COMPUTATIONAL REPRESENTATION OF COGNITIVE MODELS IN THE METACOGNITIVE ARCHITECTURE CARINA

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SUMMARY

Cognition bases can be explained through cognitive modeling, by creating cognitive models analyzing processes, representations, and mechanisms. With studies in cognitive modeling, it is possible to create them to describe, to predict and to prescribe human behavior. A cognitive model is runnable in a cognitive architecture. Based on scientific theories, the cognitive architectures are created, which are a general-framework control system to explain cognition in animals and humans. CARINA is a metacognitive architecture used to create artificial intelligent agents. This paper presents a computational representation of a cognitive model in the metacognitive architecture CARINA.

Key words: Cognitive Modeling, Cognitive Models, Cognitive Architectures, Metacognitive Architectures, CARINA.

I. INTRODUCTION

Human cognitive processes can be explained by cognitive sciences through the methodology of cognitive modeling and create cognitive models [1]. These cognitive models are inspired by a theoretical representation and empirical guide using a specific cognitive function, which makes mental processes and representations [2]. Cognitive models are created with the purpose to study characteristics of cognition, i.e., attention and multitasking, decision-making, judgment and choice, and skill acquisition in complicated conditions [3]. Cognitive models of a set of intelligent systems are made with cognitive architectures [4]. A variety of behaviors can be analyzed when a cognitive task is created and implemented in a cognitive architecture [5]. Cognitive processes in animals and humans can be explained through control systems based on scientific theories, known as cognitive architectures [6]. Thus, from the *MISM Metacognitive Metamodel*, CARINA is derived as a metacognitive architecture for the construction of artificial intelligent agents. CARINA is composed of two cognitive levels: *object leve*l and *meta-level*. *The object level* has an agent for reasoning about the world and solving problems. *The meta-level* has a variety of models coming from the object level [7]. To represent computational cognitive models in CARINA, it is necessary to consider the GOMS, NGOMS-L and M++ notation. Goals, Operators, Methods and Selection Rules (GOMS) is a designation of the information that a system requires for achieving a cognitive task [8]. NGOMS-L is a natural language representation for explaining GOMS models and describe processes for creating them [8], [9]. Finally, M++ is a visual language to represent models [9], [10]. The central objective of this paper is to develop a computational description of a cognitive model in the metacognitive architecture CARINA. This article is structured by the following chapters: Chapter one, explains the CARINA metacognitive architecture. Chapter two describes the specification of a cognitive model in CARINA through denotational mathematics. Third, the computational representation is made. Finally, an illustrative example of the cognitive task of the Tower of Hanoi is shown through a computational cognitive model in CARINA.

II. THE METACOGNITIVE ARCHITECTURE CARINA

According to [11] CARINA is a metacognitive architecture designed with the purpose of creating artificial intelligent agents. CARINA is obtained from the *Metacognitive Metamodel MISM* [12]. CARINA has its functional bases according to the functioning of the human mind. CARINA has as its main characteristics self-regulation and

metamemory using metacognitive mechanisms of introspective monitoring and meta-level control. [11],[13].
CARINA, according to [14] is constituted by three elements. Thus, the term, "mechanism" incorporates entities and activities (i.e. it contains two types of static and dynamic characteristics). An additional element are the entities in CARINA which are called "cognitive elements".
Basic, structural, and functional elements are integrated into CARINA thanks to MISM [15]. Structural elements that allow the creation of functional and basic elements. In the structural elements the main one is called "cognitive level". In this sense, the tasks that execute reasoning and decision making are called functional elements. And the basic elements allow reasoning and meta-reasoning processes to be realized.

III. FORMAL REPRESENTATION OF COGNITIVE MODELS IN CARINA

According to [17] cognitive models in CARINA are structured by:

$CM \triangleq (P, G, S, MS, PK, SK)$

Where:

P is the problem to be solved using CARINA.

$g \in G$, where g represents a Goal. A goal is an objective whose the running system must complete. Thus, Goals are objectives that allow the accomplishment of a task or process [16].

$s \in S$ where s is a Sensor. The Sensor has the purpose of monitoring the profiles of cognitive tasks to prevent irregularities that may create reasoning failures in the execution of a cognitive task [17].

$m \in MS$, where m is a Mental State. Mental States are defined as Boolean variables that can be true or false. Thus, a MS indicates the current state in which an intelligent cognitive agent is found [9].

PK, is the specification of the Procedural Knowledge System required to accomplish the cognitive task. I. e., the production rules structure the Procedural Knowledge in CARINA [18].

