewing the system as a whole, functions of individuals within the system environment, actions on the environment or other individuals in the environment.

In addition to the above, the reproduction, growth, and feeding of a cultural system, [2], (ch. 0), are relevant at the micro-level of individuals. Culture *reproduces* as the spread of beliefs across different systems achieves stabilization within other systems. Also, culture may be seen to *grow* according to the number of individuals within a system that share the same beliefs. *Feeding* of culture may be considered at the level of the individual as well, as the reinforcement of a belief, hence increasing its ability to be shared over (versus) other beliefs. These, in conjunction with the factors mentioned above can provide a strong ontology for discussing culture from the complex systems standpoint.

4 A Multi-dimensional Framework for Culture Modelling

It is important to distinguish the key components of culture, as these are diverse, and largely intangible, but still need to be described adequately. It is also necessary to outline the main properties of each component since these determine the *kind* of culture that will result within the system. Knowing both the components and their properties will provide useful parameters for changing, and exploring a cultural system from the bottom-up.

This work advocates a model of culture that consists of seven key dimensions. The selection criteria for these dimensions has been motivated, for each dimension, by the answer to a primary question: *"Does component, or property, X affect the emergence or evolution of culture?"* The answer to this question determined the inclusion of each dimension, and directed the study towards the focus of this work, on emergence, evolution, and equilibrium. The seven-dimensional framework for investigating cultures builds on our previous work related to modelling organizations in joint emergency-response operations, [8], [9], which used the physical, functional, human, normative, and physical dimensions. Each of the seven dimensions of our framework for modelling culture is described in a separate section below.

4.1 Physical Layer

A *Physical* dimension of culture relates to its components in the actual world, ranging from the tools and technology it uses, to the forms of its common assets such as buildings, cars, clothing, etc. Environment shapes different cultural beliefs and understandings by having impact on perceptions, interactions, and communications, and as a result, behaviours of the members. In every system, either natural or artificial organizations, there are many environmental aspects such as size, location, physical distance, quality of life, etc. affecting the behaviour of agents. On the other hand, due to the advancements in technology, the ways of communication have changed from face to face conversations to rich electronic interactions via phone, email, and Web 2.0 tools (internet, blogs, online media, social networks, etc.). Moreover, in addition to the environment, the physical characteristic of the agents is also an important factor. For example, gender plays an important role in forming cultures. Gender refers to the value placed on traditionally male or female values, [10]. Male values for example include competitiveness, assertiveness, ambition, and the accumulation of wealth and material possessions. It should be noted that some factors appear in more than one dimension. This speaks to the interweaving and connectedness between dimensions. All these physical features affect the emergence of culture as they have direct impact on the behaviours, limitations, beliefs, and desires of the members of an organization or community. Accordingly, culture evolves in a society where there are changes in the different components of the actual world.

4.2 Individual Layer

The *Individual* dimension encapsulates the component actors in the culture, on every level of the agency spectrum; whether they be simple ants, or complex machines like smart sensors, or sophisticated cognitive actors like humans. This level focuses on elucidating the unique characteristics of the individuals, which eventually propagate throughout the culture. Individual factors such as physical and gender related elements or cognitive semi-social ones, highly affect the culture. Cognitive elements are beliefs and desires of any member. Some of these factors are built up over time such as personality, conformity, interests, and experiences. Other attributes are acquired by social interactions and what influential third parties believe about an individual. For instance, trust values in a simulation may be set to be believed by other interacting agents as a belief. As described by Schein, [11], this layer deals with the professed culture of an organization's members (i.e., the values). At this level, local and personal values are widely expressed within the organization. Organizational behaviour at this level usually can be studied by interviewing the organization's membership and using questionnaires to gather attitudes about organizational membership. These elements modify the attributes within the members and change the evolution of culture. Individuals have an impact on culture and culture drives the behaviours within the members of each community.

