Some notes on the possibile role of cognitive architectures in serious games

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Abstract. This paper provides a preliminary analysis of the possible role of cognitive architectures in the field of Serious Games. The seminal works that explore the use of Cognitive Architecture in games will be analyzed in the light of an emerging perspective of the games AI research area. Finally, an initial proposal of application of Cognitive Architecture for the design and implementation of non-player characters will be presented.

Keywords: Serious Games · Cognitive Architecture· Cognitive Science · Artificial Intelligence

1 Introduction

Serious games are tools designed with a purpose other than pure entertainment, such as educational games [19]. According to Dorner et al. [14] serious games can be described as digital games developed not with the only intention to entertain but to achieve at least a goal named “characterizing goal”. Usually such a goal is to enhance learning or to foster the development of skills and abilities through the use of a highly motivating teaching technology. Moreover, on the basis of their natural engagement and learning features, serious games allow:

- to extend the learning time, taking advantage of non-school times as a reinforcement mechanism;
- to develop skills and abilities in domains where it is difficult to have training opportunity through a realistic simulation of complex scenarios;
- to train soft skills such as problem-solving and decision-making [20], social and communication skills[7], etc. .

In the literature, an interesting research area focuses on the use of serious games in Educational Sciences [9] but, despite the growing interest in the sector, some scholars [16, 23, 46] highlight and suggest that Serious Game (SG) sector can benefit from

a constructive dialogue with another field of knowledge, Cognitive Science (CS), that could and should provide an essential theoretical reference for dealing with some crucial issues such as modeling the player's behaviour and evaluate his/her interaction. Specifically, CS would be able to provide SG research with results and research methodologies on cognitive principles and models for explaining the cognitive processes that underlie learning through SG[23]. This kind of research would help researchers in the design and the evaluation process of an SG giving valuable indications on how cognitive skills, and in particular, according to Anderson [5], declarative and procedural knowledge are acquired in the game phases.
On the other hand, analyzing this relationship from the inverse point of view, SGs could provide CS with an appropriate experimental environment able to overcome the limitations of some cognitive experiments. In CS, experimental designs are generally carried out in aseptic environments (e.g., the laboratories) very distant from everyday reality to isolate all the factors that could influence the studies. Unfortunately, this approach leads to results often refuted when tested and analyzed in "real" contexts. SGs can represent a good compromise between structured experimental settings and less structured experimental settings closer to daily reality. In fact, SGs are generally designed to be realistic, and research confirms that SGs can "immerse" the player in a cognitive flow that leads him to experience the situation as if it were real. In addition, the handcrafted nature of SGs gives the researchers the possibility to manipulate the game to stimulate/test and verify certain cognitive processes. The analysis of the user's interactions collected during the gameplay would allow researchers to verify the validity of the theorized models, thus representing a promising research paradigm for the cognitive sciences of the computational approach.
In this paper, by focusing on a specific Computational branch of Cognitive Science, we deepen the specific aspect related to Cognitive Architectures (CA) and their possible role in the SGs domain.

In the next section, starting from the analysis of the literature in the intersection between games and AI, we present the proposal of organization of the new *games AI* field by Yannakakis and Togelius [49]. After a brief introduction of the cognitive architecture concept, we will analyze the contributions that apply cognitive architectures in the field of games and more specifically, where present, in the field of serious games according to the proposed perspective. Finally, we will sketch a preliminary analysis on the limits and possible solutions that derive from the use of cognitive architectures in the realization of non-player characters.

2 Artificial Intelligence and Games

Since its foundation, Artificial Intelligence (AI) has considered games one of the main fields of study and experimentation. From the analysis of classic board games such as chess, backgammon and more recently Go [44] the interest of AI researchers has been growing during the time. Also thanks to the development of the digital games market a new field of research called games Artificial Intelligence (games AI) [49] has emerged.

Workshops such as the first and second International Workshop on Agents for Games and Simulations [12, 13] and conferences such as the AAAI Artificial Intelligence and Interactive Digital Entertainment (AIIDE) [43, 37] and IEEE Computational Intelligence and Games (CIG) [1, 2] played an essential role for the consolidation of the *games AI* research area.

A fundamental step in this process took place in May 2012 when, during the Dagstuhl seminar [35], about 40 world-leading experts convened to discuss future research directions and key research challenges for artificial and computational intelligence in games. While the studies on board games were almost exclusively aimed at creating virtual "players" able to compete with human opponents, according to the experts the new *games AI* field was supposed to include a broader range of research objectives. The experts identified ten different research themes (i.e. Non-player character (NPC) behavioral learning, Search and planning, Player modelling, Games as AI benchmarks, Procedural content generation, Computational narrative, Believable agents, AI-assisted game design, General game AI, AI in commercial games).

After this first attempt to give shape to this new sector, over time other works [13, 48] have contributed to the definition of the field of research. Among others, the recent book "Artificial Intelligence and Games" [49] presents a systematic review of this field, coming to identify three main areas of research:

– playing game;
– generating content;
– player modeling.

