Machine Situation Assessment and Assistance: Prototype for Severely Handicapped Children

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***Abstract*— A multi-disciplinary system development aiming to build collaborating environment is reviewed here. The system is supposed to analyze and help the communication and the daily activities of severely handicapped non-speaking, but speech understanding children. The task poses considerable challenges for the backing cognitive theory; these children can not express themselves properly. The key concept is augmentative and alternative communication, which concerns both novel technology tools and individual contacts for each children. On the technology side, we have tools like (i) human-computer interfaces, e.g., webcams, RF-MEMS tools, see-through HMDs, as well as a robotic dog (ii) technology elements for situation analysis and situation assistance, which can forecast tasks and distribute the resources in order to respond adequately and pro-actively to ongoing activities, the tasks undertaken, and the emotional signs available. Usage of these tools requires a deep understanding of human cognition, including the potential to develop individual 'sign languages'. Thus, theory and practice should be closely linked. We have been developing a cognitive architecture, which has its roots in neuroscience and, in principle, can build the language with other cognitive entities. Here we elaborate on the technology components, the theoretical approach and the (future) plans to connect them.**

I. INTRODUCTION

Intelligent environments [1] may become available in the near future. It has long been recognized that emotional signs are very important in such endeavors, because they enable fast communication and provide information about 'hidden' variables of the partner [2]. There has been a very fast development on the technology side [3]; theory of distributed computing is advancing very quickly [4], [5], [6], progress of measuring tools and methods for the modeling of social structures and the dynamics of social networks is also fast (see, e.g., the collection in [7]). Furthermore, there are recent evidences that prediction of events in intelligent environments is much more reliable than expected [8].

It is then a challenge for cognitive system research to start to put pieces of the technology together. There is a synergy here: research on cognition may promote the development of intelligent environment, and vice versa, constraints of ambient intelligence may provide a hint about the secrets of cognition. This synergical development has been undertaken in our approach that I review here. First, in Section II, I describe the prototype project, the tools and the environment we have been developing for severely handicapped, non-speaking, but speech understanding children. Development is concerned with the software that connects the pieces to each other and to the user, too. Some preliminary results are presented in Section III. The next section (Section IV) puts forth the theoretical layout, i.e., the backing cognitive architecture, which should support individual practices, should respond to particular signs of individuals, should be adaptive and goal oriented. The paper ends with a description of future work needed to make ends meet (Section V).

II. PRACTICE: PROTOTYPE INTELLIGENT HOUSE

A. People in the House

The software and hardware components are assembled in the Augmentative and Alternative Communication (AAC) Center of the Hungarian Bliss Foundation (Fig. 1).

Doctors, psychologists, experts of special education, conductors guide the complex rehabilitation program for children and young adults between 18 months and 25 years, who have special complex communication needs. Different tools have been designed, tested and corrected jointly, experiences have been collected and documented at the AAC Center for later analysis and datamining.

B. Hardware in the House

The house has WiFi communication. There are several wheelchairs equipped with laptops and webcams. There is robotic dog, and children have see-through HMDs, among many other things. RF-MEMS MICA motes[1] of different kinds are used for acceleration measurement, measurements of directions relative to the North pole, and position measurement. These tools can determine configurations and positions, for example. Some of the tools are shown in Fig. 1.

[1]CrossBow Technology Inc.