4.3 Functional Layer

The *Functional* dimension associates a particular role to the individuals within the system, and rests on the notion that the culture preserves itself through what it does, and hence who is performing that action. This level highlights the characteristics of what is performed by the culture through its components. The role of every individual indicates their permissible functionalities and actions. Functions influence roles and therefore have significant impacts on individuals in a community. Similar functions between individuals makes closer association amongst them and results in group formations. The development of formal qualifications based on education, knowledge, and functions can be considered as professions, [12]. The culture among the members of same professions also tends to be similar. As discussed before, this is due to the fact that people in similar professions share knowledge and functions, and individuals with similar functionalities connect to each other using a shared ontology. For instance, medical-related professions such as doctors, nurses, surgeons, etc. develop a similar culture to interact within their organizations. They share (some) knowledge about their domain and communicate through a known ontology. Although these are important factors affecting the culture, there can be sub-cultures developing within professions. Section 4.5 discusses more about cultures bearing new sub-cultures.

One of the key criteria in setting functionalities in different communities is the amount of available resources. Less restricted communities in terms of resources have more choices when performing an action or making a decision. Individuals in very restricted environments with low amounts of available resources tend to develop a more conservative culture, always using the minimum amount of the available resource. Moreover, shared resources across individuals affect the functionalities of individuals and therefore have a direct impact on their culture. Accordingly, functionalities and availability of resources affect the evolution of culture, and therefore, play an important role in the development of culture in societies.

4.4 Social Layer

The *Social* dimension is used to classify the type of interaction that takes place between actors within the cultural system, as the particular nature, and speed of social communication are essential to functional effectiveness of the whole system. Social interaction refers to how the individuals in the system interrelate, including factors such as trust and reputation ("willingness to take risk," [13]), and information sharing (willingness to share sensitive information). Social memory refers to the means of storing information in individuals within the system. Social adaptation is an evolutionary element in cultural systems that arises from this dimension as well. The social aspects of culture arise by the formation of different norms in human-centered societies. Interrelation and interaction between individuals follow a certain set of social rules derived from their normative framework, [14]. Hence, they have substantial impact on the culture by modifying the attributes of the cultural elements.

4.5 Structural

The *Structural* dimension of culture characterizes the organizational hierarchy that exists within the system and how that hierarchy effects the functioning of the whole. In artificial systems such as organizations, companies, etc. the structure forms based on rules and roles. Rules pertain to the structure or behaviour internal to an organization while roles are authoritative and functional attributes of the members. Traditional organizations shape their structure based on hierarchical levels of authorities where there is a chain of command of superiors, subordinates, and colleagues at the same level. This model of structure not only affects the culture of members between different levels of the hierarchy but also has direct influence on the formation of the sub-cultures inside every level. Members of each level of hierarchy have a set of goals, actions, beliefs, and practices in common and this results in a new culture emerging inside the organizational culture. Some systems develop a network structure preventing inter-cultural differences in their organization. However, most systems tend to have a mixed structure, i.e., a hierarchical structure with many levels of hierarchies, with network structure inside every level of the hierarchy.

Different informal structures result from different moral attributes. Friendships and proximity-based relations are examples of this kind of structure. In these structures, there are no differences between the members of the system, although these members can have different values of trust and reputation from the other member's perspective. The form of the structure changes the behaviours, norms, and understandings of members, and in this way, affects the culture within each community.

4.6 Normative Layer

The *Normative* dimension of culture characterizes the primary policies and rules that govern behaviour of individuals within the culture. This highlights not only what ought to be done by whom, but also when it needs to be done. This dimension is highly important, as it dictates what the system looks like and how it ultimately behaves and adapts. Culture can be seen as the aggregation of norms that are common to a certain group of agents, leading to the emergence of dominant culture in that system, [15].

