

Framework for Modeling Partial Conceptual Autonomy of Adaptive and Communicating Agents

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Abstract

We consider the idea of conceptual autonomy of natural and artificial agents. We claim that agents that have explicit, propositional representations are limited in their conceptual autonomy. We discuss how partial conceptual autonomy is obtained through a self-organization process. The input for the agents consists of perceptions on the context, expressions communicated by other agents as well as recognized identities of the other agents.

Agents and communication

Agents communicate by sending and receiving messages. In the primitive case, all the agents have a common model of their environment, and the messages are signals that have fixed and common interpretations. In the advanced level of multi-agent co-operation each agent has its own model of the environment. Thus, each agent has a “subjective” interpretation for the relation between the messages and its environment. The differences in the models motivate development of methods for providing learning abilities. Each agent might then learn to interpret messages from other agents. In this paper a general scheme for multi-agent communication is first presented providing views on the applicational and methodological alternatives.

The basic elements of a generalized model of multi-agent communication are: the environment of the agents, the language used in the communication, and the input-output functions, and the memory and processing mechanisms of the agents.

The agents can perceive their environment, they are part of it, and possibly they can change it. The environment may be computerized representation, constructed, or natural. The borderlines of these domains may, of course, be vague. Especially a natural environment is changing, and consists of various continuous phenomena.

In its simplest form, communication may be based on a fixed set of distinct signals. Here we consider the possibility of applying a natural, or near-to-natural language as communication media. The general properties of natural languages necessitate some capabilities that autonomous agent need to have in

such a case. The basic properties of natural languages and their interpretation include ambiguity, contextuality, open-endedness, vagueness, and sub-jectivity.

Ambiguity, for instance, is a “virtue” when the communication media is used in an open and changing environment in which having a distinct and before-hand determined symbol, or combination of symbols would be difficult, or practically impossible. To ensure successful communication, the sending and the receiving agent must have similar enough framework of interpretation, and the message or the situation (“context”) must contain enough information to activate proper framework of the receiver.

Cognitive capabilities of agents

The basic cognitive functions of agents consist of their input and output functions, memory and processing mechanisms. The agents can perceive their environment and have a model or representation of it. This representation may be

- static or dynamical,
- given from outside or autonomously learned,
- common with the other agent or individual which makes learning capabilities necessary, and
- symbolic, non-symbolic or hybrid (Wermter & Sun, 2000)

Steels (1995), among others, presents division into explicit and implicit representation. He states that in the traditional AI models usually use explicit representation. Implicit one is defined to emerge once the agent behaves appropriately in a specific situation with respect to the task, and to the other agents without having any explicit model. The robots of Brooks are perhaps the best-known example of agents based on such representations (Brooks 1991). According to Brooks the robots should react directly to the stimulus based on their behavioral models.

Brazdil and Muggleton (1991) show how to use symbolic inductive inference as a means to learn to relate terms in a multiple agent communication. They have shown how to overcome language differences between agents automatically in a situation

where the agents do not have the same predicate vocabulary. The system consists of a number of separate agents that can communicate. Each agent has certain perceptive, communicative and reasoning capabilities, being able to (1) perceive a portion of the given, possibly simulated world, (2) accept facts and rules from another agent, (3) formulate queries and supply them to another agent, (4) respond to queries formulated by another agent, (5) interpret answers provided by another agent, (6) induce rules on the basis of facts, and (7) integrate knowledge. Such symbolic model of the environment is closely related to the model-theoretic approaches in defining the semantics of formal languages. The problem lies in the fact that the meaning of an expression (queries, responses) in a natural domain is fuzzy and changing, biased by the particular context.

It is also important to mention that the notion of autonomy can be considered critically as, e.g., Alterman (1997) does. He points out that the aspects of collaboration and distributed cognition have to be taken into account. These considerations are central also in this paper. In particular, the domain of conceptual autonomy will be studied in more detail and the concept of partial autonomy will be adopted.

