

An intelligent decision-making system for autonomous units based on the mind model

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Abstract—The article presents current trends in autonomous robotics. Especially, it brings to the front aspects of cognitive architectures, and shortly describes them. After that it briefly describes the Intelligent System of Decision-making developed in Gdask University of Technology.

Index Terms—Cognitive informatics, Cognitive robotics, Cognitive science, Psychology, Artificial intelligence, Intelligent robots, Knowledge representation

I. INTRODUCTION

For a long time, we can observe a progressive automation. More and more devices have built-in microcomputers, which can make partial decisions. Robotics went to schools, where children learn languages or solve math problems in cooperation with robots. There are many reports (in the internet) about jobs which will take over by robots driven by artificial intelligence (e.g. business analyst, cashiers, etc.). Most likely, professions such as firefighters and soldiers soon will completely change their profile [1]. Robots are also currently used in medicine: ultra-precise surgical robots (operating with much greater precision than a human), robots helping in rehabilitation, or dealing with elderly people, children, people with disabilities, etc. [2, 3, 4]. This progress is taking place with the increasing autonomy of the robots [5, 6]. The projects of autonomous cars are developing more and more dynamically.

One of the most interesting examples of recent years is SYNAPSE¹ (Systems of Neuromorphic Adaptive Plastic Scalable Electronics). This program, carried out on behalf of DARPA, HRL, HP and IBM, aimed to create a system (at the level of a cognitive computer) which can imitate the way of work of the mammalian brain. As a part of the project, a microcomputer was designed (24 nm technology, with 5.4 billion transistors) which can model one million neurons with 256 million synaptic connections. The computer works on the principle of teaching neurons (the Hebb rule), in a manner analogous to the biological [7].

Another IBM project, called Blue Brain, is a neural network that illustrates the cat's cortex. It can simulate about 10 billion of synapses [8], operating on 147 thousand processors and 144 TB of memory. Earlier, as part of the same project, the brain of the rat and its somatosensory cortex was simulated in a

very precise manner [9, 10]. Currently they try to improve the speed of the model, because the whole program works about 100 times slower than the real brain [11].

Looking further, from the detailed point of view, we can distinguish the aspect of *iudicium corpum* (body decision), which focuses on the problem of controlling manipulators using the human body (haptically). A typical example of such an approach is an artificial hand controlled by the myograph signals (EMG) of the chest [12, 13], or forearm [14]. An extensive haptic remote control system for an industrial mobile robot is presented in [15]. This type of projects can also include moving the mouse cursor only with the help of eye movements – CyberEye system [16]. Such systems allow for the implementation of the idea of building equipment that guesses what people mean.

Another example of such ideas may be a verbal communication at a level passing through the Turing test [17]. In other words: a machine capable of extracting information from a sentence written in natural language about the task it is to perform. Obviously, there is no program that is able to pass the Turing test, although depending on the exactness of the test definition, some chatterbots (Cleverbot, Eugene Goostman) are already classified as such [18]. Recently, Microsoft has presented a chatterbot, Tay, which imitated an American teenager on Twitter. The program very quickly and effectively learned, in particular, the obscene, racist and abusive content that Twitter users fed its AI. For this reason, the project has been closed [19].

The higher stage of the presented idea is to create an interactive human companion. Not so long time ago, there were several attempts to create an artificial dog, cat, or other robotic pets [20]. One of the most famous examples is Sony's Aibo. Despite the cessation of production and support (in 2014), the community of Aibo holders still exists (it also protested widely against *killing* their pets).

Interactive companion, artificial babysitter, or robot policeman are also currently available on the market or currently created as R&D projects [21, 22]. This is the so-called social aspect of the robotics. Although such projects are very advanced, in terms of design or control methods (they can, for example, walk on two legs, open doors, or use simple tools), it is easy to recognize artificiality in terms of behavior.

¹The project was completed in 2014.