Organizational culture has been defined as the specific collection of values and norms that are shared by people and groups in an organization and that control the way they interact with each other and with stakeholders outside the organization, [16]. Norms are generated over time through a series of interactions amongst the individuals with different beliefs, intentions, and traditions and affect the behaviour of agents. Every domain has its specific set of norms that can be generally valid in other environments. These norms arise from the agent-environment interaction and usually guide the behaviour of agents, [14]. Consequently, norms characterize and form the primary policies in every organization. These policies are sometimes formal, written and coined in a certain environment, or informal, based on descriptive actions of the members of the

organization that are observed over time by individual agents. For instance, traditional beliefs, ideas, and practices are passed down from generation to generation, originally without the need for a writing system. Traditions serve to preserve a wide range of culturally significant ideas, specific practices and the various methods used by distinct cultures.

As discussed in, [14], [17], in reality, norms often evolve in a bottom-up manner. Individuals have a quite useful understanding of the environments, roles and goals, possible actions, and policies as they are constantly interacting with the environment and other homogenous (or heterogenous) members. Since these individuals have the best view of the problems and are actually in action, they can easily obtain information about the domain where they are active. This way, norms can be established in their natural form and can be updated or even altered without the heavy expenses of top-down decision-making procedures. Norms are being created on the fly and can be dynamically changed depending on the environment's dynamics.

One can think of norms based on their flexibility and jurisdiction. Authoritative norms are enforced by law or the structure of each organization in a top-down manner, while many other social or behavioural norms are emerging bottom up in societies based on the context and interactions of agents with other agents or the environment. Although authoritative norms are strictly enforced and controlled in societies, they are more subject to disobedience by the member of societies due to their low social acceptance compared to emerging norms. Nevertheless, these norms are vital in every human society or organization. For example, governments usually set large numbers of rules and policies to prevent conflicts and confusions between members of government with different beliefs and goals.

Regardless of the type and origins of norms, they play an important part in forming and alternating cultures in human societies. The norms of culture also address how an agent is able to understand the culture when facing a new system as well as how norms and normative actions drive (or sometimes affect) decision making and also allow a degree of autonomy to the agent individuals, [18], [19].

4.7 Informative Layer

The *Information* dimension represents the informational elements that the system both consumes and produces as it performs its function. This level characterizes the information as well as the producers and consumers of this information, at a given time. Information has many meanings as a concept, [20]. Moreover, the concept of information is closely related to notions of constraint, communication, control, data, form, instruction, knowledge, meaning, mental stimulus, pattern, perception, and representation. The type of information can be classified into two major parts from the plasticity point of view. The flexibility of information affects the culture in which the information flows in. For instance, traditions in a society dictate some rigid beliefs to the members of that society and vastly influence their comprehensive vision and ideologies. These traditions

have a critical role in defining culture and beliefs of a society. Hence, culture relies on both oral and exercised beliefs coming from traditions over a long period of time.

The speed of information exchange is another important aspect that impacts the development of culture. Information exchange is inevitable in all the communities. However, due to technological advancements, this pace is increasing every day. Today, most people are able to communicate and share ideas using Web 2.0, phones, etc. People talk to other people millions of miles away, share their stories and insights, learn about other cultures and traditions, and try to improve their life style and the intellectual understanding using this shared information. This is interesting in the way it facilitates change in culture through improved sharing of beliefs. As a result, methods of information spreading and the level of access to information changes the cultural beliefs and understandings. For instance, members of organizations are aware about the rights, limitations, and risks by accessing the information available through different media.

4.8 Related Work on Cultural Modelling

It should be mentioned that the multi-dimensional view of culture is not new. Other key dimensions have been identified in organizational culture research texts, as seen in, [5]. Hofstede, (ch. 25), promotes a four dimensional, and a six dimensional model. The four dimensional model targets culture as it relates to nations and governments while the six dimensional model targets organizations. Payne, (ch. 10), presents three-dimensional model of culture. Ashkanasy, et al, (ch. 8), promote a ten-dimensional model of culture. Lastly Dickson, from the GLOBE group, (ch. 28), have presented a nine dimensional model. These are seen in Figure 1, however a detailed comparison with the proposed seven-dimensional model is left for future studies.

