Indian Journal of Science and Technology, *Vol 9(4), DOI: 10.17485/ijst/2016/v9i4/81628, January 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Bottom–up Approach of Modeling Human Decision Making for Building Intelligent Agents

R. John Martin[1]* and S. Sujatha[2]

[1]School of Computer Science and Engineering, Bharathiar University, Coimbatore – 641 046, Tamil Nadu, India; jmartin.in@gmail.com
[2]Department of Computer Science, Bharathi Women's College (Autonomous), Chennai – 600108, Tamil Nadu, India; sujaphd@gmail.com

Abstract

Background/Objectives: Cognitive modeling of decision making with reference to the cognitive architectures and base theories is an ideal approach for building intelligent agents. This work is to conceptualize the modeling process as a bottom–up approach to build cognitive agents. **Methods**: Among the existing cognitive architectures, four system level architectures which are in similar nature are being sampled and different factors affecting the decision making scenarios reflected in the architectures are closely reviewed. Base theories of human cognition are also adopted for the chosen architectures to strengthen the modeling process. **Findings:** LIDA and CLARION are the two cognitive architectures found similar in symbolic and connectionist nature and are open architectures for modeling cognitive processes like high level decision making. The cognitive base theories are found suitable for modeling decision making with these architectures. On this way modeling process is to be done in a bottom–up fashion to build intelligent agents. **Application/Improvements:** The two analogous approaches with LIDA and CLARION will provide number of cognitive models of decision making. On implementation of these different models, diversified agents can be generated and their performance will be studied empirically.

Keywords: Cognitive Modeling, Cognitive Architectures, Decision–Making, Intelligent Agent

1. Introduction

Modeling cognitive processes is a key requirement to bring out intelligent agents for wide variety of applications. Using existing models for the cognitive processes is not a good idea as the environment and interacting platforms are changing frequently. There is a major scarcity especially in modeling high level cognitive processes like learning, decision–making and problem solving in the present technological era. Although many decision tools build upon neuro–fuzzy system[1], the agent based decision making models[2] are anticipated by the cognitive research groups and the usability analysts. Although many cognitive models are in place to address decision making scenarios, it is essential to apply scientifically proved theories in the computational modeling of decision making so that wide variety of cognitive agents can be put forth for usability studies on various interacting mechanisms.

This paper is a part of the effort in modeling human decision making behavior in line with system level cognitive architectures and related theories for its computational framework. The study aimed at analyzing the architectural frameworks of decision making in all the cognitive architectures subjected to review. The subsequent sections of this paper describe the cognitive theories of decision making on which the architecture has been based and the conceptual framework of cognitive model building.

2. Cognitive Architectures

2.1 ACT–R

The ACT–R theory of cognition[3] evolved towards the mission of understanding modeling human cognition. It is rule based cognitive architecture used to model the basic and higher level cognitive and perceptual operations of

**Author for correspondence*

the human mind. ACT–R (Adaptive Control of Thought–Rational) is a quantitative framework that applies to a broad array of behaviors and tasks, formally integrating theories of perception, memory, action and other cognitive processes. The ACT–R architecture supports procedural knowledge through a production system[4].

ACT_R also supports implementations of decision making at micro level distributions and the data can be made and compared with the data through empirical studies. Several implementations of compensatory and non–compensatory decision strategies have been reported in the recent past[5,6]. Those implementations modeled how decisional processes interacting with memory, perceptual and other motor processes, which allowed them to quantitatively predict the response time distributions by using forced two–alternative choice decision task.

In addition with its applications in cognitive Science, ACT–R has also been used in producing user models to assess different interfaces and usability study, cognitive agents for virtual learning systems and intelligent systems to enhance the Artificial General Intelligence.

2.2 CLARION

The CLARION (Connectionist Learning with Adaptive Rule Induction On–line) is a symbolic and connectionist nature of cognitive architecture consists of distinct subsystems. They include the Action–Centered Subsystem (ACS), the Non–Action Entered Subsystem (NACS), the Motivational Subsystem (MS), and the Metacognitive Subsystem (MCS). It includes two levels, the top level is conceptual level used to encode explicit knowledge and uses symbolic representations, whereas, the bottom level is sub–conceptual used to represent implicit knowledge and uses distributed representation[7].

In CLARION architecture, cognition is formulated in terms of three main components: 1. A perception module for collecting and interpreting signals from the environment; 2. A central process module for reasoning and decision making; and 3. An action module for implementing decisions and behavior. The function of the motivational subsystem is to provide underlying motivations for attention, perception, cognition and action through feedback whereas the metacognitive subsystem is to observe and modify the operations of all the subsystems.

The architectural theory of CLARION showed that it was possible to develop cognitive phenomena in decision–making. Over the years, several cognitive models of decision–making have been proposed[8]. In CLARION the decision making is embodied in its NACS. The DFT (Decision Field Theory) is adopted in many implementations for modeling decisions with NACS of CLARION.