In addition, such projects, for the most part, do not include the manner of *human* decision making. Their decision systems are mostly based on expert systems, fuzzy systems, and even simple behavior rules [23, 24, 25].

In all of the above-mentioned projects, the main essence is the attempt to imitate the real organism. In order to achieve such a goal, we should strive not only to imitate mechanics (in particular neurological), but also the psyche. It is worth noting, that there is already a strict science trying to imitate human ways of solving problems - it is the theory of decision. The method of mathematical modeling of cognitive psychology, including some elements of personality psychology, is no less interesting and interesting approach.

II. COGNITIVE ARCHITECTURES

In general, a cognitive architecture is a model that aims to summarize the achievements of cognitive psychology. In particular it should present a coherent structural model of the human mind. In other words, the main goal of creating cognitive architectures is to isolate all permanent elements in the life of a human or an agent [26]. Among these elements, and with respect to cognitive psychology, we can distinguish:

- memory systems, in particular:
 - short-term memory
 - declarative long-term memory
 - non-declarative long-term memory
- way of representing knowledge contained in declarative memory
- perception processes
- systems of attention
- mechanisms of decision-making
- different types of learning mechanisms.

There are many different cognitive architectures [27]. In principle, they can be divided into symbolic (high level), emergent/connectionist (low level) and hybrid [28]. It should be noted that in symbolic approaches the memory has a form of rules database or semantic webs, while in low-level architectures dominates the letter approach. Among many cognitive architectures, we can distinguish for example: ACT-R, CLARION, Google DeepMind, LIDA, MANIC, Soar and many others [28, 29]. A basic example of such architecture can be the Google DeepMind system, which maps certain human cognitive structures (especially short-term memory). It has ability to learn playing computer games only by playing it, just like normal people (with quite a good result).

III. INTELLIGENT SYSTEM OF DECISION-MAKING

One of the projects that focuses on modeling human psychology is the Intelligent Decision System (ISD) created in Gdask University of Technology. This system can also be classified as a hybrid cognitive architecture. Its main structure is based on the human information processing model, can be shown in fig. 1.

Similarly to a human being, stimuli received by the agent/robot are processed by sensory perception to pure, raw

information (e.g. in a case of robotic perception it is processing of data from distance sensor by the certain characteristic). This information is stored in an ultrashort-term memory which have a flip-flop character. Then, by applying various types of processing (e.g. in the context of an image, it is using of both simple color filters or shapes filter, as well as complex deep neural networks to detect certain features of objects) the impressions – the features of the object – are stored in low-level short-term memory. The next stage of processing is using the spatial grouping algorithms (e.g. image segmentation or segmentation of data from depth sensors). Impressions, recognized earlier, are assigned to certain groups which characterize one object. With the help of unconscious attention processes (which supports access to semantic memory) the discovery perception allows to recognize previously known discoveries – the representation of objects in agents memory [30]. The grouped objects (not all of them must be recognized) are stored in the part of the high-level short-term memory called scene memory. Memory systems in ISD are illustrated in fig. 2. As a result, the agent is able to orientate itself in the environment and detect most of changes occurring in it. The systems of conscious attention are responsible for the analysis of objects in the agent’s scene memory. They are mainly correlated with aspects of motivation. The thinking system is responsible for making decisions based on the possibility of performing certain reactions. At the same time, during processing, both the impression and the observations are analyzed in terms of the agent’s security. If a dangerous element is detected, the unconscious (based on a certain impressions) or subconscious (based on certain discoveries) reactions are activated.