5 Modelling and Simulating Organizational Culture in a Multi-agent System

From our definition, culture represents a shared understanding or acceptance of a set of beliefs that determine such things as accepted behaviour, [21]. While each member of the organization may have his or her own particular beliefs about a specific element, ultimately there is an overarching belief that becomes part of the culture. The way in which culture emerges is based heavily on the members of the organization. Particularly, the position taken in this chapter is that the influence of existing organizational members affects the culture of new members. In this section, the mechanisms used to store cultural beliefs, calculate influence, and modify beliefs using a multi-agent systems approach will be examined, along with a discussion of the organizational culture literature that was used as the basis for these mechanisms.

Hofstede Model for Nations	Hofstede Model for Organizations	Payne Model	Ashkanasy Organizational Culture Profile	GLOBE Model for Organizations	*Seven Dimension Model for Agents***
1990	1990	1996	2000	1999	*2010*
Power distance	Process-oriented versus Results-oriented	Strength of Consensus	Leadership	Power distance	***Physical***
Uncertainty avoidance	Job-oriented versus Employee-oriented	Pervasiveness	Structure	Uncertainty avoidance	***Structural***
Individualism versus Collectivism	Professional versus Parochial	Psychological Intensity	Innovation	Humane orientation	***Functional***
Masculinity versus Femininity	Open-system versus Closed-system		Job Performance	Assertiveness	***Individual***
Long-term versus Short-term Orientation	Tightly controlled versus Loosely controlled		Planning	Gender egalitarianism	***Social***
	Pragmatic versus Normative		Communication	Future orientation	***Normative***
			Environment	Performance orientation	***Information***
			Humanistic Workplace	Individualism versus Collectivism	
			Development of the Individual	Organizational Collectivism	
			Socialization on Entry		

Fig. 1. Culture Dimensions in Literature and the seven dimensional model (end column)

5.1 Cultural Belief Set

The cultural belief set (CBS) contains beliefs that exist in the organization's cultural landscape. These may be beliefs about particular attitudes, values, goals, or practices. Each belief in the CBS can assume one of three values, based on deontic logic: prohibited, permitted, or obligated. As an example, a belief that "punctuality = prohibited" means that it is culturally unacceptable to be punctual; "punctuality = permitted" means that it is culturally neutral whether or not someone is punctual; and "punctuality = obliged" means that it is culturally required to be punctual.

Since the belief value in the CBS has been restricted to three possibilities, the current culture's value of a particular cultural belief, x, in the CBS can be ascertained by determining which of the three possible values has the greatest consensus among the various individuals in the organization.

5.2 Influence Calculation

The influence of one agent over another agent is used as the mechanism for changing culture. It is based on the notion described previously that key individuals in the organization have a greater influence on its culture. This influence can be computed using factors from each of the seven dimensions. In this chapter, the factors in Table 1 have been incorporated into the influence calculation and are part of the influence factor set (IFS).

The equation used to calculate the influence of one agent over another is presented in Equation 1. The above factors have been included, along with an impact ratio, α_j, for each factor. The latter allows the particular factor's influence to be customized for each agent.

$$\iota_i = \sum_{j=1}^{k} \alpha_j * IFS(j), where \sum_{j=1}^{k} \alpha_j = 1 \tag{1}$$

Each agent also has a belief about the "influence of self" – i.e., how much it is influenced by its own belief. This value ranges from 0 to 1 inclusive, and is used in the confidence calculation presented next.

