Research Output Journal of Biological and Applied Science 3(1):1-6, 2024

ROJBAS Publications ISSN: 1115-6120

https://rojournals.org/roj-biological-and-applied-science/

Cognitive Robotics and Human-Robot Interaction

Kabiga Chelule Kwemoi

Faculty of Engineering Kampala International University Uganda

ABSTRACT

Cognitive robotics is an interdisciplinary field focused on endowing robots with cognitive capabilities, enabling adaptive and rational behavior in human environments. This paper explores the intersection of cognitive robotics and human-robot interaction (HRI), delving into key concepts, theories, and technologies that drive these fields. The discussion spans the historical evolution of HRI, foundational components, cognitive architectures, and the significance of social and emotional intelligence in robots. Future challenges and research directions are also addressed, emphasizing the need for more naturalistic and human-like interactions. This comprehensive analysis aims to provide a deeper understanding of cognitive robotics and its implications for developing effective and ethical HRI systems.

Keywords: Cognitive Robotics, Human-Robot Interaction (HRI), Cognitive Architectures, Adaptive Behavior, Social Intelligence.

INTRODUCTION

Cognitive robotics is an expansive, multifaceted, and multidisciplinary domain that attempts to provide mechanisms for robots of the future that will be capable of adaptive rational behavior in human environments. Human-robot interaction (HRI) is a subdiscipline of cognitive robotics that encompasses combining aspects of robotics, artificial intelligence, psychology, and philosophy. As such, it is both an empirical human science and a normative one, encompassing both the study of human cognition and its underlying inputs and outputs, along with the evaluation of the study's data and the assumptions upon which the beliefs or assumptions are based. Such a blending of philosophical speculation and psychological experimentation necessitates the inclusion of a section that sets out the principles of the theories and interpretation being explored elsewhere [1, 2]. In this review, we will explore some of the concepts and theories relevant to cognitive robotics and human-robot interaction, not all of which originate from Anglo-European traditions of philosophy and psychology, and which present approaches that might be given support, although controversially, respectively by other traditions including those arising from process philosophy and radical behaviorism. The subsequent this review will explore the scope of cognitive robotics and its implications for the design of HRI systems, discussing how the nature of such robotics will force us to fundamentally rethink our stance on such issues as agency and developing an appropriate conception of workable moral cognition [3].

DEFINITION AND SCOPE

While no singular definition of cognitive robotics exists, the general consensus is that cognitive robotics deals with robotic systems that make use of the knowledge from cognitive science in order to endow the robots with cognitive capabilities. Another way to think about cognitive robotics is to consider it to be robotics from a particular viewpoint—or a certain way of thinking about, designing, and constructing robotic systems, and programming them—using ideas and principles that are relevant to cognition. Cognitive robotics also has a special focus on interaction, a defining aspect of perception and action, which makes the field unique and technique-development oriented. In interacting with humans or other robots, cognitive robots are generally assumed to be open systems that must interpret and reason about their limited interpretation from imperfect perception. The expansive nature of cognitive robotics means that it forms a hub around which many disciplines orbit [4]. [5] and [6], have characterized cognitive robotics as dealing with artificial organisms, situated in complex and dynamic environments of all kinds, designed to reason explicitly about the distinctive tenets and methods of the three views—perceptual, technical, and embodied—that together constitute the endeavor. Thus, in cognitive robotics, a robot is an embodied autonomous agent—'embodied' in the sense that it is situated in, and interacts with, its world via mechanical and computational means. It is 'autonomous' in the sense that it operates as a free agent in the space it occupies, limited only by its physical and computational capabilities, the architecture of its computation, and assorted ethical guidelines—both those imposed by the environment in which it interacts and those imposed by human designers.

KEY CONCEPTS AND THEORIES

Cognitive robotics, situated robotics, cybernetic systems theory, multi-modal perception, integrative multi-modal representation, reinforcement learning, integration of world and expertise knowledge [5, 6].

