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Brain-Computer Interfacing for Interaction in Ad-Hoc Heterogeneous Sensor Agents Groups

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We propose a formalism for representing concepts at a cortical level in order to abstractly reproduce human reasoning as captured via a brain-computer interface. The same model provides intelligent agents with reasoning, learning and decision capacity when interacting in heterogeneous ad-hoc sensor networks. The agents are endowed with self-awareness, and awareness of peer intentions and group gain. They rely on epistemic and belief logic in order to make individual or group decisions in the context of imperfect information and faced with the possibility of malicious agents impersonating group members or injecting corrupt information. Human agents can communicate with the group by natural language or a brain-computer interface.

1. Introduction

Our aim is tracing a path from emotion representation towards abstract reasoning, firstly by generalizing the mathematical representation of emotions to that of abstract concepts. We attempt to capture intention, self and malicious intention in peers, motivation, self-gain, versus group-gain. Our goal is finding a mathematical model to express abstract sentences, and for this we take into account concept algebra, inference algebra and dispositional explanation. Our contributions focus on several directions: (1) the algebraic model for cortical representations of concepts (mental words) is translatable and can be used for interoperation with formal models of knowledge representation as employed in heterogeneous agent groups; (2) translation - high level interoperability mechanism that is information and knowledge representation independent and permits learning; (3) learning - we propose a model that allows agents without prior experience of instances of a concept, to operate with and include a concept in their knowledge base and visible universe; (4) the high-level formalism aims to emulate human-like reasoning, with its *dimensions* (trust, belief, intention, goal) and to simulate coalition-forming, interaction and decision making.

We will outline the steps towards formalizing a model for a transducer, our approach being novel in the sense that until now there is no algebraic formalism for group interaction between swarms of intelligent agents with capacity for independent action and decision, and human users. Our proposed model aims to permit translation of commands and requests between human and non-human agents.

2. Operating Concept Base

We start with the following premises: a) our universe U is composed of Agents, Groups and Environment; b) the Environment E consists of all observable entities, actions, reactions and phenomena, all inferrable information and latent information; c) Groups may coexist simultaneously, with or without interaction or awareness of one another;d) Agents (and therefore Groups) have visible (Vi) and invisible (Inv) universes; e) the union of all individual visible universes in a group forms the visible universe of the group; f) the intersection of all individual invisible universes in a group forms the invisible universe of the group; g) likewise, the same above applies to groups of groups; h) observational Knowledge(a), (K(t)) is the cognition at a given time (t) of the environment E, as perceived by *a*, it being an agent, group or group of groups.

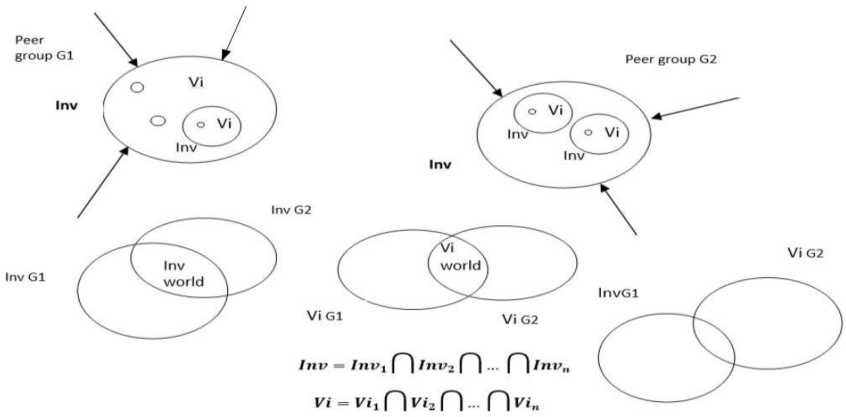

Fig.1:Sensory perception of universe of knowledge by groups of agents

From the knowledge gained by observing and interacting with the environment E, there is a core of axiomatic rules and laws for a given environment that are immutable and unquestionable to agents and groups and the value of truth and meaning of which are non-disputable. We label this AK ("axiomatic-knowledge").