5.3 Updating the Cultural Belief Set

In the simulation, agents share cultural beliefs with other agents whenever a cultural event takes place. These events occur whenever an agent tests a cultural belief in its CBS'. (CBS' is used to distinguish the agent's personal belief set from the organizational belief set CBS.) These events take the form of a fact in the world, e.g., $agent_m culturalbelief = value$. The current agent, $agent_m$, is enacting a specific belief in its CBS'. This agent will receive direct feedback–praise or chastisement–from the other agents in the organization. This feedback is in the form of $agent_i culturalbelief = value$. If the value from $agent_i$ matches

Table 1. Factors incorporated into the influence calculation and influence factor set(IFS)

Cultural Influence Factors		
Structural	1	How does agent X relate structurally (within the context of an organization) to agent Y? {supervisor, subordinate, colleague}
Physical	2	How close is agent X's workstation from agent Y's workstation? {proximity_Threshold} (agent X has a greater chance of being influenced by agents within its proximity threshold)
Functional	3	How similar is agent X's role to agent Y's role? [0-1]
Individual	4	Do agent X and Y share the same gender? {true, false} (agent X has a greater chance of being influenced by an agent with the same gender)
	5	Are agent X's and Y's personalities congruent? [0-1] (agent X has a greater chance of being influenced by an agent with a congruent personality)
	6	How does agent X's experience in the organization compare with agent Y's experience? (agent X has a greater chance of being influenced by an agent with more experience)
	7	How does agent X's leadership ability compare with agent Y's leadership ability? (agent X has a greater chance of being influenced by an agent with more leadership ability)
Normative	8	Is the particular belief from the CBS formally or informally specified? (an agent has a greater chance of quickly shifting its cultural belief if it relates to a norm that is formally specified)
Social	9	Does agent X seek peer validation from agent Y? [0-1] (this may be due to several factors)
	10	Does agent X trust agent Y? [0-1]
	11	Through what medium does agent Y principally communicate to agent X? {face-to-face > Web 2.0 > phone > email}
Informative	12	Does agent X experience the cultural feedback first-hand or second-hand from agent Y? (this speaks to the strength of the confidence interval)
	13	If directly, does agent X receive feedback via verbal or non-verbal cues? (this speaks to the strength of the confidence interval; besides verbal cues may be misinterpreted)

$agent_m$'s value, the behaviour or belief is being positively reinforced; otherwise, it is being negatively reinforced.

An agent's cultural beliefs are reconsidered everytime the agent experiences an event. The other agents also experience the event, but their feedback is received second-hand, or indirectly. Events that are experienced first-hand by the agent will have a greater impact on the value of a cultural belief than events that are experienced second-hand. This is accomplished via $IFS(12)$ in Figure 1.

For each belief, x, in an agent's CBS', a confidence value is associated with each of the three possible values—i.e., prohibited, permitted, or obliged. In order for the value of x to change, the confidence related to one of the other possible values must become the new maximum. These confidence values are based on the beliefs expressed by other agents, following a cultural event, combined with these other agents' influence factor from the perspective of the current agent.

Equation 2 is used to compute these confidence values. The value of $CBS'(x)_i = \mu$ becomes 1 if the value from $agent_i$ matches the value whose confidence is being computed. Otherwise, the value is zero, as it is, when $agent_i$'s belief value is unknown to the current agent. The sum is taken over all agents, n, including the current agent.

$$\Phi(CBS'(x) = \mu) = \sum_{i=1}^{n} \frac{(CBS'(x)_i = \mu) * \iota_i}{n}, where \mu = \{prohibited, permitted, obligated\} \tag{2}$$

As it relates to the CBS', if there is a tie between the confidence values for belief x and one of the tied values matches the agent's current belief value, then the agent's current belief value will be used. Otherwise, permitted will always be used if it is part of the tie, and obliged if permitted is not in the tied set.

Ultimately, the belief value with the greatest confidence will be selected by the agent for cultural belief x. However, if an agent's confidence is below a certain threshold (unique to the agent), then the agent will feel free to "test" this cultural belief by performing counter-cultural behaviours. When the confidence value for all agents is above their individual thresholds, the CBS will stabilize and be in equilibrium.