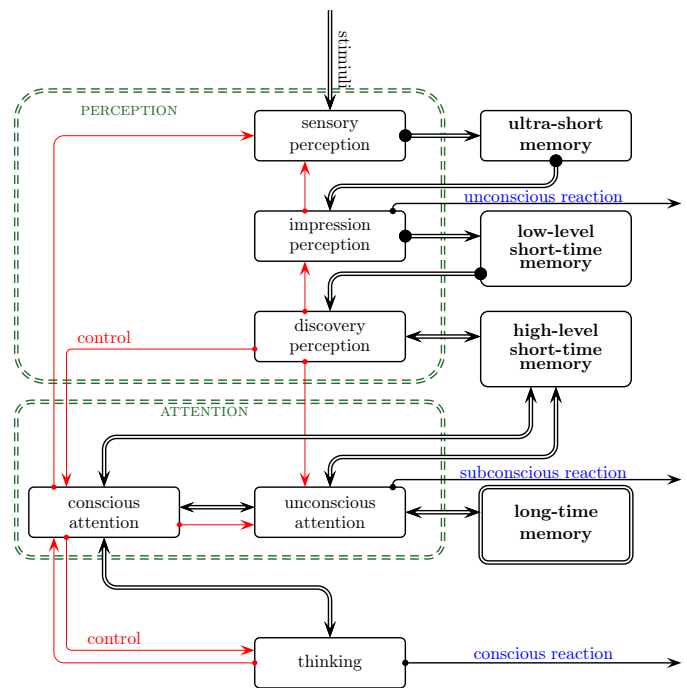


Fig. 1. Cognitive processes in ISD [31].

Among the memory systems in ISD, we can distinguish



classically: sensory/ultrashort-term memory, short-term and long-term memory. In turn, short-term memory can be divided (from the type of objects point of view) to low-level (storing temporary impressions), high-level (storing temporary discoveries), the scene memory and its copy – the imagination memory. The scene memory, as it was mentioned before, stores all observations from the current agent’s environment. Whereas the memory of the imagination is responsible for the analysis of this environment (e.g. in terms of determining the trajectory and future positions of objects, as well as in terms of simulating the hypothetical effects of the agent’s reactions). In turn, are all kinds of descriptions of objects (discoveries) along with their semantic relations are stored in the semantic long-term memory. Existing (real) objects are stored in the individual part and they are instances of objects described in the abstract part. Of course, objects stored in the scene memory are instances of objects from semantic memory. All agent or objects actions from the environment are saved in the procedural memory. The agent learns them, for example, through copying mechanisms. Objects from the scene memory together with their actions (including agent actions) are stored in episodic memory. One can be tempted to call it autobiographical memory, and point out that most forgetting mechanisms occur mainly in it.

The last aspect of ISD cognitive architecture is based on the human psychology model. Especially the motivational factors in ISD are based on humanistic psychology and emotions theories. Two complementary mechanisms have been implemented in it: the commonly known mechanism of needs (humanistic) and the xEmotion – emotional system [36]. Both of these mechanisms work together and allow the agent to choose the most adequate response (reaction) at the moment (described by scene memory and agent’s internal system variables such as states of need and emotion).

The agent’s needs system is based on Maslow’s hierarchical pyramid, which allows for scheduling needs according to the five basic classes [31, 32, 33]. Each of the needs has its own internal function of weight depending on its degree of unfulfillment. The degree of unfulfillment or dissatisfaction is determined by belonging to one of three fuzzy sets defined by linguistic values: satisfaction, pre-alarm and alarm (the sets are differently defined for each need). The set of agent’s needs depends on its specific purpose/goal. It is defined in the agent configuration process. Also, there are defined several mechanisms designed to allow the evolution of the agent’s needs system. One of them can extend needs to further dimensions, e.g. the next dimension may be called the lack of diversity [34]. The system of needs has been tested in several scenarios described in [31, 35].

The second motivational system – xEmotion has been presented in [36, 37, 38]. It consists of components based on the somatic theory of emotions [39, 40], cognitive appraisal theory [41], and partly on the combined theory of Izard [42]. As part of these theories we formed three emotional layers, which was depicted in the fig. 4:

- somatic

- appraisal
- personal.