3. Propagation of Knowledge in Time Quanta

Agents are mobile or stationary entities endowed with sensory perception and/or reasoning ability, as well as communication capacity via secured channels. They may have the ability to form ad-hoc coalitions and negotiating capacity. Agents may have or assume (under given circumstances) decision and/or leadership ability. An agent has a personal task, a group task (either can be null), a cost for each performed action and a gain for a task. Also, agents may interact with central authorities that can superscribe (if authorized) decisions and alliances performed by agents in lower roles. Central authorities may be human users.

For processing purposes we resort to what we label operational knowledge, which comprises ontologies used for classification, object model databases, visual words (Szeliski) databases, etc.

Sentences can be: a) observations; b) reflections; c) deductions; d) intentions; e) commands; f) negotiation. Sentences are conjunctions of words. Words are concatenations of symbols over an alphabet chosen to correspond to features defining objects and events from the sensory input.

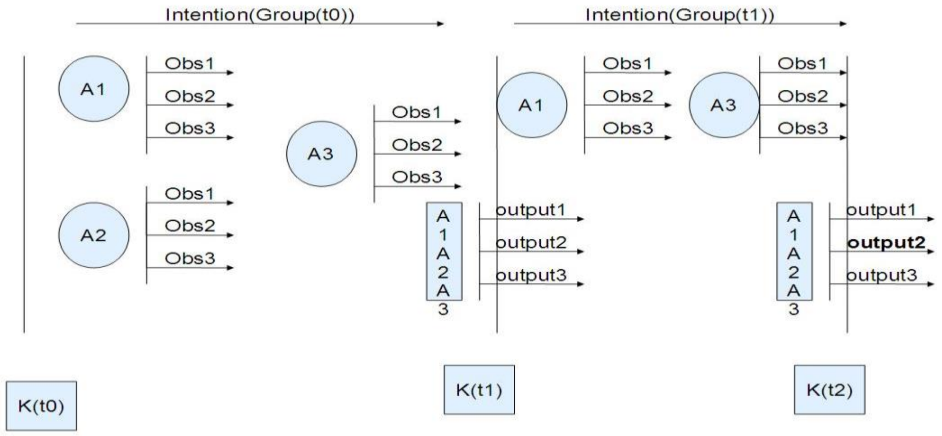

Fig.2: Propagation of knowledge in time and cascading reasoning; underlying group intentions;

Predicates are defined over the same alphabet. Words can admit synonyms. An ambiguous sentence over a type of input will accept a disjunction of possible words leaving the final meaning to be clarified by reasoning or sensor fusion with another agent. We further detail sentences :

a) Observations are sentences in the above form, that are restricted to information gathered at a given time t, directly from the environment E, without further deduction, application of axiomatic knowledge, group communication or querying of peers.

b) Reflections are pieces of abstract knowledge that are not necessarily related to objects or events in the given agent's visible universe but can be deduced from previous knowledge, axiomatic knowledge, observational knowledge and peer and group knowledge; they can contain self-adjusting and adapting of agent's knowledge.

c) Deductions are sentences obtained by applying inference rules over sentences in the previous knowledge and are aimed at obtaining a concrete statement about the sensory data;

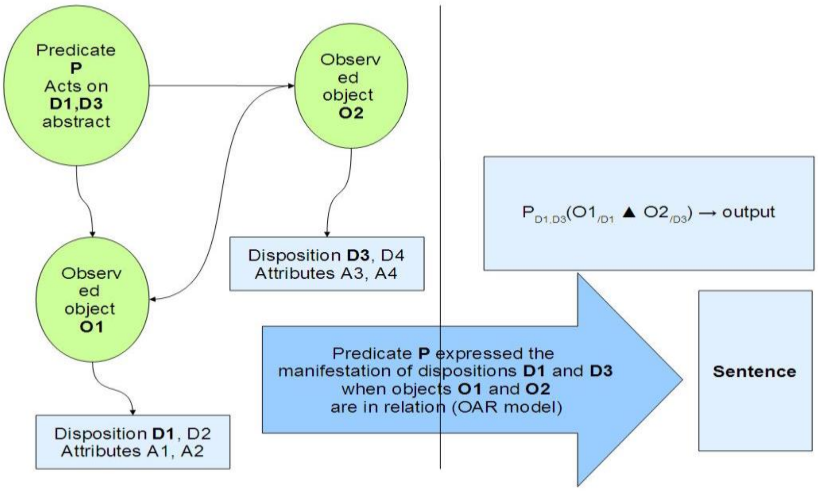

Fig.3: Inference on an image by single agent (first level understanding)