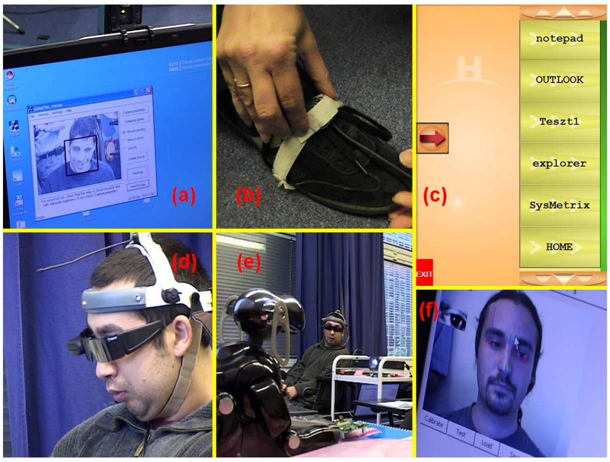

Fig. 1. High tech tools used at the AAC Center. (a): laptop with webcam and the webcam based head tracking software (webcam head-mouse). (b): RF-MEMS accelerometer measures direction of the leg (leg-mouse), (c): board based navigation with self-calibrating calibrating and predictive capabilities, (d): RF-MEMS head-mouse and see-through HMD, (e): person is watching what is happening behind him, by controlling the head of the robotic dog and using the see-through HMD that transmits the information from the camera in the nose of the dog, (e): webcam based gaze-tracking during calibration. For *demonstrations*, please, 'click here': http://nipg.info/smf/index.php?topic=112.0.

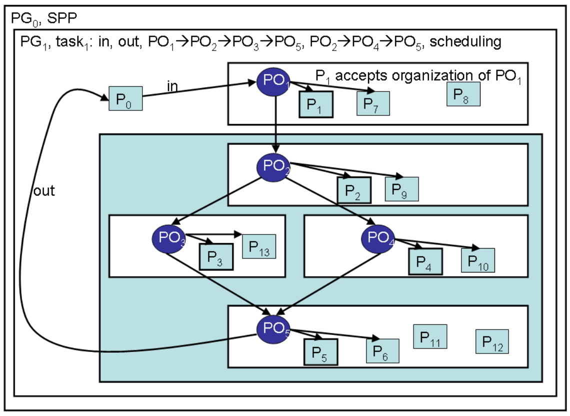

Fig. 2. Sketch of the Survivable Pipeline Protocol. A task with a CDFG description is advertised over the P2P network. CDFG expresses time constraints in terms of restart time and latency. Units may try to organize hierarchical groups to solve the task. Unit P_1 organizes the first pipeline operation (PO_1 and searches for partner to solve the second operation, i.e., PO_2. Pro-active and robust operation is achieved by the time constraints that are checked from time to time. To each operation a friend list is constructed and updated given the experiences.)

C. Software in the House

Software components serve to build the links at all levels, including the links between human and computer, the links between human users in the house, the links and safety between the hardware components, including bandwidth sharing and wheelchair collision avoidance, and the links between humans and external organizations, e.g., doctors. I start the description from the user interfaces and finish with the connections to external organizations.

User interfaces include different mice, such as the webcam and RF-MEMS based head-mice, the leg-mouse, and the webcam based gaze tracking software as well as self-calibrating applications, such as the board based navigation tool make an other software type (Fig. 1).

Practicing tools have the form of training routines, games, and testing routines. Some of these are standardized, some others are supposed to undergo standardization, but these form the smaller portion of this type of software.

Connections between hardware tools at the lowest level may break and we develop *self-organizing communication* between mobile units (Fig. 2). The example that we studied is wheelchair monitoring using RF-MEMS Crossbow crickets. The protocol that we developed is called Survivable Pipeline Protocol (SPP). SPP assumes that both data transfer and computation are distributed and may be troublesome. SPP organizes computations according to Control and Data Flow Graphs (CDFG), the principle used for hardware design. Beyond that, SPP assumes that certain events may occur repeatedly, they can be forecasted and the trust level of the different participants can be estimated. The algorithm [9] utilized by SPP is based on trust level and thus it mimics the organization of collaborating groups in social structures that develop upon experience [10], [11], [12]. The software is a JAVA based general purpose peer-to-peer (P2P) software package. It supports work-sharing between computers. For RF-MEMS tools, part of the SPP has also been developed in TinyOS.