2.3 SOAR

SOAR (State, Operator and Result) is a theory of cognitive architecture that incorporates knowledge–intensive reasoning, hierarchical reasoning, planning, and learning. The SOAR architecture is designed to create general computational system that has the similar cognitive abilities as humans[9]. SOAR follows means–ends approach of problem solving. The goal is achieved by decomposing the problem into hierarchical sub problems.

SOAR is based on symbolic procedural architecture, comprised of episodic and semantic components to represent long–term memory; episodic memory holds previous states, while semantic memory keeps declarative facts. Learning has given important role for problem solving in SOAR; chunking and reinforcement learning use procedural knowledge, while episodic and semantic learning use declarative knowledge.

Although the underlying concept of SOAR is symbol processing, the recent developments shows that the non–symbolic representations applied towards reinforcement learning, imagery processing, and emotion modeling.

While the SOAR architecture is devised to achieve general intelligence, there are no achievements manifested in the recent years. Researchers recognized that it is still missing few aspects of intelligence like creating new representations by its own through hierarchical clustering.

The decision behavior is poorly manifested in the architecture in such a way to use it in an interactive decision– making processes. Recent researches showcased that additional theories are incorporated with SOAR architecture to improve the human decision behavior[10].

2.4 LIDA

The LIDA (Learning Intelligent Distribution Agent) is a cognitive architecture capable of modeling comprehensive, conceptual, and computational frameworks of human cognition. It was build based on the well–established Global Workspace Theory (GWT)[11]. The comprehensive framework of LIDA includes a series of cognitive modules and processes. This cognitive model is an extended form of its predecessor IDA and technically proven software agent[12]. Part of this architecture has been implemented and in place. LIDA cannot be implemented as a whole. Every unique implementation of the LIDA architecture is considered as a software agent and will be working with its own domain. The computational framework provides software support for the development of LIDA based cognitive models as software agents and intelligent control systems[13].

The LIDA cognitive model is working in a principle of cognitive cycles. The agent's actions are viewed as iterations of these cognitive cycles. A cognitive cycle begins with conscious stimuli and ends with an action. The cognitive cycle is conceived of as an active process that keeps interacting with different components of the architecture. Each cognitive cycle consists of three major phases, an understanding phase, an attending phase, and an action selection phase. Its cognitive cycles closely resemble in other cognitive architectures too. The LIDA architecture is partly symbolic and connectionist nature[14]. Thus the architecture is embodied one.

The consciously mediated action selection and action execution are recently implemented as stated in[15]. But the action selection mediated by unconscious cognition (volitional)[16] is underway by the research group.

3. Theories of Decision Making

There were many computational cognitive models of decision making developed in the past based on well–developed cognitive architectures and was become unacceptable by the successive researchers. This is due to inconsistent performance factor and most importantly due to baseless theories. In this section two popular theories are being proposed with significant importance. The first one is neuropsychological theory called DFT. And the second is a cognitive theory towards mathematical modeling of decision making.

3.1 Decision Field Theory

Decision Field Theory (DFT) is a stochastic dynamic model of decision theory based on neuropsychological principles of approach–avoidance behavior. Decision field theory was developed for theoretical modeling of choice behavior for decision making under uncertainty[17]. Years later, they extended this theory to explain the relationships among choices, selling prices, and certainty equivalents. The DFT is then extended for multi–attribute decision making[18]. However, the early applications were limited to binary choice behaviors; the current development extends the theory into problems of multiple choice behaviors[19].

DFT is one of the types of sequential sampling models used in a variety of fields in cognitive modeling[20]. Thus the DFT can also be presented as a model of decision making scenarios found in the cognitive interactions of computing systems[21].

This model is more broadly applied to decision making processes as compared to other computational theories. Many agent based models evolved using DFT in CLARION and other cognitive architectures.

3.2 Cognitive Theory of Decision Making

The cognitive theory is a descriptive theory based on empirical observation and experimental studies of choice behaviors[22]. It adopts 'axiom of choice' philosophy. The decision depends on decision goals, alternative choices and selection criteria. These are the three components in decision making theory. In cognitive theory of decision making the decision maker can be a human or an artificial agent.

3.3 The Mathematical Model of Decision Making

The mathematical model of decision making is fundamental for any decision making behaviors demonstrated through software agents. The axiom of choice states that there exists a selection function for any non–empty collection of alternatives.

Let $\{ X_i \mid i \in I \}$ be a collection of disjoined sets, $X_i \subseteq U$ and $Xi \neq \emptyset$, a function

$c: \{X_i\} \rightarrow X_i, i \in I$ is a choice function if $c(X_i) = x_i, x_i \in X_i$

Or an element $x_i \in X_i$

Where X_i is called the set of alternatives, U the universal set and I a set of natural numbers

The decision can be defined based on choice function and axiom of choice.

A decision, d, is a selected alternatives $x \in X$ from a non–empty set of alternatives X, $X_i \subseteq U$, based on given set of criteria T, i.e.:

$$d = f(X, T) = f: X \times T \rightarrow X, X \subseteq U, X \neq \emptyset$$

Where × represents a Cartesian product Decision Making is a process of decision selection from available alternatives against the chosen criteria for a given decision goal.