Among the somatic layer there can be specified: pre-emotions – emotional signals corresponding to previously remembered and emotionally associated impressions (e.g. a red color that evokes the pre-emotion of anger). On the other hand, the appraisal layer is the layer of the *conscious* evaluation of surrounding phenomena (both events and discoveries) in the context of previous agent’s experiments. In this way, sub-emotions arise which, in turn, affect the emotional state of the agent called the classical emotion. Emotions in the appraisal layer are based on the wheel of emotions [38], which is the reversed Plutchik paraboloid [43, 44]. On the other hand, the personnel layer is actually a copy of the mechanism of the appraisal layer with the assumption of the lack of any predefined linguistic emotional labels. In the case of the personnel layer, the signals associated with objects or events had been named sub-equalia, while the state of the agent’s personal emotion – equalia. A long-term emotional factor called mood is determined, based on classical emotion and agent’s equalia.

Both the emotional states of the agent and the entire motivation system affect its decision-making mechanism. On the basis of needs and emotions, with the help of attention systems, the agent determines the list of reactions that are possible to implement at a given moment. The agent chooses the reaction, trying to optimize its impact on the system’s needs.

A schematic description of the above presented system, with some simplifications, is presented in fig. ???. This figure introduces the learning aspect. Namely, the description of the reaction contained in the agent’s memory is modified, basing on the observation of its results. Thanks to this, in the future the agent is able to better estimate the impact of a given reaction on its condition.

IV. SUMMARY

Intelligent Decision System introduces an innovative direction to cybernetics, which has recently focused mainly on modeling economic dependencies. ISD is an interdisciplinary project combining psychology, automation, elements of software engineering, plastic and computational techniques in various aspects of computing and robotics. Currently observed trends in robotics usually rely on the development of methods to improve the HSI. More and more scientific units are trying to create a coherent anthropoid system.

Based on a cybernetic approach to AI, the ISD project models the way of human action (starting from the position of cognitive psychology and the theory of motivation). The ISD system can be implemented in many fields, mainly in broadly understood robotics, but also in psychology and interactive systems. ISD can be also treated as a estimation system of a human condition. The case of estimating the human condition is very interesting, especially since it can also improve the ISD system.



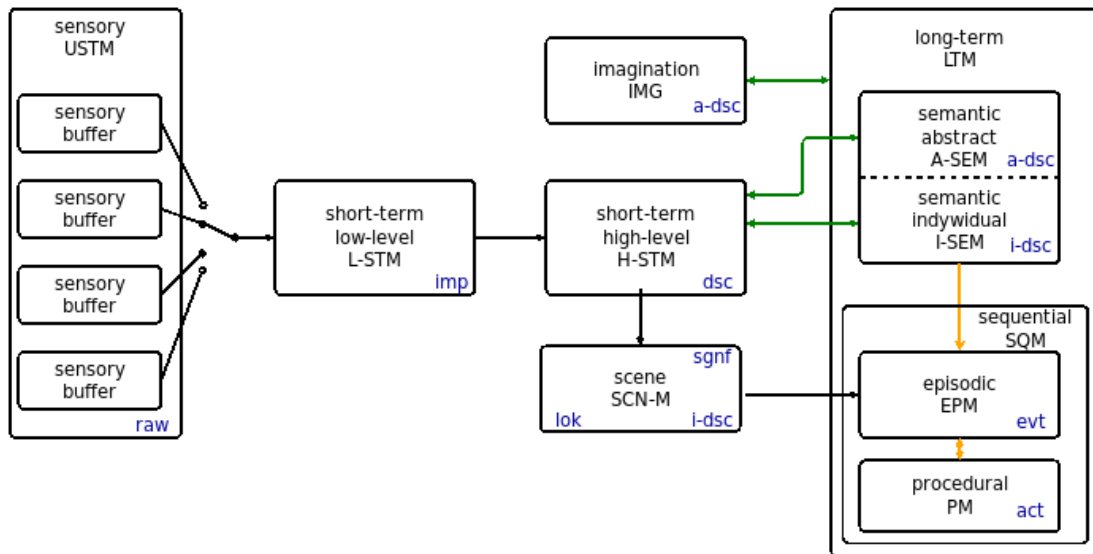


Fig. 2. Memory model in ISD system.