INTRODUCTION

The principal relationship discussed in this article can be understood in terms of the theoretical, practical, and phenomenological import of cognitive robotics for human-robot interaction. Before my analysis begins in the next subsection, it is, however, important to unlock or expand some of the key concepts and some of the theories influencing the key concepts that are referred to. In carrying this out, I shall demonstrate the importance of the latter to this article, i.e., the above [7, 8]. In discussing the latter here, some preliminary insights will also be provided. Some possible contributions of the article are also indicated. Despite these indications, these broader questions will only be answered systematically in what follows. Indeed, the ultimate aim of this article is to provide an extensive analysis of what it takes to understand cognitive robotics and, on this basis, to get to the bottom of the relevance of human-robot interactions in general and the practical import for the aforementioned theoretical characteristics or phenomena [9].

FOUNDATIONS OF HUMAN-ROBOT INTERACTION

Human-robot interaction is concerned with the interaction between humans and robots. In recent years, the HRI research community has spread in the field of cognitive robotics. Earlier work in the area of human-robotic interaction was carried out mostly by the robotics community and dealt with investigating safety, communication modalities, social behavior, and interfaces. To formalize the question about the fundamentals of HRI in the field of cognitive robotics, it is useful to speculate on the coupling between robots and humans within a broader historical context [10, 11]. Various ingredients ought to be revisited to understand the foundations of HRI in the context of cognitive robotics. We look back at some developments and technologies framed in boundaries spanning from adaptive-dynamic controls and human motor behavior to interfaces for man-machine communication. These periodic revisions give us some insights that are relevant for a foundational discussion about HRI. Neuroscience representation clarifies brain functioning touching on specific interests (the role of the cerebellum in motor learning). The advent of interactive contexts has drawn attention to couplings that are typical of the social environments based on interaction. The expansion of technology includes brain-computer interfaces, tools able to read signals from the gray matter and translate them into control signals. In the quest for augmentive and assistive devices, robotic technologies have taken a special role because of possibilities and issues connected to their use by human beings [12].

HISTORY AND EVOLUTION

Human-Robot Interaction (HRI) – "the study of interactions between humans and robots" – is a direct evolution of human-computer interaction (HCI). Butler (2001), when reflecting on human-robot interaction, stood on the shoulders of all HCI research and practice, thus joining the rich forty-year tradition of research in this field. This historical sketch shall give a brief overview of the evolution of HRI, covering different perspectives, applications, and understanding of human-robot relationships and investigations with varying foci. This might support an understanding of why and how a certain type of HRI "is about to happen". A plethora of discussions around differences and similarities between virtual agents, social agents, and robots will be left out of this article. It should suffice to say that the rich body of work investigating the differences between these agents is also based on related discussions from HCI [13]. When one looks at the literature of HRI, a variety of different terms and goals appear to have played a role in the genesis of the field. There are references to robots, interfaces, social agents, interactive systems, virtual agents, avatars, and tele-operated systems. Thus, there is no clear-cut beginning, no undefined point where "the HRI" started. There was, however, one particular robot that drew a great deal of attention and considerably pushed forward the HRI field: Kismet. Launched in the late 1990s, this sociable robot could engage in a form of "facial motion and gaze coupling" and was praised by many researchers from a variety of disciplines. Kismet was followed by a sequence of many other robots with elaborated human-like motricity, an artificial skin with tactile abilities, emotion classification abilities, brain-like cognitive functions, and morpho-functional features. These successes in terms of funding, hardware, software, and techniques led to countless investments and debates. Kismet piqued the imagination of many researchers and helped to depict some of the future directions of this new field [14].

KEY COMPONENTS AND TECHNOLOGIES

Development of robots has been driven by fundamental mechatronics technologies such as motor control and integration, as well as the structure of walking mechanisms, including sensors and decision-making functions. These technologies have now reached a very high level of sophistication. Individuals or teams of researchers interested in developing robots for use with and by humans have begun to work on the cognitive capabilities necessary for effective interaction with humans. To provide a clear understanding of the potential applications of these machines in response to society's increasing needs, we will take a closer look at some of the core components and technologies. In particular, we will highlight examples of existing commercial products currently used by individuals who require assistance in daily life and care settings [15]. Future robotic systems require the ability to act autonomously in the environment and dynamically integrate sensed information with the ability to perform useful tasks within that environment. In addition to operating in dynamic and uncertain environments, robots must also be able to act safely and coexist in human-occupied areas while performing tasks. There are several key technologies that support these principles for future robotic devices in human-robot interaction (HRI). Some of these technologies are new and still in development, while others have been in development for some time and have a mature body of work. In supporting HRI, we are particularly interested in the ability of robots to operate in dynamic and uncertain environments. Therefore, the following areas are highlighted as particularly important for HRI applications [16].