d) Intentions are sentences involving a word describing an action, that involves the agent expressing it or it's group; intentions do not have the same life cycle as observations, as they are more related to the task and gain attributed to the agent or group rather than to changes in the environment; intentions are undercurrents that drive the agent interaction with the environment.
e) Commands are sentences translated in a language that is semantically universally comprehensible to all agents, can be externally or internally triggered and are in strict relation to agent role, task and resources.
f) Negotiation describes a sequence of exchanged sentences between agents, sub-coalitions and groups, where stable coalitions and results of negotiation are established via game theory. It consists of cooperative game solutions such as the τ-value, Shapley value, nucleolus, and clan games.

4. Our Goal

Our goal is allowing communication between agents independently of their specific data representations and data nature, at a semantic level. The information exchanged between agents does not depend on direct observations of the environment, but rather on understanding the necessary action and relaying it to the most adequate agent or person that should receive it for maximal group gain. Different types of input are translated and fused into high level, abstract sentences, that express the situation in the environment at a given time and the necessary actions to be undertaken. Agents operate with abstract concepts, and do not need to perceive and understand a concept through their own knowledge or senses, but only at a semantic level, through its dispositions and semantic dimensions. This equates to the fact that a terrestrial vehicle without computer vision capacity could understand the fact that it is being followed by an UAV, that a doctor could receive an alert that a patient under surveillance is having an epileptic crisis (without receiving the raw EEG data), etc.

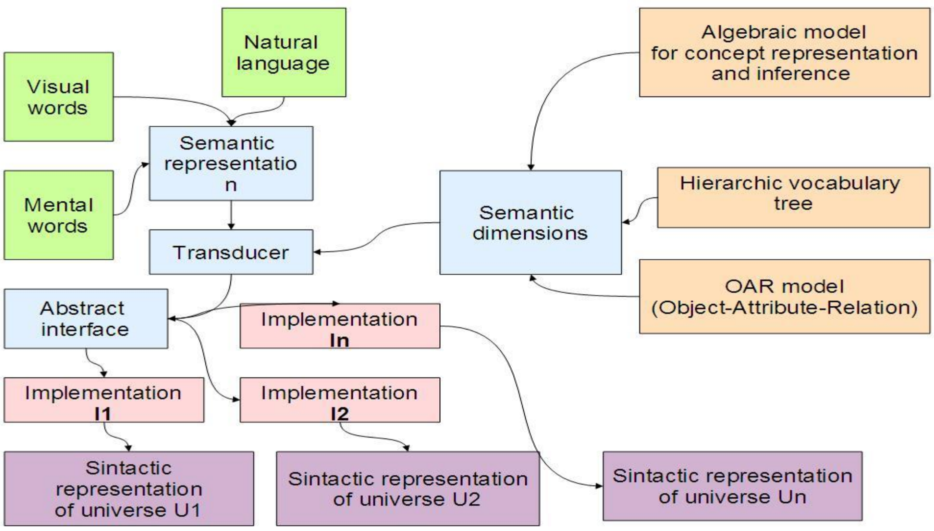

Fig.4: Application architecture for interoperability in heterogenous sensor agent groups