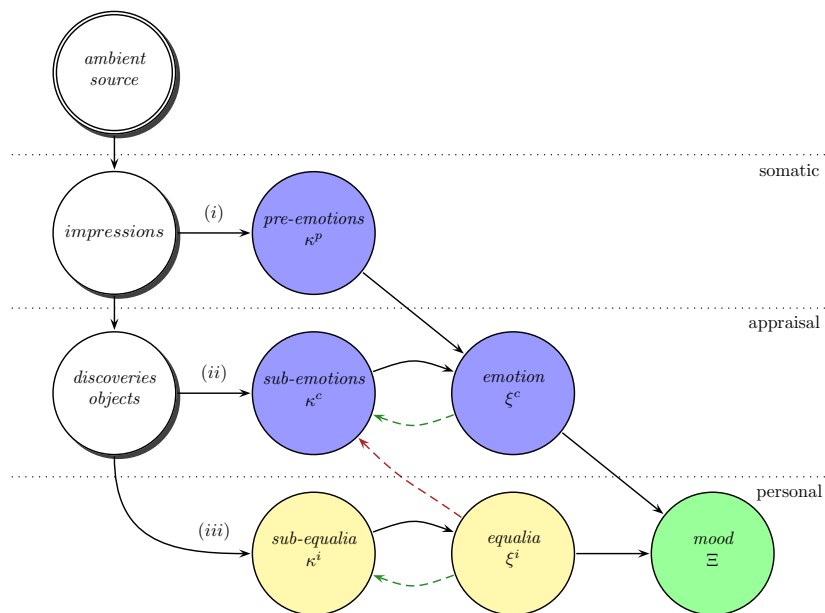


Fig. 3. Types of emotions as a motivational factor in ISD [37].

REFERENCES

- [1] S. Breland, D. McKinney, D. Parry, and C. Peachey, "NRL designs robot for shipboard firefighting," *Naval Research Laboratory. SPECTRA*, vol. 1, pp. 8–10, 2012.
- [2] S. Boucenna, A. Narzisi, E. Tilmont, F. Muratori, G. Pioggia, D. Cohen, and M. Chetouani, "Interactive technologies for autistic children: A review," *Cognitive Computation*, may 2014.
- [3] S. Shamsuddin, H. Yussof, L. I. Ismail, S. Mohamed, F. A. Hanapiah, and N. I. Zahari, "Initial response in HRI- a case study on evaluation of child with autism spectrum disorders interacting with a humanoid robot NAO," *Procedia Engineering*, vol. 41, pp. 1448–1455, jan 2012.
- [4] E. Broadbent, R. Stafford, and B. MacDonald, "Acceptance of healthcare robots for the older population: review and future directions," *International Journal of Social Robotics*, vol. 1, no. 4, pp. 319–330, oct 2009.
- [5] R. Saunders, "Towards autonomous creative systems: A computational approach," *Cognitive Computation*, vol. 4, no. 3, pp. 216–225, mar 2012.
- [6] K. Magill and Y. J. Erden, "Autonomy and desire in machines and cognitive agent systems," *Cognitive Computation*, vol. 4, no. 3, pp. 354–364, may 2012.
- [7] N. Srinivasa and J. M. Cruz-Albrecht, "Neuromorphic



