Design of a Cognitive Control Mechanism for a Goal-based Executive Function of a Cognitive System

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Abstract

Self-control includes processes of reasoning control, address and evaluation, goals in process of simulation of drives, setting essential parameters, interrupting, and changing ongoing processes. A cognitive system is a computational framework that simulates the cognitive processes of perception and action for which executes work of knowing, understanding, planning, deciding, problem solving, analyzing, synthesizing, and assessing. This paper aims to present a computational representation of a self-control mechanisms for an executive function of a cognitive system. A formal representation is described as well as a class-based computational representation. These results enable to have a new approach to build cognitive systems.
Keywords: Cognitive control, Executive Function, Goal-based Cognitive System.

1. Introduction

Human daily activities like observation, reading, listening, looking, among others, are coordinated by functions that synthesize external stimulus through goal-directed behavior to create new goals, strategies, actions, and plans (Banyard, 1995; Fuenmayor & Villasmil, 2008; Luria, 1973). These functions are called cognitive or executive functions (P. Anderson, 2002; Cartwright, 2012; Denckla, 1994).

The development of computational models about brain processes that simulate specific aspects of reasoning that facilitate interaction computer-human is one of the purposes of cognitive computing (Sommer, 2017). A cognitive system is a computational framework that simulates the cognitive processes of perception and action for which executes work of knowing, understanding, planning, deciding, problem-solving, analyzing, synthesizing, and assessing (Lintern, 2007). Detection, evaluation and solve of anomalies is a metacognitive ability in intelligent systems that commonly is called cognitive control (M. L. Anderson & Oates, 2007). Processes of reasoning control, address, and evaluation, as well as also including goals in process of simulation of drives, setting essential parameters, interrupting and changing ongoing processes are included in this metacognitive skill (Coward & Sun, 2004; Sun & Mathews, 2012). Cognitive control is important to information-processing executed by EF because facilitates the development of mechanisms of control and coordination of information in the service of goal-directed actions (Willoughby et al., 2012). Many studies have tackled creating computational model of self-control with the objective to proportionate autonomy to intelligent systems (Caro et al., 2018; Dannenhauer et al., 2014; Grislin-Le Strugeon et al., 2005; Oh et al., 2021a, 2021b; Samsonovich, 2014), and theoretical approaches inspired in the human brain (P. Anderson, 2002; Koechlin & Summerfield, 2007; O'Reilly, 2006; Pezzulo & Castelfranchi, 2009; Verguts, 2017).

This paper aims to present a computational representation of a self-control mechanisms for an executive function of a cognitive system. A formal representation is described as well as a class-based computational representation. The structure of this paper is the following: Section 2 describes a several theoretical approaches about executive functions and cognitive control. Then, a formal and computational representation of the cognitive control mechanism for an executive function is showed. Section 4 presents a summarize about an illustrative example of that mechanism. Finally, conclusions are described.

2. Executive functions and Cognitive Control

Executive function (EF) is the set of necessary skills for resolving purposeful, goal-directed activities. Some of them are anticipation, goal selection, planning, initiation of action, self-regulation, mental flexibility, attention deployment, and feedback utilization (P. Anderson, 2002). EF incorporates multiple inter-related high-level cognitive processes as an integrated supervisory or control system for information processing, formulating goals, planning, self-monitoring, and self-regulation (P. J. Anderson & Reidy, 2012; Glozman & Shevchenko, 2015). The study about neuropsychology shows that executive functions are mediated by the prefrontal cortex of the brain, more specifically in the lateral surface of the frontal lobes. At a more fine-grained level, a set of cognitive control skills (e.g., attention, inhibitory control, self-monitoring, and flexibility is defined as specific interrelated information-processing abilities that are involved in the control and coordination of information in the service of goal-directed actions (Willoughby et al., 2012).

Some theoretical models about executive functions have been developed (P. Anderson, 2002; Kelly, 2000; Levin et al., 1991; Welsh et al., 1991). These models have found variables related to EF in psychological tests. Among these variables are planning, cognitive control, reasoning, and response speed. According to the above, (Anderson, 2002) identifies specific executive domains that group previously mentioned variables. Also, this author proposes an EF model which conceptualizes EF as four distinct domains: (i) attentional control, (ii) information processing, (iii) cognitive flexibility, and (iv) goal setting. According to Anderson, these executive domains are discrete functions that are related to specific frontal systems. Nevertheless, they operate in an integrative way to execute specific tasks, and together they can be conceptualized as an overall control system. Attentional control is the capacity to attend to specific stimuli and inhibit predominant responses. Thus, attentional control involves the regulation and monitoring of actions and plans, which are executed in the correct order to identify errors and achieve goals (P. J. Anderson & Reidy, 2012). Solving complex real-world situations requires cognitive processes oriented to improve the system´s efficiency (Roberds, 2015). These processes called cognitive control include working memory, management of attentional resources, control of unexpected and erroneous responses, and monitoring of motivational and emotional state (Buehler, 2018). An EF is a set of cognitive processes used to develop a specific action. According to (Caro et al. 2014), this type of function is a functional element that allows information processing to achieve the system's objectives. On the other hand, (Koechlin & Summerfield, 2007) developed a model based on concepts from information theory to describe how executive function can be subdivided into hierarchically ordered control processes, each responsible for selecting an action on the basis of information that is successively more remote in time.