5. Algebraic formalism

In order to capture the manner in which thoughts follow in the human brain, one must first be capable of encoding cortical representations of concrete objects, verbs and abstract notions. It has a been proved that imagined motion, emotion and objects elicit the same cortical response as the actual triggers [1, 2, 3, 4]. Mitchell [5] proves that concrete countable nouns can be represented using underlying brain codes, where a semantic dimension of a given concept can be encoded as a given cortical location. Our own work [6,7] proves that it is possible to express emotional responses as cortical activation patterns that equate to words over an alphabet that encodes cortical locations and features of the EEG signal. However, we have observed the fact that emotional responses may vary over time, and according to the state of the subject. Thus, a response to a fear trigger in a state of emotional balance will differ from a response to the same trigger when applied to the same subject in a post-traumatic or otherwise perturbed emotional state. Also, there may be shifting in the emotional pattern over time (rewiring of the neural pathways). In consequence, there may be synonymous emotional patterns, that activate under different circumstances, which leads us to consider using an epistemic approach via dispositional properties and dispositional explanation [8]. Dispositional explanation makes it possible to explain why a certain event or behavior was present given a set of observed circumstances, known dispositions of the object (here, possible synonymous mental states) and behavioral rules. By using multiform dispositions it is possible to introduce beliefs in the reasoning process, thus being able to express the subjective dimension of human reasoning. This is combined with Wang's approach to concepts and inference via concept algebra [9] and inference algebra [10]. For Wang, knowledge becomes a concept network based on the object-attribute-relation (OAR) theory. Wang accepts the fact that a concept is given by the closure of the attributes of the set of objects that instantiate it, making it possible to map dispositional properties over attributes (semantic dimensions, cortical locations). The algebra described has relational operations (concept equivalence, super and subconcepts) and compositional operations (inheritance, tailoring, extension, substitute, composition, decomposition, aggregation, specification, and instantiation). For knowledge manipulation, the algebra relies on a generic topology of abstract knowledge systems K that is a hierarchical concept network. Wang attempts in [10] to model human-like reasoning using inference algebra (IA), which he structured as a set of algebraic operators on a set of formal causations. The latter are mapped to three categories (according to [10]): “logical inferences on Boolean, fuzzy, and general logic causations; analytic inferences on general functional, correlative, linearregression, and nonlinear regression causations;hybrid inferences on qualification and quantification causations“. A calculus of discrete causal differential and formal models of causations are introduced, and based on these nine algebraic inference operators of IA are created in order to manipulate the formal causations. By joining dispositional explanation and inference algebra it becomes possible to formally express human reasoning, for agents to infer based on their sensory input and knowledge, and to reason about and understand their own train of thought, as well as that of other agents, since we use dispositional explanation which pertains to scientific explanation.

6. Group Interaction for Agents Emulating Human Reasoning

Steps are taken to the new generation of cognitive computers, and cognitive agents. Thus, we assume that our agents are equipped with the fore-mentioned formal framework, sensors and an initial knowledge base. They have self-awareness, awareness of the group and personal and group task. Each agent communicates with the others via sentences in the given inference algebra, and is aware of the existence of an invisible universe given by the data it does not possess or cannot perceive via its own sensors. Also, it is aware of the existence of malicious agents that can infiltrate the group in any way. Thus, interaction is composed of various types of communication: information requests (in which the source credibility and reputation is considered); knowledge gathering (source credibility and principle of majority); action requests and beacons; coalition requests and group gain calculation (Shapley value, core, nucleolus etc.); reasoning about other agents and sharing the results (warning other group members of potential malicious agents, threats

etc.). Agents are equipped with an initial knowledge base, self-awareness, group awareness, a task and gain sense(individual vs group gain) and awareness of invisible universe.
Agents are capable of communication and producing and enhancing joint knowledge, by employing trust and reliable information. Agent communication consists of: a) information requests (upon reputation and credibility); b) knowledge gathering (by learning and reasoning); c) action requests and beacons; d) coalition requests and group gain calculation; e) reasoning about other agents and self. In case of interaction between agents in two peer groups, the following may occur: a) A1, A2, A3 form a stable coalition within the same peer group; b) A8, A9, A10 form a clan game, Big-Boss game, etc., with A11, A12, A13, that are members of the coalition without relevant decision capacity; c) A14 will be included in a coalition according to the Shapley value, core or t-value; d) A5 and A6 are both part of the same group G1, even though A6 also operates on the area of G2, and choose to cooperate; e) A4 and A7 belong to different groups, and are engaged in a non-cooperative game. Beliefs, trust and reputation are established by using epistemic logic, belief logic and a logic of trust. Dispositional properties and dispositional explanation are employed in order to explain actions in perceived sensory input and deduced or acquired knowledge. We take into account the fact that we are dealing with imperfect information in a hostile environment, thus the issues of trust and malicious agents, impersonation, infiltration, handling intruders and group resilience are raised.

7. Conclusion

We have attempted to propose a formalism for representing abstract thoughts, that resembles the manner in which the human mind expresses a train of thought. The starting point have been representations of concepts at the cortical level, which we mapped onto an algebra. We briefly expressed how these translate in interactions in groups of sensor agents.

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