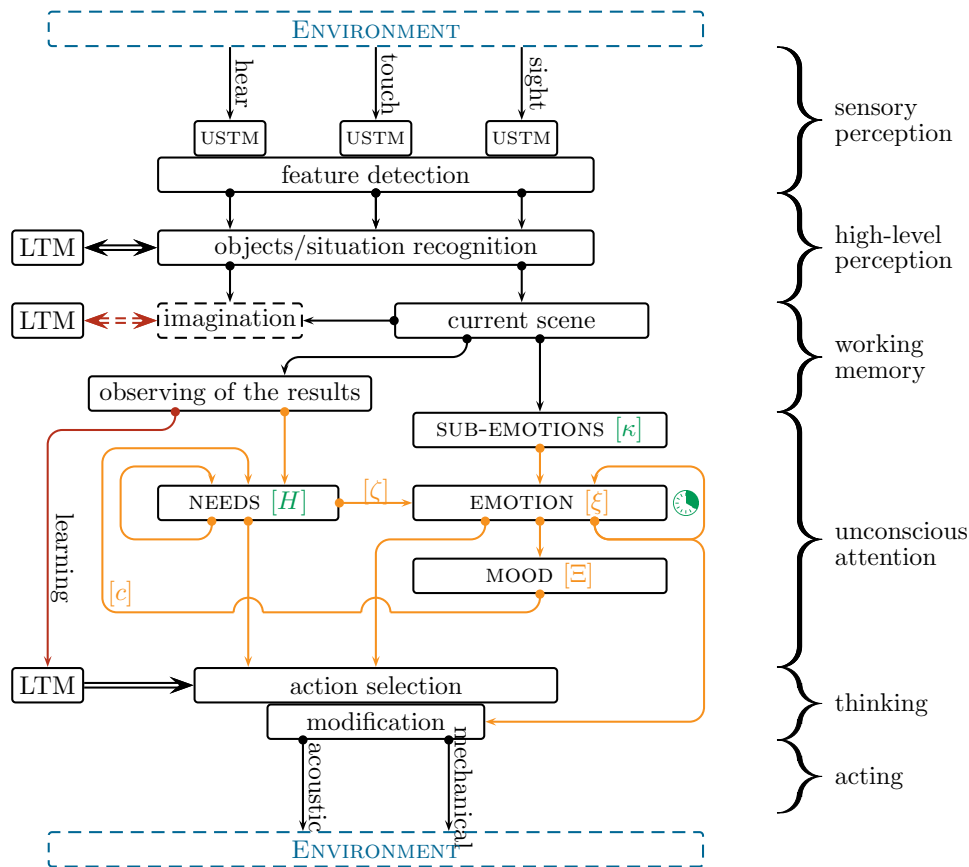


Fig. 4. Schematic view on the Intelligent System of Decision-making. [29].

adaptive plastic scalable electronics: analog learning systems," *IEEE Pulse*, vol. 3, no. 1, pp. 51–56, 2012.