Kirsh (2001) expresses that in ecological systems each component of the system has a causal influence on the other. In the biological world organisms interact with their environment and with other organisms, who, of course, also tend to be part of each other's environment, the whole system of components being interdependent and interlocked. The result is a highly complex system displaying attractors, instabilities and cycles typical of dynamical systems. (Kirsh, 2001)

Subjectivity and vocabulary problem

In the field of information retrieval, Furnas et al. (1987) have found that in spontaneous word choice for objects in five domains, two people favored the same term with less than 20% probability. Bates (1986) has shown that different indexers, well trained in an indexing scheme, might assign index terms for a given document differently. It has also been observed that an indexer might use different terms for the same document at different times.

Moore & Carling (1988) state: "Languages are in some respect like maps. If each of us sees the world from our particular perspective, then an individual's language is, in a sense, like a map of their world. Trying to understand another person is like trying to read a map, their map, a map of the world from their perspective."

As an example related to the vocabulary problem, two persons may have different conceptual or terminological "density" of the topic under consideration. A layman, for instance, is likely to describe a phenomenon in general terms whereas an expert uses more specific terms. This aspect of partial concep-

tual autonomy will be discussed later in this paper in more detail.

Communication and Context Sharing

The model of communicating agents consists of three modalities:

- expressions used in communication (shortened as "E"),
- contexts ("C"), and
- agents' identifications ("A").

An agent can process any channel of input alone if the other two are missing, or it can associate two of the pairs (the "A" channel is only present when the "E" is in use), or even all the three input domains.

Alternatives of abstract situations

Next we'll consider the most relevant input combinations one by one using a distinction into separate learning and communication phases. Such separation is not strictly necessary but it simplifies the description of the model. In the learning phase the main input combinations are:

- C as input: formation of the representation of the context domain
- C+E as input: associating contexts patterns with the expressions
- C+E+A as input: associating context-symbol associations with the agent identifications, or more accurately, associating all the three input "channels".

Also the secondary input combinations may be listed for completeness.

- E as input.
- A as input.
- E+A as input.

In the communication phase the following input-output combinations are the most relevant.

- C as input, E as output: the agent names the "object" it has been "shown".
- E as input, best-matching instance of a list with C as output: the agent points out from a list an "object" that best matches the expression.
- C+A as input: E as output: the agent names the "object" taking into account the receiving agent of the message.

- E+A as input, best-matching instance of a list with C as output: the agent points out from a list an “object” that best matches the expression taking into account the agent that expressed itself.
- E+C as input, E as output: the agent evaluates whether it would use the same expression as the description of the “object”.
- E+C as input, A as output: the agent specifies which agent is the likely utterer of the expression in the particular case.

Example: color naming

A practical example can be given related to the domain of colors. Naming the colors in particular has certain invariant features as well as a potentially large number of borderline cases in which two subjects often name the same color differently. The alternatives considered above give rise to following cases: two subjects are comparing their expressions on some color that the both can perceive. Strictly speaking, the different visual points of view should be taken into account which was one essential factor in the Talking Heads project (Steels & Kaplan, 2002). If two subjects state same expression the situation is unproblematic. If they use different expressions the following options are possible: one can agree that the expression used by the other subject is a viable alternative, e.g., a piece of furniture is considered sky blue by the other and plainly blue by the other but they agree that both expressions can be used. As another options, they may disagree on the applicability of each other's expressions. An additional level of increased realism and complexity to the model can be obtained by considering the fuzziness of the color naming process. The borderlines of three-dimensional domains of color features for each color name are not crisp. Similarly, the degree of agreement or disagreement on the use of a color term can be considered in the framework of fuzzy set theory (Zadeh, 1965). Another point of view can be obtained by taking into account the distinction into active and passive vocabulary. One agent names one color with a certain term but is ready to accept alternative expressions denoting the same color (e.g. 'dark salmon' versus 'rosy brown').

The previous discussion handled a situation in which both subjects experienced the same (or approximately the same) color perception and were comparing their associated color terms. However, if the perceptual input is missing for one or both of the agents, there is no direct source of evidence to check the agreement on naming. Thus, if one agent expresses a color name the other agent interprets this name within its own scheme. However, there may be other, indirect evidence on (dis)agreement. Namely, the color names can be expressed in the context of symbol-level context, i.e., for instance, with associated nouns. The two subjects can check whether

they share the conception of the color name 'sienna' by comparing whether they agree upon the nouns that this adjective can readily qualify. Similarly, the agents may compare the conceptually neighboring color terms within some, implicit similarity metrics scheme. For instance, one agent might state that the color 'light coral' is between the colors 'salmon' and 'rosy brown'. MacWhinney (1989) mentions that the prototype theory fails to place sufficient emphasis on these kinds of relations between concepts. MacWhinney also points out that prototype theory has not covered the issue of how concepts develop over time in language acquisition and language change, and, moreover, it does not provide a theory of representation. MacWhinney has presented a model of emergence in language based on the SOM (MacWhinney, 1997). Gärdenfors (2000) has presented a detailed account on the motivation for the use of the SOM in modeling conceptual spaces. This topic will be discussed in more detail in the following section.