Thus:

$r \in R$, r is a production rule, with

$r \triangleq (\text{condition, conclusion})$

With:

$\text{condition} \triangleq (AS, C)$

With AS are a set of variables that specify the values used to activate the rule (r), in this context a rule (r) is activated if exists a complete coincidence with the variables of AS

$c \in C$ and $c \neq C$ and $c \neq AS$

c is a constraint, it is used to specify an additional constraint created by the cognitive designer. Thus, constraint in some cases could be $c = \{\ \}$

C are conclusions. Conclusions are actions which are activated when the rule (r) is achieved.

Thus, $a \in A$ where a is an action.

SK is the Semantic Knowledge. Semantic knowledge is the knowledge necessary to fulfill the cognitive task, that is, SK is a set of beliefs stored in semantic memory to be used when the reasoning process occurs.

With:

$f \in F$ with f is a Field

Where:

$F_D \subset F \wedge F_B \subset F$

F is an attribute which belongs to the SMU

SMU is the Semantic Memory Unit, which belongs to Semantic Memory and has:

F_D is a type of data (e.g. string and integer)

F_B is a type of data with the purpose to select the Beliefs located in the Semantic Memory.

Finally, β which are Beliefs. Beliefs are elements of Declarative Knowledge, i. e., information which takes facts or notions from the environment, which are stored. Furthermore, Beliefs are the minimum unit on which the structure of Semantic Memory is based on CARINA [17], [19].

IV. COMPUTATIONAL REPRESENTATION OF COGNITIVE MODELS IN CARINA

CARINA receives information about the environment using an open standard data interchangeable format (JSON). In order to describe it in a computational way, the cognitive models in CARINA, the elements are detailed through a JSON file (See Figure 1).

```
{
  "name": " ",
  "type": " ",
  "problems": {
      "type": " "
  },
  "mentalStates": {

  },
  "goals": {
    " ":{
      "mental_state":"empty",
      "current_value":false,
      "target_value":true
    }
  },
  "productionRules": {
    "rule": {
      "condition": {
        "attention_system": {
          "problem": " ",
          "mental_state": "empty",
          "goal": " ",
          "state": "empty",
          "sensor": "empty"
        },
        "constraint": {}
      },
      "conclusion": {
        "action1": {
          "name": "accomplishGoal",
          "complete": false
        }
      }
    }
  },
  "beliefs":{
    " ": {
      "typeSMU":" ",
      "have":{
        "type": " ",
        "value": 0
      }
    }
  }
}
```

Fig. 1. Computational specification of a cognitive model in CARINA [Own source].

According Figure 2, a JSON file based on a cognitive model to be executed in CARINA, this model has the following elements:

`name`: it is the name given to the knowledge domain to be solved in CARINA.

`type`: it is the classification made by the cognitive designer to characterize the cognitive model to be created.

`problem`: is the name of cognitive task to be solve, which is conformed by: a `"type"` `()` and variables where calculations will be saved, and are triggered in `"empty"`.

`mental States`: are variables Booleans (true or false).

`goals`: A goal is an objective that aims to accomplish a task or process, characterized by: `"mental_state_name"` (mental state's name) which is initialized in `"empty"`, also, `"current_value":false`, determinates the value which characterizes the current state of the mental one, it is started by default in `"false"`; and a `"target_value":true`, defines the value which must be achieved by the system after realizing the cognitive model and it usually starts by default in `"true"`.

`production rules`: Production rules are conformed by the Procedural Knowledge in CARINA, which are compose by: `"rule_name"` (rule's name), `{"condition", "attention_system", "problem": "problem_name" , "mental_state": "empty"` (started in "empty"), `"goal", "state": "empty"` (started in "empty"), `"sensor": "empty"` (started in "empty"), `"constraint":` (some cases is empty), `"conclusion"`: which have: `"action1", "name_action", "complete"`: (state of action, started in "false").

`beliefs`: Beliefs are the minimum unit that structure Semantic Memory in CARINA. Which have: `"typeSMU"`: (knowledge's type, saved in semantic memory) and has `"type"`, i.e., the variables' name and `"value"`, which modified if it is a different special data for storing Beliefs.