- [8] H. Markram, "The blue brain project." *Nature Reviews Neuroscience*, vol. 7, no. 2, pp. 153–60, 2006.
- [9] S. Muralidhar, Y. Wang, and H. Markram, "Synaptic and cellular organization of layer 1 of the developing rat somatosensory cortex." *Frontiers in Neuroanatomy*, vol. 7, p. 52, 2013.
- [10] S. Ramaswamy, J.-D. Courcol, M. Abdellah, S. R. Adaszewski, N. Antille, S. Arsever, G. Atenekeg, A. Bilgili, Y. Brukau, A. Chalimourda, G. Chindemi, F. Delalondre, R. Dumusc, S. Eilemann, M. E. Gevaert, P. Gleeson, J. W. Graham, J. B. Hernando, L. Kanari, Y. Katkov, D. Keller, J. G. King, R. Ranjan, M. W. Reimann, C. Rössert, Y. Shi, J. C. Shillcock, M. Telefont, W. Van Geit, J. Villafranca Diaz, R. Walker, Y. Wang, S. M. Zaninetta, J. DeFelipe, S. L. Hill, J. Muller, I. Segev, F. Schürmann, E. B. Muller, and H. Markram, "The neocortical microcircuit collaboration portal: a resource for rat somatosensory cortex." *Frontiers in Neural Circuits*, vol. 9, no. October, p. 44, 2015.
- [11] W. W. Lytton, A. H. Seidenstein, S. Dura-Bernal, R. A. McDougal, F. Schürmann, and M. L. Hines, "Simulation neurotechnologies for advancing brain research: parallelizing large networks in NEURON," *Neural Computation*, vol. 28, no. 10, pp. 2063–2090, 2016.
- [12] D. Farina, N. Jiang, H. Rehbaum, A. Holobar, B. Graimann, H. Dietl, and O. C. Aszmann, "The extraction of neural information from the surface EMG for the control of upper-limb prostheses: emerging avenues and challenges," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 22, no. 4, pp. 797–809, 2014.
- [13] N. Ge, P. M. Goebel, S. Amsuess, L. Paredes, R. Pawlik, and D. Farina, "Evaluating upper-limb EMG-prosthesis user performance by combining psychometric measures and classification-rates," in *International IEEE/EMBS conference on neural engineering, NER*, 2013, pp. 359–362.
- [14] M. Drzewiecki and Z. Kowalczyk, "Prototyp biomaniplikatora protezy ręki," in *XV krajowej konferencji naukowej biocybernetyka I inżynieria biomedyczna*, Wrocław, 2007.
- [15] Z. Kowalczyk and M. Tatara, "Sphere drive and control system for haptic interaction with physical, virtual and augmented reality," *IEEE Trans. Control Systems Technology*, no. in review, 2017.
- [16] A. Czyżewski, P. Dalka, B. Kunka, A. Kupryjanow, M. Lech, and P. Ody, "Multimodal human-computer interfaces based on advanced video and audio analysis,"



in *Human-Computer systems*, ser. Advances in Intelligent Systems and Computing, Z. S. Hippe, J. L. Kulikowski, T. Mroczek, and J. Wtorek, Eds. Springer, 2014, vol. 300, no. 3, pp. 87–102.