Software design is eased by the socket system. Designers can develop their own software tools and to other services through the JXTA system. This socket system has been made *intelligent* by adding the prediction by partial matching (PPM) algorithm [13]. The possible organization and the interaction of the SPP and the intelligent socket system (ISS) is shown in Fig. 3

Connections to external organizations, e.g., parents, doctors, legal entities are necessary. Then one is concerned with privacy, its guarding and controlling, subject to the regulations of the interacting communities [14]. Methods and principles that enable the collection of experiences while still saving privacy of the individuals are necessary, because of the following reasons. For one, the collection of experiences makes the database that supports quick personalization. On the other hand, the

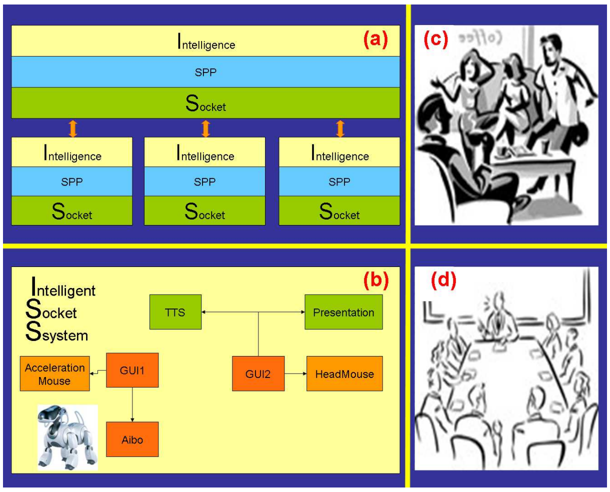

Fig. 3. Intelligent Socket System (ISS) with SPP. (a): SPP organizes and maintains the connections among services. When taking part, participants use the sockets. PPM predicts the next operation and starts to organize it before the demand appears. (b): Components needed at a presentation in the house. (c) and (d): many of the events occur on a regular basis, which allow the organization of the communication and computation tasks in advance.

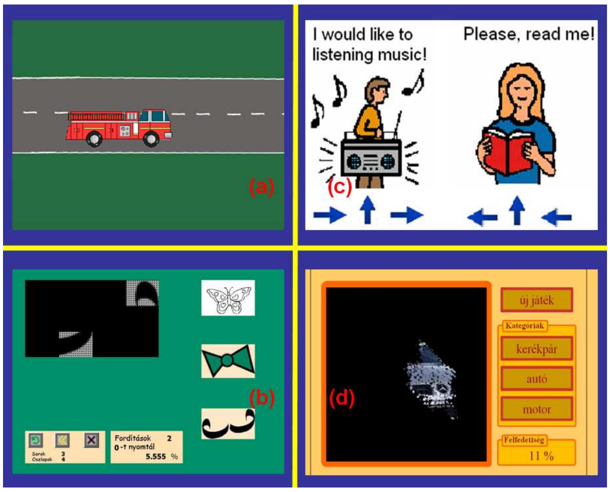

Fig. 4. Practicing games for children. (a): practicing motion from left-to-right. (b): recognition from parts, (c): communication using eye-gestures. Moving the eyes to the right then up then right again, instructs the computer to send to the TTS 'I would like to listen to music!', (d): uncovering images; a task for trajectory planning.

majority of the data should be hidden from the general public because of privacy rights. The emerging concept is blind datamining (or blind vision). The idea is that access to the data is warranted if permission is given. Access to other data is not provided and the fact that the data is searched at a given moment is also hidden [15].

We also develop 3G tools, because this technology component is important and the expected future price is low.

III. UTILITY

A. Practicing for Healthy Subjects

We have studied the performance enabled by the head-mouse, e.g., for typing [16]. A reasonable 0.5 Hz typing frequency can be achieved without the PPM, whereas the PPM improves typing frequency by a factor of 2, i.e. to 1 Hz. Upon practicing, we found no differences between head-mouse and the traditional desk mouse. Careful (hidden Markov model) analysis of the data showed that there were individual differences between the subjects and that the performance could be improved, e.g., by quickly noticing the intentions to correct typing errors. Differences between users and this observation underline the need for personalization.