5.4 Relevant Literature on Cultural Events, Influence Factors and Perspectives

Literature to support the theoretical approach of the previous section is found in, [5]. Social actors engage in social processes called events, (ch. 3), which result in the notion of meaningfulness and is created by powerful organizational actors, such as managers, who are able to construct and maintain organizational rules. Anyone participating in an organization does so by interpreting events and influencing the meanings that others give to these events, (ch. 6). Rules develop and change through the actions of numerous actors as they establish, enact, en-

force, misunderstand, resist, and/or break the rules. In fact, it is precisely the configuration of the rules and actors involved that constitute a specific culture.

Various influence models have also been discussed in the literature, and influence factors include role (superior, subordinate, colleague), self, and leadership characteristics of the individual (ch. 6, 10). These have been captured already, along with other factors, using the seven-dimensional approach.

Finally, (ch. 10), discusses three perspectives of culture: the integration perspective, where people share a common set of beliefs; the differentiation perspective, where different subgroups have different beliefs, but must learn to resolve conflict; and the fragmentation perspective, where, because of such ambiguity in beliefs, individuals fragment into ever-changing subgroups. With the notion of CBS, it is the integration perspective that is being utilized in this chapter. However, as will be seen in the experiments, the cultural equilibrium does change, but it does so in a direction that is always toward achieving cultural consensus.

6 Experiments

In order to test our notions of culture, we model a basic organization — its roles (i.e., functions and norms) and structure — using multi-agent systems simulation. We also model a set of workers, having unique characteristics described using the individual dimension, that can potentially occupy any of the organization's roles.

In order to display culture we use the notion of a *belief set equilibrium*, representing the balance of order and decay in beliefs, at a given time, over all individuals in the system. By modelling each agent individually, each can have its own unique beliefs about culture. When multiple agents begin interacting, certain forces will cause some beliefs to be accepted by the community and become part of the culture (i.e., part of the social memory). Such a force may be a new manager, for example, who has authority over (a) particular agent(s). Moreover, we believe that culture stabilizes as more agents join the organization, so it becomes resilient to change. However, we still maintain that if a major destabilizing force occurs (e.g., a key agent such as a manager in an organization is replaced), then a cultural shift may occur, resulting in a new equilibrium.

We have chosen to use the Brahms multi-agent development environment, [22], that builds on the Beliefs-Desires-Intentions (BDI) paradigm, [23], with the concept of work practice, which attempts to capture what workers actually do. This allows our worker agents with unique beliefs to influence how culture emerges through their interactions.

6.1 Scenario

For the experiments in this chapter, a small generic organization (less than 10 employees) is considered, along with the following roles: owner (1), receptionist (1), payroll manager (1), IT manager (1), and generic workers (5). As this is a multi-agent system approach, agents are used to represent the individuals in the

organization, and each agent begins with an initial set of beliefs pertaining to both the CBS and the influence factors and impact ratios which were described previously. Agents in the organization are fully connected to each other, but with 'subordinate-to' and 'colleague-of' relationships based on role. Agent_1 is the owner, Agent_2 is the receptionist, Agent_3 is the payroll manager, Agent_4 is the IT manager, and the remainder are generic worker agents under the IT manager (See Figure 2).

The CBS in the following experiments is comprised of the following elements. These capture three beliefs that are heavily determined by the culture of the organization.