The *playing game* area collects large portion of the research done to the date in games AI, which concerns two main themes: 1) the development of intelligent systems capable of playing independently with performance behaviours comparable to those of a human player; 2) the research on systems able to control the so-called non-player characters (NPCs) present in the game, in order to endow them with human-like behaviors and thus make them credible and engaging for human players. The *generating content* area refers to methods for generating game content (e. g. levels, maps, game rules, textures, stories, objects, missions, music, weapons, vehicles, characters), autonomously or with a limited human contribution. Content generation has seen an explosive growth of interest in the gaming industry. Examples of games incorporating automatically generated content already exist since the early 1980s, such as Rogue [8] and Elite [17]; however, in the second half of the last decade interest in academic research has increased significantly. Finally, the *player modeling* area collects all those researches that aim at the detection, prediction, and expression of the human characteristics of the player using cognitive, emotional and behavioral models during the game. Player modeling mainly studies the use of AI methods for the construction of players' computational models, i.e., representations capable of capturing the underlying functions between the player's characteristics and his/her interaction with the game.

The modeling of the player's behavior and experience has a primary value in the application of games AI because it has a direct influence also in the other two areas. Just think for example of the problem of the game adaptivity according to the player's profile that leads to the need of automatic content generation [41, 38].

According to this perspective, we will investigate the contributions that apply cognitive architectures in the field of games and serious games.

3 Toward the use of Cognitive Architectures in Serious Games

3.1 A brief overview about Cognitive Architectures

Cognitive architectures have been historically introduced in the fields of AI and Computational Cognitive Science i) to capture, at the computational level, the invariant mechanisms of human cognition, including those underlying the functions of control, learning, memory, adaptivity, perception and action [40] ii) to reach human level intelligence in a non narrow setting, by means of the realization of artificial artifacts built upon them and iii) (ii) to form the basis for the development of artificial cognitive capabilities through ontogeny over extended periods of time (this goal is one of the main target of the so called emergent perspective) [47]).

During the last decades many cognitive architectures have been realized, - such as SOAR [27], ACT-R [4] etc. - and have been widely tested in several cognitive tasks involving learning, reasoning, selective attention, recognition etc. The modern instantion of the most mature cognitive architectures is, tipically, a hybrid computational model describing, as accurately as possible, the basic infrastructure of an intelligent agent. Current cognitive architectures, in fact, usually combine low-level neural components for the modeling of perceptual aspects and high-level logical and symbolic components for automatic reasoning and planning activities [31]. Over the last 30 years, these systems have had an extensive application in the various sectors: from robotics to tutoring systems [34]. The use of cognitive architectures, in fact, allows the construction of artificial agents able to use decisional and behavioral heuristics of cognitive inspiration, thus proposing specific models for the creation and the analysis of the mechanisms of such agents [32]. Kotseruba and Tsotsos provide an updated and broad overview of the last 40 years of research in cognitive architectures [25]. In this review, the authors analyze a set of 84 architectures, 49 of which are still actively developed.

3.2 Cognitive Architecture in games AI

Literature reports a few examples of the application of cognitive architectures in games and obviously an even smaller number in the specific field of SG. In this section, we analyze these works according to the organization of the *games AI* area described in the previous section, emphasizing the possible role of cognitive architectures in games.

In the *playing game* area, the aim is to automatically control the player character or the non-player character of the game. Controlling the player character allow experts in AI to focus on optimizing the play-performance and/or testing the advancements algorithms and techniques for general cognitive processes such as perception, planning, decision-making and so on. From the point of view of game designer, the availability of intelligent agent able to human-like play game is an opportunity to test and evaluate of the game design.
About the design of non-player character, Ramirez [10] have pointed out that the enormous progress in game technologies to improve the physical realism of environments and characters does not correspond to an adequate level of "cognitive" realism of the characters.

In this area falls the work of Laird, the creator with Newell and Rosenbloom of the cognitive architecture SOAR [28, 29]. He was one of the first researchers exploring the use of cognitive architectures in games [26]. In fact, with his research group, Laird has been investigating the use of games as an experimental environment in which testing the CAs features to control either the player character or the non-player character of the game[26, 30]. As an example, Magerko et al. [36] applied the Soar architecture to design and develop complex AI characters in their games *Haunt 2*.

According to Streicher [45] CAs can play a primary role in *player modeling* area. It is a matter of fact that, one of the successful application of cognitive architecture is the creation of intelligent tutoring systems [34]. One demonstration is the application of ACT-R for the creation of an intelligent tutoring system widely used in the educational context of the United States [42, 6]. In the same area, Ghosh and Verbrugge [21] offer an example of an application of the PRIM cognitive architecture.