From color naming to societies of agents

An additional aspect of modeling is obtained if the agent takes into account in its internal interpretation the utterer of the color expression. Namely, if one agent uses a particular color term in an unusual manner, the other agent can learn this specific relation and use this naming convention while communicating with each other. In general, this phenomenon is called meaning negotiation. The phenomenon can be considered as something happening between two communicating individual agents. In addition, the consideration is important while comparing the naming conventions between two more or less isolated agent communities.

Agent Learning and Self-Organizing Maps

One novel approach to aim at modeling the learning, interpretation and use of natural language has been to develop systems that simulate the learning process. In the area of machine learning methods for generalization, i.e. inductive inference have been implemented. However, many of such models are based on symbolic representation of rules that makes it difficult to create means for symbol grounding into continuous and changing perceptual domains.

The self-organizing map (SOM) (Kohonen, 1982, 1995) is a information processing model which is often considered as an artificial neural network model, especially of the experimentally found ordered “maps” in the cortex. There exists quite a lot of neurophysiological evidence to support the idea that the self-organizing map captures some of the fundamental processing principles of the brain.

Knowledge Representation Aspects

The self-organizing map can be viewed as a model of unsupervised machine learning and also, importantly in this context, as an adaptive knowledge representation scheme. The traditional knowledge representation formalisms (semantic networks, frame systems, predicate logic, to provide some examples) are static and the reference relations of the elements are determined by a human. Those formalisms are based on the tacit assumption that the relationship between natural language and world is one-to-one: the world consists of objects and the relationships between the objects, and these objects and relationships have straightforward correspondence to the elements of language. Moreover the representations are "programmed", not learned through experience.

The self-organizing map is described in the following using agent terminology (slightly adapted from (Lagus et al., 1996)). Consider a collection or system of agents which must learn to carry out very different tasks. Let us assume that the system may assign different tasks to different agents of the collection that are able to learn from what they do. Each new task is given to the agent that can best complete the task. Since the agents learn, and since they receive tasks that they can do well, they become even more competent in those tasks. This is a model of specialization by competitive learning. If the agents are interconnected in such a way that also the neighbors of the agent carrying out a task are allowed to learn some of the task, the system slowly becomes ordered so that agents near each other have similar abilities, and the abilities change slowly and smoothly over the whole system. This is the general principle of the self-organizing map.

Self-organizing map algorithm

In the following, the self-organizing map algorithm is described in some more detail based on (Kohonen, 1995). Assume that some sample data sets have to be mapped onto a two-dimensional array, a sample set is described by a real vector $x(t) \in R^n$ where t is the index of the sample, or the discrete-time coordinate. In setting up the Self-Organizing Map, we first assign to each unit in the array a parameter vector $m_i(t) \in R^n$ called the codebook vector, which has the same number of elements as the input vector $x(t)$. The initial values of the parameters (components of $m_i(t)$) can be selected at random. The process described below changes these parameters.

The "image" of an input item on the map is defined to be in the location, the $m_i(t)$ of which matches best with $x(t)$ in some metric. The self-organizing algorithm that creates the ordered mapping can be described as a repetition of the following basic tasks:

1. An input vector $x(t)$ is compared with all the

codebook vectors $m_i(t)$.