For handicapped children, we have developed games that scale from easy-to-hard and have some flavor of cognitive testing. Principled testing for our case, when there is little way of knowing if the question or the task is understood is under construction. A few examples are shown in Fig. 4

B. Therapeutical Advantages for Handicapped People

Performance of handicapped children covers a very broad range. In some cases, fast learning was seen (Fig. 5). Performance that suits the constraints of board based communication (Fig. 1(c)) was achieved upon a few trials. In another case, we found that the child did not use his neck muscles although he could have done so. He became motivated by the computer games, started to use the tools and produced large uncontrolled and hyperkinetic looking head motions. Then, during a few months, control improved and smooth normal head control developed. Such therapeutical advantage may be present in other cases, e.g., in the treatment of muscle atrophy. It is important that the tools are used under expert guidance.

C. P2P protocol

The SPP protocol has been studied for TinyOS RF-MEMS crickets. The protocol can work up to 6 cricket motes and can self-organize itself. Time differences between join request and actual joining were 250 ± 8 ms and 350 ± 15 ms for 5 and 6 motes, respectively. Beyond 6 motes, the system collapsed, because ultrasonic transmission and reception were not stable. The simultaneous constraints on single RF transmission frequency and single ultrasonic frequency are too restrictive. Multiple transmission ranges are necessary for more sophisticated self-organizing mote communities. Fast advances on the technology side can be expected in this field.

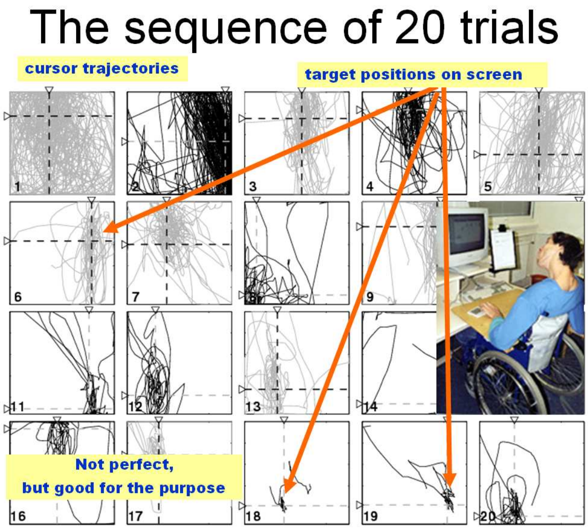

Fig. 5. Subfigures and crossing points of the dashed lines represent the screen and the position of the target, respectively. Grey and black lines: trajectories 'towards' the target point. Grey: somewhere within the screen, black: close to the sides of the screen. Numbers: trial numbers.

The JXTA based SPP and the ISS have much less constraints and the protocol is promising for pro-active organization of communication and computation tasks.

In sum, technology components are available. The backing cognitive architecture, which should become a partner for the children, should help them, guide them and set the alarm if necessary, can not be ad hoc; a principled approach is in need.

IV. THEORY: COGNITIVE ARCHITECTURE

In this section we consider the cognitive tasks and the cognitive model backing the developments. At all levels of goal-oriented problems —including sensory observation, sub-task execution, organization of sub-tasks in space and time— the designer faces high complexity (combinatorial) problems, subject to combinatorial explosion. First, we treat this issue, i.e., the combinatorial nature of the problems at the sensory level. Then we review the problems of control, robust control, goal oriented control, goal oriented decision making and the route to link those. Finally, we turn to the problem of communication about partially observed phenomena. It is an impossible mission to review the literature here. I shall focus on the particular approach we accomplished with my coworkers. Other references can be found in cited literature.

A. Combinatorial Representation

One of the recent advances in data analysis is called independent component analysis [18]. In essence, it assumes that the sources in the world produce noise, noise is not Gaussian and it is emitted by the sources independently. It seems that statistical properties of natural phenomena are in support of these assumptions. There are many developments along this line, which include ideas on sparse coding [19], a relative of support vector machines [20], as well as energy based models [21], and so on.