In this context, the use of CAs may also provide the basis for overcoming the lack of adequate tools able to overcome traditional evaluation methodologies (e.g., questionnaires, self-evaluation tests), that, being external tools, do not allow to exploit the potential offered by SGs. The growing interest in learning analytics is leading the trend towards the realization of embedded objective measures able to evaluate the progress of students in real time; measures defined starting from the considerable amount of data generated by the "high frequency" interactions of the player with the SG.

However, despite the potential offered by these tools, the analysis of the literature shows that the learning analytics methods rarely refer to cognitive models. Liu et al. [33] conducted a systematic review to understand what are the evidence there are in using analytics in SG to support teaching and learning. Recently, Alonso-Fernández et al. [3], presented a review of their experiences in Game Learning Analytics for serious games

The cognitive-grounded analysis of the user's interactions collected during the gameplay would represent a promising research paradigm both for the cognitive sciences of the computational approach as well as for serious games scientists.
Moreover, starting from a cognitive model of the player, it will be possible to improve also the research in personalization and adaptivity of the "game content" to the specific needs of the player.

According to this analysis, it emerges that cognitive architectures can naturally play a primary role in all three areas.

3.3 A Proposal of application NPC

Despite the interest of academics and researchers, several factors have limited the applicability of cognitive architectures for these purposes. In this section, we propose a possible line of exploration to overcome the limits of applicability of CA in games, and in particular with reference to the creation of NPCs.

As stated by Dignum [13], among the main reasons that limit its applicability, there is undoubtedly a purely technical and technological reason. At present, cognitive architectures are difficult to integrate into the platforms currently used for the creation of games (e.g., Unity and Unreal). As the game engine, also the CAs demand a considerable computational capacity to satisfy the needs of responsiveness required by many types of game.

In order to overcome these problems, several solutions have been proposed based on the creation of communication middleware able to connect a proxy version of the agent that lives inside the game with a remote and complex one, based on cognitive architectures [30, 18, 39, 26]. These solutions have been designed to theoretically interact with any cognitive architecture unless of the creation of a specific integration module.
Even though the quality of the proposed solutions, the effort required in terms of design and development and some technical limitations, such as the inability to take advantage of algorithms already integrated in game development environments, have limited the applicability of such solutions.

The proposed approach is based on the assumption that it is possible to create a mapping between "complex" agents and "simplified" agents to overcome all the computational limitations raised above. The goal is to allow designers, to model agents according well-grounded cognitive model, and allow the developers to implement simplified agents directly integrated into the gaming platforms (e.g., Unity and Unreal), but able to "simulate" complex behaviors.

Evidences from CS suggest that the simplification could be achieved at the cognitive level, modelling cognitive processes on the base of heuristics able to preserve the input-output functions of cognitive architectures through an efficient development of the dynamics of information processing provided by them. In other words: the computational model instantiated with a cognitive architecture can be compliant with the architectural constraints of the system but, at the same time, can implement more flexible heuristics enabling the creation of a computational model that is easier to integrate with other technological environments.

Heuristics (or judgements heuristics) are, according to the positive definition from Gigerenzer [22], shortcuts of thought that take a minimum amount of time, knowledge and calculation (computation) to process adaptive choices in concrete environments. This kind of shortcuts guides, on the basis of empirical rules (emerging from previous experience and knowledge), our daily actions that must be carried out immediately or in a short time and relying on limited knowledge. Kahneman [24] defines them in terms of paths of reasoning or mental events that occur automatically, have to do with both some innate skills (e.g. recognizing objects, orienting attention, perceiving the world) and learned skills (e.g. reading and/or understanding the shades of a situation) and take the form of automatic activities of different types (e.g. reading the words on a billboard, understanding simple sentences, noticing that an object is further away than another, driving a car etc.). Cognitive heuristics can be described as fast, automatic and implicit paths of reasoning that reduces the load on working memory. They characterize precisely the steps of collection and processing of information that are involved in certain decision-making processes and therefore it is possible to instantiate them in computational terms [22]. This approach is part of the research on dual systems, that suggests a path to consolidate process of type 2 cognitive processes in automatic processes typical of the type 1 system [15].

4 Conclusion

In this paper, we have proposed some preliminary insights about the possible role of cognitive architectures in the context of Serious Games. To instantiate these insights, new tools and frameworks for the aforementioned gaming platforms need to be created in order to improve game design according to more realistic modeling of human cognition. This is true both about the creation of intelligent NPCs as well as for the modeling of the player and the subsequent real-time adaptation of the game itself. As a mid-term goal, we aim at verifying to what extent cognitive architectures can be integrated into game technologies as they are, or instead they need to be specifically adapted/extended for the implementation of NPC in games. The research could highlight the need to use technologies such as deep learning and probabilistic models to reproduce the behavior of intelligent agents realized through cognitive architectures. As an additional goal of this investigation, we aim at providing useful guidelines about how to make cognitive architectures a ready-to-use tool 1) for the design and implementation of games especially in relation to the creation of so-called non-player characters and 2) for player modelling, as a fundamental step in the generation of adaptive content that can keep the player in a state of flow [11].

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