COGNITIVE ARCHITECTURES IN ROBOTICS

Cognitive architectures researchers emphasize that biologically inspired models and available technologies have radically different competences. The knowledge of 3D environments and objects and the actual robotic actions in a realistic time are still large problems without a universally accepted solution. These and other problems are addressed by cognitive architectures. The International Conference on Cognitive Modeling (ICCM) is the main forum for assessing the latest results of cognitive architectures based on computational simulations, which can be used in robotics and assist human operators in the control of complex systems [17]. In robotics, cognitive architectures have been actually implemented in physical robots or in humanoids too. Cognitive architectures organize their main topics and methods in the development of physically and socially embedded agents, as shown in a short list in the first paragraph. In this article, we survey these architectures, indicating the main elements of the architectures and examples of their implementations in robots. We refer as examples to the works presented in the sections with the following architectures' names: CAM-Brain architecture, PsychSim-Extract architecture, Meta-Cognitive Control architecture, Distributed Cognitive Robotics (DCR) architecture, Minimally Cognitive Model (MCM) architecture, BICA Competitions Cognitive Models [18].

OVERVIEW OF COGNITIVE ARCHITECTURES

Cognitive architectures encompass general control mechanisms for coordinating basic activities of a complete intelligent agent, such as perception, memory, learning, reasoning, decision, and action, from low-level to high-level functions. In this way, these models furnish internal representations that mirror the real external world, in some way. These representations allow the robot to perform forward inference in virtual simulations of the real world. The common denominator of those control systems is that they implement some sort of information processing model. Besides this, this information processing is coordinated according to a generic scientific model with several anatomical layers [19]. The organization of cognitive architectures relies on the intricate structure of the human brain. It involves reverse engineering the brain's processing and organization through the abstraction of neurons. These processing nodes receive, manage, and process inputs, forwarding the results to other nodes. The brain's network of interconnected nodes allows for adaptation and learning, forming connections to properly execute correlations and make decisions. This adaptability is a biological foundation for human cognition [20].

APPLICATIONS IN ROBOTICS

The prime application areas for cognitive architectures in general, as deployed in robots, are in the field of human-robot interaction (HRI) and multi-robot systems. Cognitive architectures find applications in companion robots taking care of children, elderly or sick individuals, in entertainment robots (museum, edutainment systems, humanoid robots, robotic toys, etc.), in organizations (simulation for training threat recognition, rehearsal of crisis management), and in everyday use (smart home systems, embedded in mobile phones, etc.). Cognitive architectures can be a part of systems that enhance the capabilities of robots, such as robots for health monitoring, in disaster-devastated areas, in agriculture, for precise surgery and diagnostics. Furthermore, similar systems can be used for the development of service applications, for example by incorporating robots in supermarkets, as tour guides, as virtual assistants, etc [21]. Cognitive robotics aims at enhancing robotic systems with multiple cognitive abilities in order to obtain intelligent behavior, to allow these systems to perform tasks without human intervention, and to adapt to changing environments. Adaptation, reactivity, and autonomy are particularly interesting aspects of cognitive systems, which can be achieved if a robot is embedded in a cognitive architecture that grounds reasoning on task context and is capable of dealing with incomplete and uncertain information. Cognitive robotics also strives to model the interaction and collaboration process with human partners, i.e. to enable human-robot interaction, and because of its generality and adaptability, can establish communication between disparate robot systems thus enabling multi-robot cooperation. Cognitive robotics offers a way of designing robot architectures that support a range of application scenarios, as well as the domain-independent 'pure' robotics research problem [22].