We have made two theoretical extensions recently:

1) We formulate noise as *causes* that initiate (drive) the processes. We used autoregressive moving average models to remove the processes and to uncover the original, but hidden sources, the causes [22].
2) We showed that discovery of independent causes may not require combinatorial efforts, whereas computational gains upon such discoveries are exponential [23].

These observations can decrease combinatorial explosion at the observation level. This is the basic level of the multi-agent goal-oriented control architecture. In our architecture, goal-oriented problems are optimized by reinforcement learning (RL) [24], one of the most promising approaches in the arsenal of machine learning.

B. Reinforcement Learning with Robust Control

There are crucial bottlenecks blocking the developments in RL. One of them is the Markovian assumption about the state representation. Error correcting algorithms, including robust control schemes, however, are not Markovian and their time depth is uncertain, too. Thus, it is of practical importance if a particular type of robust controller can be embedded into the RL framework. When the answer is yes, then (i) the robust controller extends the discrete action space to a continuous one, (ii) the controller may stay precise even if the conditions change, (iii) temporal changes introduced by the controller disturb the Markovian assumption only slightly under modest conditions [25]. Then the architecture becomes simpler, because one can take advantage of the (approximate) Markovian assumption.

We have also shown that not-too-deep non-Markovian decision problems can be solved by means of recurrent neural networks [26]. Such recurrent and sparse networks form a central part in our architectural considerations.

In spite of the extension with a robust controller and in spite of the potential solution to the problem of temporal memory, Markovian assumption is still subject to combinatorial explosion, because the state space scales with the number of the features in the exponent.

C. Low-Complexity Problems in Reinforcement Learning

The problem mentioned above is known as the 'curse of dimensionality' problem in the literature. We have acknowledged it and ended up in a compromise: we limit ourselves to low-complexity problems. It means that not all, but only a small fraction of features and actions can be combined at a given time. We have shown that this idea lends itself into a highly efficient RL algorithm [27], e.g., by applying the cross entropy method (CEM) [28] to improve the RL strategy. In the demonstration we used Ms. PacMan. A year earlier, we demonstrated the efficiency of CEM for RL in the game Tetris a[29], where we improved existing methods by more than two orders of magnitude. This result started an international competition for ICML 2008.[2].

D. The Problem of Communication

One may assume that features are available for the cognitive system and that these features suit problem description, which means that the problem can be solved by low-complexity combinations of the features. Then, in case of an intelligent environment, either the computer or the user should be able to express itself and herself, respectively to its 'partner', i.e., to the other. Thus, the problem of communication appears, because 'partners' are different and they have different representations.

Here, we made two observations. For one, the agreement between the agents about the signal and its task related meaning is hard if both of the agents are learning. This is so, even in the simplest situations. Emotional coupling, however, can make a difference [30]. Here, emotional coupling means that at least one of the agents has some insights about the *rewards* received by the other and thus it can optimize the actions for the approximated sum of the long-term expected rewards. The other observation is that two agents can correct their representations mutually and the correction is easier if the representations are combinatorial [31].

In sum, we found that if the combinatorial explosion is solved or if it can be limited to low-complexity problems, then communication may become simple, provided that agents are emotionally coupled. In the present context, combinatorial representation means that the same feature may appear in different combinations with other features and the combinations are still meaningful. In language theory, combinatorial features make the compositional language.

We found experimentally that the signal-meaning association problem subject to (a) emotional coupling and (b) active model construction about the other agent, gives rise to game-like situations and traps even in the simplest cases [31]. We expect that this observation will blend important results of game theory with the RL machinery.