V. ILLUSTRATIVE EXAMPLE

According to the cognitive modeling methodology proposed by [20] a user-based cognitive model for the algorithm of the Tower of Hanoi in the metacognitive architecture CARINA [8] is presented below:

1. *Selection of Cognitive Task:* In this example, the cognitive task selected was a cognitive model for the Towers of Hanoi Algorithm in CARINA.
2. *Obtaining Information for Describing the Cognitive Task:* Cognitive task information was obtained using users and some documentary sources as background information. *Users:* four high school 8th grade students from a programming course. *Description of Cognitive Task to be Developed by User:* A user-based

cognitive model allows the user to accomplish a specific cognitive task to analyze mental processes and make predictions based on observations and then express them in algorithmic terms. This is possible using well-structured problems such as the Towers of Hanoi [21]. The technique Goals, Operators, Methods and Selection Rules (GOMS), facilitate the analysis of this type of cognitive models, which is a specification of the knowledge that a system needs to achieve a cognitive task. In addition, a well-defined natural language notation called NGOMS-L is necessary to express the GOMS models [8].

3. *Description of Cognitive Task in Natural Language:* After classification of the participants, three of them understood the cognitive task, where they applied the correct mental actions and understood the rules of the problem. The fourth participant deserted from the game before completing it, explaining that he did not understand it (see Table 1).

TABLE 1
DESCRIPTION OF THE COGNITIVE TASK IN NATURAL LANGUAGE

Successful subject	Unsuccessful Subject
Move green disk to peg B	Move green disk to peg B
Move yellow disk to peg C	Move yellow disk to peg C
Move green disk to peg C	Move green disk to peg A
Move orange disk to peg B	Move yellow disk to peg B

Description of the Cognitive task in Natural Language. This table was adapted from: Y. P. Flórez, A. J. Jerónimo, M. E. A. Gómez, "User-Based Cognitive Model in NGOMS-L for the Towers of Hanoi Algorithm in the Metacognitive Architecture CARINA," in *Proc. ICAETT*, Quito, Pichincha, Ecuador, 2019, pp. 473–484..

4. *Cognitive Task in GOMS (NGOMS-L):* In this stage, a set of goals and sub-goals are defined as the steps to be accomplished in order to achieve the cognitive task that will be computationally described. The steps are expressed in NGOMS-L denotating the Goals, Actions and Mental States. Figure 2 shows an inventory of the cognitive model elements in NGOMS-L.

Fig. 2. Description of cognitive task in GOMS (NGOMS-L). This figure was adapted from: Y. P. Flórez, A. J. Jerónimo, M. E. Castillo, and A. A. Gómez, "User-Based Cognitive Model in NGOMS-L for the Towers of Hanoi Algorithm in the Metacognitive Architecture CARINA," in *Proc. ICAETT*, Quito, Pichincha, Ecuador, 2019, pp. 473–484.

Goals Inventory	Mental States Inventory	Actions Inventory
Goalγ_{701}: Subject moves green disk to peg B.	Mental Stateσ_{703} : Green disk is moved to peg C.	α^c_{700}) Accomplish goal γ_{700}
Goalγ_{702}: Subject moves yellow disk to peg C.	Mental Stateσ_{704} : Orange disk is moved to peg B.	α^c_{702}: Return with goal accomplished.
Goalγ_{703}: Subject moves green disk to peg C.	Mental Stateσ_{705} : Yellow disk is moved to peg A.	α^c_{703}: Choose green disk
Goalγ_{704}: Subject moves orange disk to peg B.	Mental Stateσ_{706} : Yellow disk is moved to peg B.	α^c_{704}: Select peg
Goalγ_{705}: Subject moves yellow disk to peg A.	Mental Stateσ_{707} : Red disk is moved to peg C.	α^c_{705}: Put green disk in selected peg
Goalγ_{706}: Subject moves yellow disk to peg B.	Mental Stateσ_{708} : Green disk is moved to peg A.	α^c_{706}: Choose yellow disk
Goalγ_{707}: Subject moves red disk to peg C.	Mental Stateσ_{709} : Orange disk is moved to peg A.	α^c_{708}: Put yellow disk in selected peg
Goalγ_{708}: Subject moves green disk to peg A.	Mental Stateσ_{710} : Orange disk is moved to peg C.	α^c_{712}: Choose orange disk
Goalγ_{709}: Subject moves orange disk to peg A.	Mental Stateσ_{711} : Purple disk is moved to peg B.	α^c_{714}: Put orange disk in selected peg
Goalγ_{710}: Subject moves orange disk to peg C.	Mental Stateσ_{712} : Red disk is moved to peg A.	α^c_{724}: Choose red disk
Goalγ_{711}: Subject moves purple disk to peg B.	Mental Stateσ_{713} : Purple disk is moved to peg C.	α^c_{726}: Put red disk in selected peg
Goalγ_{712}: Subject moves red disk to peg A.		α^c_{741}: Choose purple disk
Goalγ_{713}: Subject moves purple disk to peg C.		α^c_{743}: Put purple disk in selected peg

5. *Cognitive Model from NGOMS-L to M++ Language:* Representation in M ++ of the cognitive model in NGOMS-L to be executed in CARINA. The Figure 3 shows that goals are achieved when the required mental state is fulfilled. Thus, the reasoning process in CARINA is performed in the *object-level*, changing a problem that has various initial states for various final states, using a set of *pre-conditional* and *post-conditional* actions.