SOCIAL AND EMOTIONAL INTELLIGENCE IN ROBOTS

One of the most fascinating aspects of human-robot interaction is the existence of social and emotional intelligence-related aspects in robots. Until relatively recently, social and emotional intelligence was not considered important when it came to creating artificial embodied systems. The idea was to build machines that were 'intelligent' but without social skills or emotional capabilities. Whether this was because such capabilities were not amenable to computational modeling or whether they were considered unnecessary is not very clear. What is interesting is that since the mid-1990s, there has been an upsurge in interest about how social and emotional intelligence in robots could be realized and whether such intelligence would need to be simulated or genuine for effective human-robot interaction. This has serious and profound ramifications for human-robot interaction if proven [23]. An important problem in conceptualizing social and emotional intelligence in robots is to delineate what these terms mean in the setting of an artificial being and potentially inside an "in-theory" framework. The problem is how these might be reflected in a robotic artifact or even in a computer-generated character. For instance, can these concepts extend to behavior alone, or should they take into account the process and the stance or indeed the subjective levels? We have vaguely identified three levels empirically theorized: (1) (in terms of behavior in-the-flesh) the instantaneous, (2) the iterated, and (3) the interoceptive [23].

CHALLENGES AND FUTURE DIRECTIONS

Cognitive robotics and human-robot interaction share commonalities concerning the seamless integration, representation, and processing of information representing perceptual and cognitive capabilities in robots. In this work, we provide taxonomies and refer to existing architectures that are well tailored to deal with some of these problems. We identified numerous problems which may affect the integration and operation of architectural fusion mechanisms when applied to real robotic systems. One open question lies in how to visualize and manage the great amount of knowledge and the sophisticated logical elaboration which could be present at the behavior description level [24]. However, we are still far from naturalistic, friendly, and really exploitable interaction and personalization. Autonomous, intelligent, anthropomorphic robots can evoke concern about the psychological, physical, envelope, and impact security risks related to their use. Currently, a combination of incompleteness, incorrectness, inconsistency, and domain specificity of KRR-based and situation-specific representation and reasoning also limits full exploitation with cognitive human-robot systems. Moreover, if research in the field of neuroscience and cognition underlines how many aspects of the human way of relating to the world are unconscious, originated and mainly directed by emotions but then consciously rationalized or expressed, a challenge— from a human- and presumably in extension robot-centered perspective—will be to develop robots with a really "human-like" behavior, that is autonomously generated and executed. Whether or not such an open challenge can be effectively addressed poses future research questions for the field of cognitive robotics [25].

CONCLUSION

Cognitive robotics and human-robot interaction are pivotal in advancing the capabilities of autonomous systems in human environments. The integration of cognitive architectures and the focus on social and emotional intelligence represent significant strides toward creating robots that can interact seamlessly and naturally with humans. Despite these advancements, challenges remain in achieving truly human-like behavior, ethical considerations, and the effective handling of incomplete and uncertain information.

Future research must address these challenges, striving for more sophisticated and human-centric robotic systems. This ongoing evolution will redefine our understanding of agency, interaction, and morality in the context of robotics, paving the way for more intuitive and beneficial human-robot collaborations.

REFERENCES

1. Martins PS, Faria G, Cerqueira JJF. I2E: A cognitive architecture based on emotions for assistive robotics applications. Electronics. 2020. mdpi.com

2. Benedictis RD, Umbrico A, Fracasso F, Cortellessa G, Orlandini A, Cesta A. A dichotomic approach to adaptive interaction for socially assistive robots. User Modeling and User-Adapted Interaction. 2023 Apr;33(2):293-331. springer.com

3. Bergmann LT, Wagner J. When push comes to shove—the moral fiction of reason-based situational control and the embodied nature of judgment. Frontiers in Psychology. 2020. frontiersin.org

4. Manzoor S, Rocha YG, Joo SH, Bae SH, Kim EJ, Joo KJ, Kuc TY. Ontology-based knowledge representation in robotic systems: A survey oriented toward applications. Applied Sciences. 2021 May 11;11(10):4324. mdpi.com

5. Dağlarlı E. Design of the Integrated Cognitive Perception Model for Developing Situation-Awareness of an Autonomous Smart Agent. Balkan Journal of Electrical and Computer Engineering. . dergipark.org.tr