The above considerations are relevant, because the children of the AAC Center may not be able to *express themselves properly* and the computer may not be able to *interpret the information properly*. Below, we sketch the cognitive architecture, which aims to take advantages of the algorithmic pieces, but this remains to be shown. Some pieces of the architecture are rooted in neuroscience and I provide a few pointers for the interested reader. The algorithmic pieces of the architecture have support in mathematics: algorithms are convergent and their errors can be estimated.

E. The Architecture: Connections to Neuroscience

1) Note on emotions: I continue the previous note as this. The whole architecture has no support in math. One may say that multi-agent situations can be stabilized to some extent by means of emotional coupling. The better the emotional coupling and the better the joint state description, the easier the optimization is. This underlies the necessity of *reading* the emotional signs of the human participants in order to infer certain problems and to offer alternative solutions. It is equally important to *provide* 'emotional signs' for the human participants, if the decision made by the computer is uncertain, if it can not decide, if something unexpected happened, or if it 'happy' because the end of the task is within reach, and so on.

2) Single agent architecture: In our model, observations are first represented in a *sparse basis* [19] that makes our recurrent network architecture. At the hidden level, the architecture uncovers hidden and approximately independent, i.e., combinatorial causes. Multilayer hierarchical structure is envisioned here [32].

Independent component analysis has been suggested as the central function of memory formation in the hippocampus and its environment by Lőrincz and colleagues [33], [34], [35]. Further, searches for independent causes by first removing the autoregressive processes, then finding the causes and finally learning the internal model of the processes seem to fit several falsifying constraints of the neurobiological structure in the hippocampal entorhinal loop [34], including the independence of representation in the hippocampus [36]. We have shown that Hebbian learning rules can accomplish this series of tricks [37]. Then an associative predictive structure at the hidden level can be build to represent the temporal processes of the environment. This structure makes the model of the environment [37].

We conjecture that there are similar aspects of (i) intra-agent information fusion, or binding and (ii) inter-agent communication, the formation of language. In the

[2]Reinforcement learning competition on Tetris at ICML 2008: http://rl-competition.org/content/view/19/35/

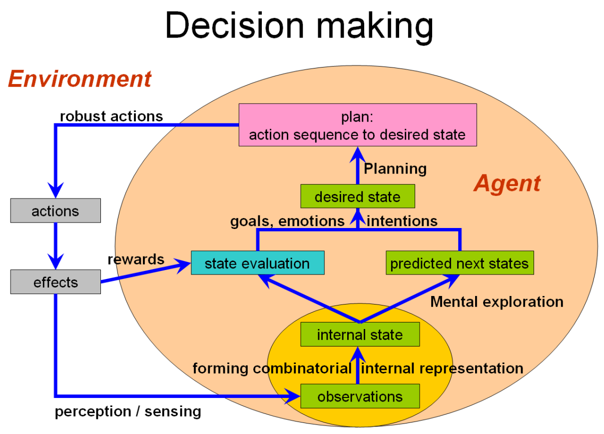

Fig. 6. Decision making for a single agent

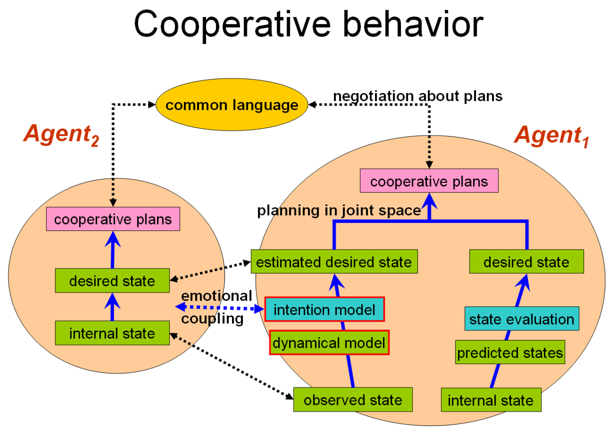

Fig. 7. Decision making in the multi-agent case

present model, they are seen as *relatives* of each other. This observation points to factored representations and factorial Markov decision problems for building joined internal models about the self *and* the other agents.