2. The best-matching unit on the map, i.e., the unit where the parameter vector is most similar to the input vector in some metric, called the winner, is identified.
3. The codebook vectors of the winner and a number of its neighboring units in the array are changed incrementally according to the learning principle specified below. (Kohonen, 1995)

The basic idea in the self-organizing map is that, for each input sample vector $x(t)$, the parameters of the winner and units in its neighborhood are changed closer to $x(t)$. For different $x(t)$ these changes may be contradictory, but the net outcome in the process is that ordered values for the $m_i(t)$ are finally obtained over the array. If the number of input vectors is not large compared with the number of codebook vectors (map units), the set of input vectors must be presented many times reiteratively. As mentioned above, the codebook vectors may initially have random values, but they can also be selected in an ordered way. Adaptation of the codebook vectors in the learning process takes place according to the following equation:

$$m_i(t+1) = m_i(t) + \alpha(t)[x(t) - m_i(t)]$$

for each $i \in N_c(t)$, where t is the discrete-time index of the variables, the factor $\alpha(t) \in [0, 1]$ is a scalar that defines the relative size of the learning step, and $N_c(t)$ specifies the neighborhood around the winner in the map array. At the beginning of the learning process the radius of the neighborhood is fairly large, but it shrinks during learning. This ensures that the global order is obtained already at the beginning, whereas towards the end, as the radius gets smaller, the local corrections of the codebook vectors in the map will be more specific. The factor $\alpha(t)$ decreases during learning.

Partial Conceptual Autonomy through Self-Organization

Consider that an agent is to denote an interval of a single continuous parameter using a limited number of symbols. These symbols are then used in the communication between the agents. In a trivial case two agents would have same denotations for the symbols, i.e. the limits of the intervals corresponding to each symbol would be identical. If the "experience" of the agents is acquired from differing sources, the conceptualization may very well differ.

One may then ask how to deal with this kind of discrepancies. The following section describes self-organizing maps and a model of their use in this task. The key idea is to provide the means for each agent to associate continuous-valued parameter spaces to

sets of symbols, and furthermore, to “be aware” of the differences in this association and to learn those differences explicitly. These kinds of abilities are especially required by highly autonomous agents that need to communicate using an open set of symbols or constructs in the agent language.

The self-organizing map is especially suitable for the central processing element of autonomous agents because of the following reasons:

- The self-organizing map algorithm modifies its internal presentation, i.e., the codebook vectors according to the external input which enables the adaptation of the agents.
- The self-organizing map is able to process natural language input to, e.g., form “semantic maps” (Ritter & Kohonen, 1989). Natural language interpretation using self-organizing map has further been examined by Miikkulainen (1993), Scholtes (1993) and Honkela (1991, 1995, 1997). In (Honkela 1995), the input data consisted of a set of English translations of fairy tales collected by the Grimm brothers. Word trigrams were used as input vectors taking the encoded representations of three subsequent words from the preprocessed text. Summarizing the results of the statistical analysis conducted by the map algorithm all verbs were to be found in the top section whereas the nouns are located in the opposite site. Among the nouns inanimate and animate nouns formed areas of their own. Similar results can be obtained using other clustering algorithms.
- Symbols and continuous variables may be combined in the input, and they are associated by self-organizing map (Honkela, 1991). Continuous variables may be quantized, and a symbolic interpretation can be given for each section in the possibly very high-dimensional space of perceptual variables (Honkela, 2000).
- Because the self-organizing map is based on unsupervised learning, processing external input without any prior classifications is possible (Kohonen, 1995). The autonomous agent may form an individual model of the environment and of the relation between the expressions of the language and the environment.
- The interpretation of the messages need to be identical among the agents. self-organizing map enables creating a model of the relation between the environment and the expressions of the language used by the other agents. In addition, generalizations of this relations can be formed (Honkela, 1993).

Discussion

We have presented a framework for considering the level of conceptual autonomy of communicat-

ing agents. Based on the framework various practical applications can be built. The use of the self-organizing map algorithm was considered as one option for modeling the internal conceptual and adaptive processes was presented.

The conceptual spaces of partially autonomous agents were earlier discussed in the context of color names. Different situations related to “subjective” variance of naming the colors were studied. The issue of the cultural and societal levels of conceptual spaces of agents is of great importance when practical political and societal phenomena are considered. Instead of names of colors the differences in the conceptual spaces can be related to expressions such as ‘democracy’, ‘freedom’, ‘equality’, and ‘terror’, etc. Whether the scientific community dealing with the study of societies of agents and conceptual spaces will ever be able to contribute to solving such problems in the future remains to be seen.

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