1. working after hours
2. appropriate business attire
3. punctuality

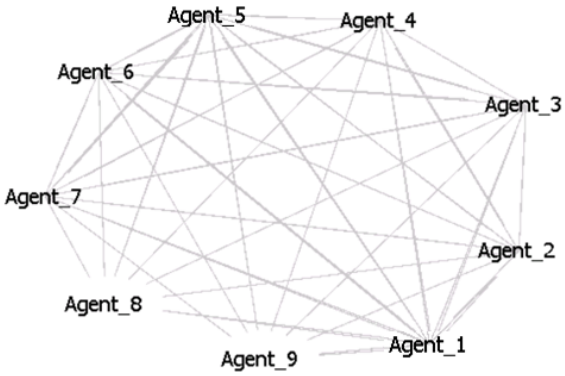

Fig. 2. Agents in the organization are fully connected to each other in a communication network of influence. Edge relationships are based on subordinate and colleague roles.

In order to show emerging culture, we demonstrate how the belief set equilibrium of our basic organization is affected under three conditions: i) the effect of adding the most influencing agents at the beginning, ii) the effect of adding the most influential in the middle, and iii) the effect of adding the most influential agents at the end. The addition of an agent may shift the equilibrium of the organization's culture, as each agent will have a different cultural influencing factor dependent on such things as role occupied, personality, and existing social connections within the organization.

6.2 Experiment 1: Adding the Most Influence Agents at the Beginning

In this experiment, the organization begins with the three most influential agents: the owner and the two managers. These agents then have one simulated month to

perform cultural interactions. During this time, two of the agents agree that employees must work after hours and be punctual, and all three agree that business attire is not that important (see Figure 3). After the one month period, another agent is added to the organization. Once again, the agents have a month to perform cultural interactions before the next agent is added.

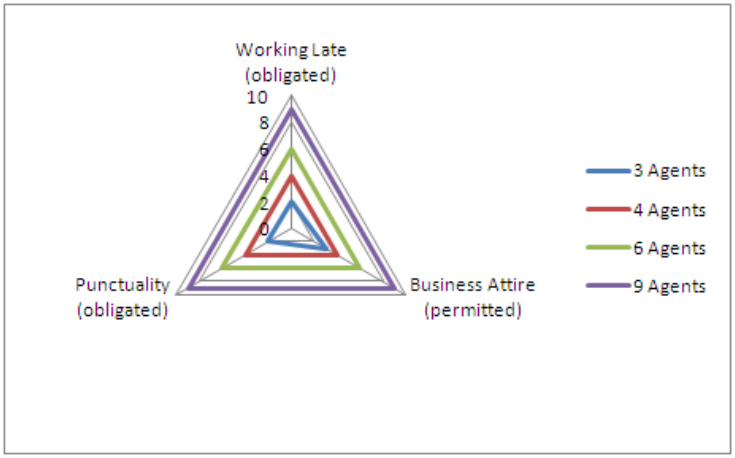

Fig. 3. Case 1: Adding Most Influential Agents at the Beginning. Cultural beliefs stabilize after the fourth agent is added.

As can be seen in Figure 3, once four agents are added to the organization, the cultural belief set stabilizes and other agents added to the system adopt the organization's culture. This is because the existing agents are sufficiently influential and eventually convince all existing agents within the organization to conform to their culture.

6.3 Experiment 2: Adding the Most Influence Agents in the Middle

In this experiment, the organization's three most influential agents are added to the organization after three other agents perform cultural interactions for a month. Once again, the additional agents are added subsequently after a one month simulated period. This continues until all nine agents have been added to the organization.

As can be seen in Figure 4, complete stabilization of the culture does not occur until six agents have been added to the organization. This suggests that the influence of the most powerful agents impacted the initial culture of the organization, which existed during the first month when three other agents were present. This likely occurred because none of the first three agents were sufficiently influential to convince the other agents to adopt their cultural position.