6. Richter MM, Paul S, Këpuska V, Silaghi M. Intelligent Interactive Communications. InSignal Processing and Machine Learning with Applications 2022 Apr 7 (pp. 583-595). Cham: Springer International Publishing. [HTML]

7. Henschel A, Hortensius R, Cross ES. Social cognition in the age of human–robot interaction. Trends in Neurosciences. 2020. cell.com

8. Jost C, Le Pévédic B, Belpaeme T, Bethel C, Chrysostomou D, Crook N, Grandgeorge M, Mirnig N. Human-Robot Interaction. Springer International Publishing; 2020. [HTML]

9. Chacón A, Ponsa P, Angulo C. Cognitive interaction analysis in human–robot collaboration using an assembly task. Electronics. 2021. mdpi.com

10. Weiss A, Spiel K. Robots beyond Science Fiction: mutual learning in human–robot interaction on the way to participatory approaches. AI & society. 2022. springer.com

11. Cangelosi A, Asada M. Cognitive robotics. 2022. [HTML]

12. Hull C. Prediction signals in the cerebellum: beyond supervised motor learning. elife. 2020. elifesciences.org

13. Schneiders E, Cheon E, Kjeldskov J, Rehm M, Skov MB. Non-dyadic interaction: A literature review of 15 years of human-robot interaction conference publications. ACM Transactions on Human-Robot Interaction (THRI). 2022 Feb 8;11(2):1-32. acm.org

14. Han IX, Meggers F, Parascho S. Bridging the collectives: A review of collective human–robot construction. International Journal of Architectural Computing. 2021 Dec;19(4):512-31. [HTML]

15. Cross ES, Ramsey R. Mind meets machine: Towards a cognitive science of human–machine interactions. Trends in cognitive sciences. 2021. cell.com

16. Kolar P, Benavidez P, Jamshidi M. Survey of datafusion techniques for laser and vision based sensor integration for autonomous navigation. Sensors. 2020. mdpi.com

17. Byrne G, Damm OF, Monostori L, Teti R, van Houten F, Wegener K, Wertheim R, Sammler F. Towards high performance living manufacturing systems-A new convergence between biology and engineering. CIRP journal of manufacturing science and technology. 2021 Aug 1;34:6-21. sciencedirect.com

18. Kotseruba I, Tsotsos JK. 40 years of cognitive architectures: core cognitive abilities and practical applications. Artificial Intelligence Review. 2020. springer.com

19. Chacón A, Angulo C, Ponsa P. Developing cognitive advisor agents for operators in industry 4.0. New Trends in the Use of Artificial Intelligence for the Industry. 2020 Mar 25;4:127. oapen.org

20. Samsonovich AV. Socially emotional brain-inspired cognitive architecture framework for artificial intelligence. Cognitive Systems Research. 2020. [HTML]

21. Darvish K, Simetti E, Mastrogiovanni F, Casalino G. A hierarchical architecture for human–robot cooperation processes. IEEE Transactions on Robotics. 2020 Nov 12;37(2):567-86. [PDF]

22. Arshad NI, Hashim AS, Ariffin MM, Aszemi NM, Low HM, Norman AA. Robots as assistive technology tools to enhance cognitive abilities and foster valuable learning experiences among young children with autism spectrum disorder. Ieee Access. 2020 Jun 11;8:116279-91. ieee.org

23. Barchard KA, Lapping-Carr L, Westfall RS, Fink-Armold A, Banisetty SB, Feil-Seifer D. Measuring the perceived social intelligence of robots. ACM Transactions on Human-Robot Interaction (THRI). 2020 Sep 11;9(4):1-29. acm.org
24. Farouk M. Studying human robot interaction and its characteristics. International Journal of Computations, Information and Manufacturing (IJCIM). 2022 May 28;2(1). gaftim.com
25. Gasser G. The dawn of social robots: Anthropological and ethical issues. Minds and Machines. 2021. springer.com

CITATION: Kabiga Chelule Kwemoi. Cognitive Robotics and Human-Robot Interaction. Research Output Journal of Biological and Applied Science. 2024 3(1):1-6