- [17] A. M. Turing, “Computing machine and intelligence,” *Mind: A Quarterly Review of Philosophy*, vol. 59, no. 236, pp. 433–460, 1950.
- [18] K. Warwick and H. Shah, “Good machine performance in turing’s imitation game,” *IEEE Transactions on Computational Intelligence and AI in Games*, vol. 6, no. 3, pp. 289–299, sep 2014.
- [19] E. Hunt, “Tay, Microsoft’s AI chatbot, gets a crash course in racism from Twitter — Technology — The Guardian,” 2016.
- [20] P. H. Kahn, Jr., B. Friedman, D. R. Pérez-Granados, and N. G. Freier, “Robotic pets in the lives of preschool children,” *Interaction Studies*, vol. 7, pp. 405–436, 2006.
- [21] M. M. A. De Graaf, S. B. Allouch, and T. Klamer, “Sharing a life with harvey: exploring the acceptance of and relationship-building with a social robot,” *Computers in Human Behavior*, vol. 43, pp. 1–14, 2015.
- [22] Y. S. Sefidgar, K. E. MacLean, S. Yohanan, H. F. M. H. Van Der Loos, E. A. Croft, and E. J. Garland, “Design and evaluation of a touch-centered calming interaction with a social robot,” *IEEE Transactions on Affective Computing*, vol. 7, no. 2, pp. 108–121, 2016.
- [23] G. Milighetti and H.-B. Kuntze, “Fuzzy based decision making for the discrete-continuous control of humanoid robots,” in *2007 IEEE/RSJ international conference on intelligent robots and systems*. IEEE, oct 2007, pp. 3580–3585.
- [24] R. C. Arkin, *Behavior-Based Robotics*. MIT Press, Cambridge, MA, 1998.
- [25] M. Fakoor, A. Kosari, and M. Jafarzadeh, “Humanoid robot path planning with fuzzy markov decision processes,” *Journal of Applied Research and Technology*, vol. 14, no. 5, pp. 300–310, 2016.
- [26] A. Newell, *Unified Theories of Cognition*. Harvard University Press, 1994.
- [27] A. Samsonovich, “Toward a Unified Catalog of Implemented Cognitive Architectures,” in *Biologically inspired cognitive architectures*, A. Samsonovich, K. Jóhannsdóttir, A. Chella, and B. Goertzel, Eds. IOS Press, 2010, pp. 195–245.
- [28] W. Duch, R. Oentaryo, and M. Pasquier, “Cognitive architectures: where do we go from here?” *Agi*, vol. 171, 2008.
- [29] Z. Kowalczyk and M. Czubenko, *Embodying Intelligence in Autonomous and Robotic Systems with the Use of Cognitive Psychology and Motivation Theories*, ser. Computational Intelligence, A. Gawęda, J. Kacprzyk, L. Rutkowski, and G. Yen, Eds. Springer, Cham, 2018, vol. 738.
- [30] Z. Kowalczyk, M. Czubenko, and W. Jędruch, “Learning Processes in Autonomous Agents using an Intelligent System of Decision-making,” in *Advances in intelligent systems and computing*, ser. Advances in intelligent systems and computing, Z. Kowalczyk, Ed. Berlin - Heidelberg - New York: Springer, 2016, vol. 386, pp. 301–315.
- [31] Z. Kowalczyk and M. Czubenko, “Intelligent decision-making system for autonomous robots,” *International Journal of Applied Mathematics and Computer Science*, vol. 21, no. 4, pp. 621–635, 2011.
- [32] A. Maslow, R. Frager, J. Fadiman, and C. McReynolds, *Motivation and Personality*, J. Fadiman and C. McReynolds, Eds. New York: Harper & Row, 1970, vol. 2.
- [33] Z. Kowalczyk and M. Czubenko, “Cognitive Memory for Intelligent Systems of Decision-Making, Based on Human Psychology,” in *Intelligent systems in technical and medical diagnostics advances in intelligent systems and computing*, ser. Advances in Intelligent Systems and Computing, J. Korbicz and M. Kowal, Eds. Springer Berlin Heidelberg, 2014, vol. 230, pp. 379–389.
- [34] M. Czubenko, “Antropoidalny Model Inteligentnego Systemu Decyzyjnego Dla Jednostek Autonomicznych,” Ph.D. dissertation, Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, Gdańsk, 2017.
- [35] M. Czubenko, A. Ordys, and Z. Kowalczyk, “Autonomous driver based on intelligent system of decision-making,” *Cognitive Computation*, vol. 7, no. 5, pp. 569–581, 2015.
- [36] Z. Kowalczyk and M. Czubenko, “Computational approaches to modeling artificial emotion an overview of the proposed solutions,” *Frontiers in Robotics and AI*, vol. 3, no. 21, pp. 1–12, 2016.
- [37] Z. Kowalczyk, M. Czubenko, and T. Merta, “Interpretation and modeling of emotions managing autonomous robots, based on the paradigm of scheduling variable control,” *Engineering Applications of AI*, vol. x, no. x, 2018.
- [38] Z. Kowalczyk and M. Czubenko, “Emotions embodied in the SVC of an autonomous driver system,” *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 3744–3749, jul 2017.
- [39] W. James, “What is an emotion?” *Mind*, vol. 9, pp. 188–205, 1884.
- [40] R. B. Zajonc, S. T. Murphy, and M. Inglehart, “Feeling and facial efference: implications of the vascular theory of emotion,” *Psychological Review*, vol. 96, no. 3, pp. 395–416, 1989.
- [41] R. S. Lazarus, *Emotion and Adaptation*. New York: Oxford University Press, USA, aug 1991.
- [42] C. E. Izard, “Four systems for emotion activation: cognitive and noncognitive processes.” *Psychological Review*, vol. 100, no. 1, pp. 68–90, jan 1993.
- [43] R. Plutchik, *The Psychology and Biology of Emotion*. Harper Collins College Publishers, 1994.
- [44] —, “The nature of emotions,” *American Scientist*, vol. 89, p. 344, 2001.