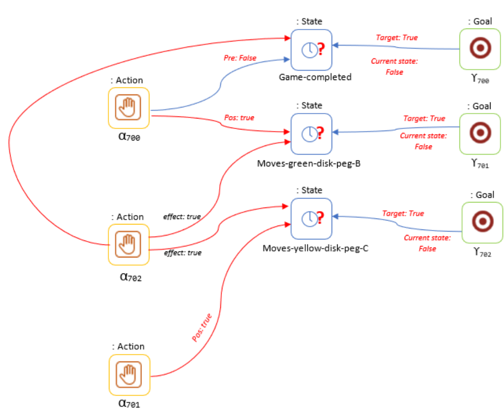

Fig. 3. Representation in M ++ of the cognitive model in NGOMS-L to be executed in CARINA [Own source].

6. *Runnable Cognitive Model in Carina of Towers of Hanoi Algorithm:* The computational cognitive model for the Tower of Hanoi algorithm was developed in an open

standard file format (JSON), thus the code is able to be executed in CARINA, see Figure 4:


```
{
  "Goal": [
    "game-complete",
    "green-disk-on-peg-b",
    "yellow-disk-on-peg-c"
  ],
  "MentalState": [
      "yellow-disk-on-peg-b",
      "green-disk-on-peg-c"
  ],
  "Action": [
    "moves-green-disk-peg-b",
    "moves-yellow-disk-peg-c"
  ],
  "Object": [
    "yellow-disk",
    "green-disk",
    "peg-b",
    "peg-c"
  ],
  "_id": "5eb45c837f14160017aa09dd",
  "User": "5da6213fceac9e2488a9b285",
  "domain": "towers of hanoi",
  "createdAt": "2020-05-07T19:07:47.295Z",
  "__v": 0
}
```


Fig. 4. Runnable cognitive model in CARINA of Towers of Hanoi algorithm [Own source].

7. *Testing and Maintenance of Cognitive Model:* Finally, the cognitive model created for the Towers of Hanoi algorithm in CARINA was tested in a functional software prototype (*MetaThink Version 2.0*). The software allows building cognitive models in a visual and quick way, based on the *Drag* and *Drop* characteristic. Figure 5 shows the executable cognitive model, which contains *Goal*, *Object*, *Action* and *Mental State*.

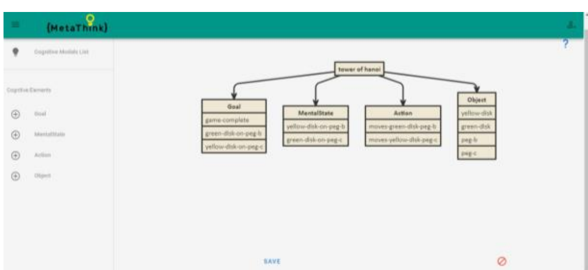

Fig. 5. Testing and maintenance of cognitive model of Towers of Hanoi algorithm in CARINA [Own source].

VI. CONCLUSIONS

The computational representation of a cognitive model in CARINA was designed using the Tower of Hanoi algorithm. This model was created with a user-based solution. The computational creation of the cognitive model was based on seven steps, which are: I) Selection of Cognitive Task, II) Obtaining Information for Describing the Cognitive Task, III) Description of Cognitive Task in Natural Language, IV) Cognitive Task in GOMS (NGOMS-L), V) Cognitive Model from NGOMS-L to M++, VI) Runnable Cognitive Model in Carina of Towers of Hanoi Algorithm and VII) Testing and Maintenance of Cognitive Model.

This computational model was executed in CARINA using a functional prototype called MetaThink Version 2.0.

Thus, the computational cognitive model executed in CARINA showed that it is possible to study user behavior and generate understandings and predictions, through observations as a means of information. Finally, it was possible to determine that the main elements in a computational cognitive model implemented in CARINA are Goals, Mental States, Actions and Objects.

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