3. Formal and Computational Representation of a Cognitive Control Mechanism for a Goal-based Executive Function for a Cognitive System

This section will describe the formal representation of a cognitive control mechanism function based on theoretical approaches (P. Anderson, 2002; Koechlin & Summerfield, 2007). A cognitive control mechanism for a goal-based executive function is a 5-tuple, i.e.:

$$\varepsilon^c = < s, o, c, G, \chi > \qquad (1)$$

Where:
ε^c represents a cognitive control goal-based executive function
s is the stimulus read by the function from a Algorithmic Knowledge Profile.
o is the output of the executive function.
c is the signals to execute cognitive control.
G is the goal to be achieved by the function.
χ is the expectation of the system.

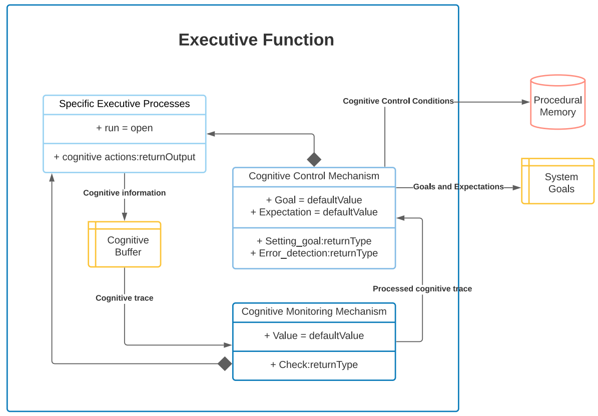

Figure 1. Functional structure of a goal-based executive function

Figure 1 presents the functional structure of a goal-based executive function, where executive processes composed by actions send the information obtained from input to a cognitive buffer. This buffer encodes information in traces, which are constantly monitored by a cognitive monitoring mechanism. When control conditions are related to the stimulus received by the executive function, the cognitive monitoring mechanism encodes the specific trace associated with that stimuli. The cognitive control mechanism receives the processed trace from the cognitive monitoring mechanism. This last mechanism can detect errors in the executive processes' cognitive actions and set goals considering current goals and expectations of the system.

4. Illustrative Example

Below, a cognitive system about basic concepts of gestational and congenital syphilis is presented as an illustrative example of the previously described model. This system is in an initial version in the Spanish language that has not been tried yet in a student's sample. The system will be used in the nursing program of the Universidad de Córdoba-Colombia in the next future. Figure 2 presents the system's output after executing an executive function that selects an educational resource for a specific lesson of the system. In this case, the system considered the student's performance, interaction history, and score ("rendimiento del estudiante, historial de interaction y calificación de recurso" in Spanish) as cognitive control conditions for selecting the resource. The chosen resource was a flowgraph about the incidence of congenital syphilis in Cordoba- Colombia.

Figure 2. Classes to executing of system's information processing.

Figure 3 describes a record of the activity of the student in the system. This record allows identifying some aspects in which the system has used its ability to control the cognitive actions for selecting resources. For example, the student named Samuel Moreno had two attempts ("intentos" in Spanish) for achieving a score ("rendimiento" in Spanish) of 100% in lesson three ("Leccion", in Spanish). However, the system chose four resources in that two attempts. Here can be observed that the cognitive actions of the executive fucntion selected a photo ("Fotografía" in Spanish), but the control mechanism changed that resource by an interactive video ("video interactivo", in Spanish) considering the control conditions previously described.
In the same way, the resource called video of a class ("Video clase") was replaced by a timeline ("linea de tiempo"). It can be observed that the student obtained a score of 100% in a time considerably less than the previous times. This situation could happen thanks to the changes done by the system considering the cognitive control cognitive stored in its procedural memory.

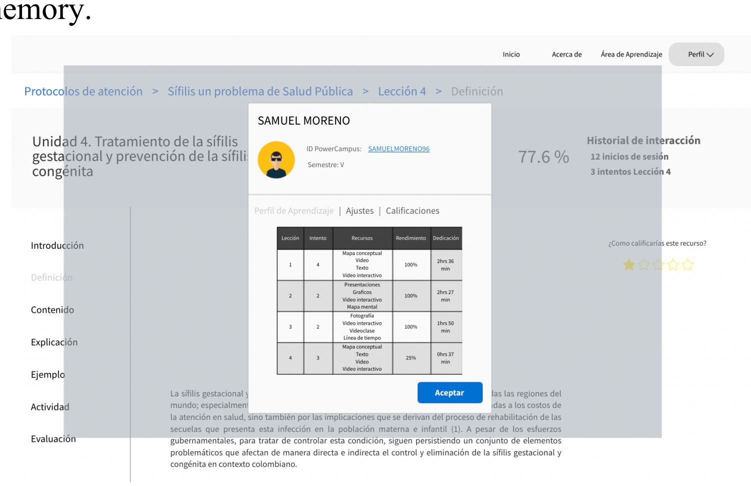

Figure 3. Output of the system.

5. Conclusions

This paper presented a new approach for the use of cognitive control mechanisms based on biological-inspired theoretical approach. A formal and computational representation are presented in a summarized way. Mechanisms use a goal system and a procedural memory for developing the setting goal process. An illustrative example is described presenting the output data of the system. These results enable to have a new approach to build cognitive systems based on theoretical and empirical assumptions inspired in biological models. However, it is necessary to continue developing cognitive systems that use multiple instances of cognitive functions in one or many reasoning cycles to solve real world problems.

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