Decision making in the RL framework starts from the internal representation of the recurrent neural network [26], [38], utilizes value estimation and a model of the dynamics to optimize behavior, finds low-complexity solutions and may devise multi-step plans. Planning has not been included into our mathematical model, yet.

The architecture may execute control actions by means of a robust controller, which can overcome problems coming from unobserved parameters, like changes in the masses or in the length of the links. A particular robust controller, which exhibits attractive global stability properties, has been developed. *The controller has some neurobiological support* [39] and it fits the RL framework smoothly [25]. It may be worth noting that *RL methods* we use have considerable support in *neuroscience*. For further information on this subject, see, e.g., [41], [42], [43] and the references therein.

The sketch of the single agent architecture is depicted in Fig. 6.

3) Two agent architecture: Agents may model the dynamics and the evaluation of each other, and take these into account when making decisions or devising plans. We have shown that this kind of 'emotional' coupling may be necessary to establish common goals for the agents. Compositional communication is needed to negotiate about plans. Communication can be made efficient by means of combinatorial generative network architecture [31].

Two agent architecture is shown in Fig. 7.

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

We have been developing intelligent environment for intelligent, severely handicapped, non-speaking, but speech understanding children between age 18 months and 25 years. This is a prototype project, executed at the Augmentative and Alternative Communication Center of the Hungarian Bliss Foundation. The project is, hopefully, relevant for all scenarios that fall into the category of Ambient Assisted Living.

We have developed and tested different software pieces. Amongst other tools, we have developed self-organizing P2P network protocols in JAVA for computers and in TinyOS for Smart Dust. We also have several user computer interfaces; the *mice*. These tools can be used if the body parts, or at least the eye can be controlled by the subject. The tools need continuous calibration, called self-calibration, here. For some of the tools, especially for our visible light based eye-mouse, data collection seems necessary. Gaze estimation is troublesome for visible light, but it is important for *situation awareness*: estimation of gaze direction is necessary to understand human communication even if *none* of the subjects is sitting in front of the high resolution cameras.

Data collection and personalization raises privacy issues. We have considered this problem and we are confident that it can be solved by combining blind vision methods [15] and threshold cryptographic algorithms for autonomous, but accountable self-organizing communities [14].

The efforts to build an intelligent environment have been accompanied by research and development on cognitive architectures. During this work, we have noticed the necessity of emotional coupling in multi-agent scenarios [30] that I have emphasized.

The cognitive architecture is made of

1) a sensory processing part, which fights combinatorial explosion for non-combinatorial costs and may give rise to exponential gains in learning time,
2) value approximation and policy gradient algorithms for optimization of low-complexity reinforcement learning tasks with the option of adding robust controllers to the architecture, and
3) algorithms for developing communication about differing sensory information.

Both the software tools and the backing cognitive architecture have their own promises. However, there are missing pieces and open issues and those might be very demanding. Complexity increases at each step, and there are many more steps to go. Both parts of the work, i.e., the engineering part and the scientific part are of high importance in these future developments

B. Future Works

Further developments are necessary both on the software side and on the theoretical side. On the software side, data collection and general object recognition algorithms are necessary. This part of the project may lead to situation understanding in the remote future. However, the understanding of simple situations, like being frustrated, being tired, the task is too easy, etc., should be within reach.

On the theoretical side, further development of the cognitive architecture is required. We are to include planning and risk analysis into the cognitive model. In this aspect, multi-agent scenarios point to factorial Markov decision problems. Learning scenarios[3] with factorial models, searches for emerging collective behavioral patters are currently under study in different simulated environments.

Some preliminary efforts have been made to map the mathematical structure to the neurobiological substrate. More importantly, studies of cortical and subcortical structures helped to develop the crucial building blocks of the cognitive architecture. Thus, these efforts should be strengthened; future work may gain from a much better understanding of recent advances in neuroscience.

VI. Acknowledgments

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