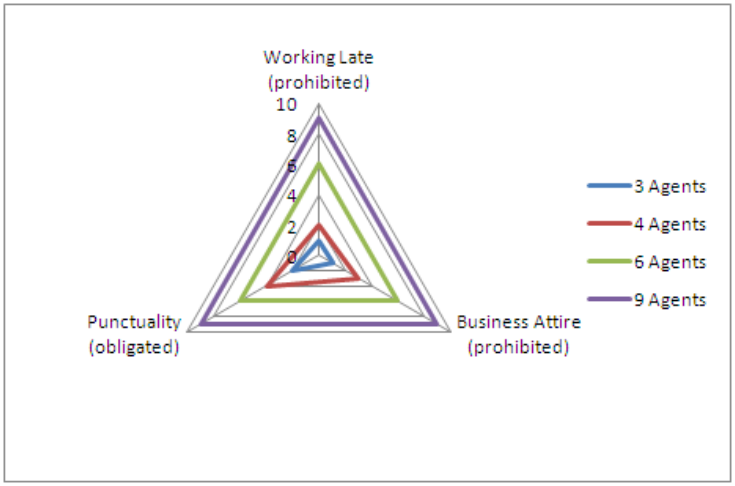

Fig. 4. Case 2: Adding Most Influential Agents in the Middle. Cultural beliefs stabilize after the sixth agent is added.

6.4 Experiment 3: Adding the Most Influence Agents at the End

In this experiment, the organization's three most influential agents are added to the organization as the last three agents. Once again, they are added in monthly increments, following the initial three agents and the three subsequently added lesser influence agents. This particular experiment may simulate the case where some key management is replaced at some interval during the lifetime of the organization.

As can be seen in Figure 5, complete stabilization of the culture occurs once six agents have been added to the organization. This suggests that even though the most influential agents are not added until the end, the first six agents are able to create enough "pull" together to compensate for the greater influence of these other three agents. Because these influential agents are added individually, neither one alone is able to overcome the cultural stability already existent within the organization.

7 Conclusion

In this chapter culture has been defined and presented as a complex, multi-dimensional, and multi-agent construct. The complex systems viewpoint is valuable as it allows for considering culture holistically, from both a top-down, and bottom-up perspective.

The multi-dimensional modelling of culture adds to existing literature on culture's component dimensions, and why those dimensions are unique and relevant. Additionally, the multi-agent modelling and simulation of culture puts the

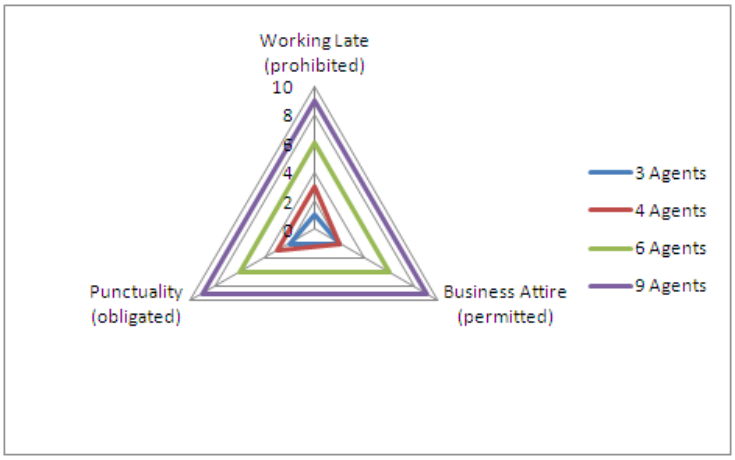

Fig. 5. Case 3: Adding Most Influential Agents at the End. Cultural beliefs stabilize after the sixth agent is added.

seven-dimensional model into perspective with the notion of achieving belief-based equilibrium of agents over time, according to the relationships, communication, and influence idiosyncracies of each one as individuals in a complex organizational system.

Agent-oriented culture modelling is a useful and powerful tool. The results have shown how beliefs stabilize for a simple example as a first step towards modelling more complicated, and diverse, organizations. This multi-agent simulation capability can also allow for studies that allow the integration of culture in an emergent and observable fashion based on the individuals. Future work should target this direction and investigate how the addition or removal of groups of agents impacts culture, as in common organizational mergers and acquisitions.

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