The axiom of choice theory is well implemented using RTPA (Real Time Process Algebra)[23]. It is considered as a platform for cognitive model building.

Table 1. System level cognitive architectures

Cognitive Architecture	SOAR	ACT–R	CLARION	LIDA
Underlying concept	Symbolic	Symbolic	Hybrid*	Hybrid*
Years of popularity	1983	1990	1998–2002	1988–2003
Methodologies adopted	• Based on the idea of problem states and problem spaces • Representation of permanent knowledge using Production rules • Representation of temporary knowledge as objects with attributes and values	• Division between procedural and declarative • Not distinction between implicit and explicit processes. • Has computational implementation using special coding language.	• Has four sub systems : Action–Centered Subsystem and the Non–Action–Cantered Subsystem, Motivational sub system, Meta–cognitive sub system • Dual representational (implicit versus explicit representations)	• The cognitive cycle consists of several cognitive modules • One or more modules contribute to a cognitive process. • Three modes of learning: perceptual learning, episodic learning, and procedural learning.
Commitment towards Decision making	Models evolved, but not verified empirically.	Some models evolved but not comprehensive.	Uses DFT model of decision making.	Facilitated for the development of high–level decision making.

*Symbolic and Connectionist

4. Results and Discussion

The Table 1 shows the extracts of the comparison between the four system level cognitive architectures. After a close review of these four architectures the two architectures CLARION and LIDA are found as ideal towards the framework of decision making model development for the following reasons:

- Both are symbolic and connectionist in nature
- Open architectures for model building
- Facilitates agent based cognitive models
- Strong software framework for implementation

Over the past two decades many efforts had been put by the research groups of these cognitive architectures towards the development of cognitive models. The decision making is considered as a high level cognition and as a complex task for the model development and implementation. Although these two cognitive architectures are connectionist nature of problem solving, the decision making behavior is not individual problem dependent rather treated as a collective behavior of cognitive architecture.

As stated in Section-3, the Decision field theory is more appropriate to model with CLARION architecture due to its stochastic nature. Alternatively, due to the generalized nature of LIDA, the axiom of choice theory will be more appropriate. As depicted in Figure 1, the decision making models are being erected on the base theories of decision making with the empirically proved cognitive architectures so as to generate large number of cognitive agents for various decision making strategies including uncertain situations. This bottom–up approach is quite different from usual cognitive model building process.

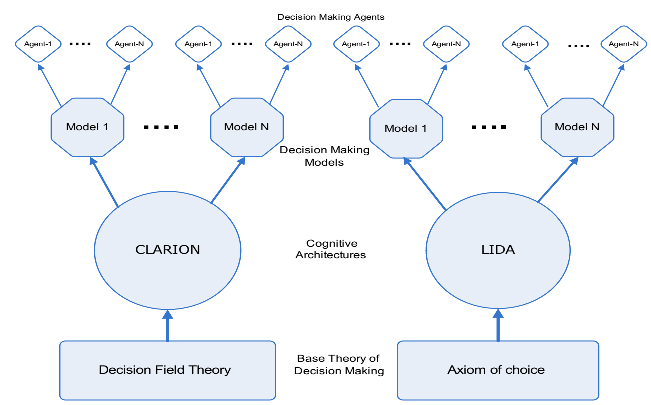

Figure 1. Bottom–up approach of cognitive model building.

On the basis of this conceptualization, we are on the way to evolve two independent models for agent based decision making based on CLARION and LIDA Architectures. Empirical analysis will be done by implementing proposed models as intelligent agents for certain decision making scenarios.

5. Conclusion

We strongly believe that no cognitive models will be successful unless it is built on empirically proved cognitive architecture and also on any neuropsychological theory. On completion of this study it has found that the CLARION and LIDA are the two ideal system level architectures that can be used to build the decision making model for the reasons as stated in section–4. Also, the chosen architectures are well managed by the two popular theories, DFT and the cognitive theory of decision respectively.

6. Future Work

Continuous efforts put upon this framework towards the mission of evolving the unique cognitive model of decision–making for intelligent agents.

7. References

1. Raj Kumar, Pathinathan T. Sieving out the poor using fuzzy decision making tools. Indian Journal of Science and Technology. 2015 Sep; 8(22).
2. Podell K, Funk BA, Goldberg E. Agent–centered decision making in normal and abnormal cognition. Revista Argentina de Ciencias del Comportamiento. 2012 Aug; 4(2):32–42.
3. Anderson JR. How Can the Human Mind Occur in the Physical Universe? Oxford University Press; 2007.
4. Trafton JG, Hiatt LM, Harrison AM, Khemlani SS, Tamborello FP, II, Schultz AC. ACT–R/E: An embodied cognitive architecture for Human–Robot Interaction. Journal of Human–Robot Interaction. 2012; 1(1):78–95.
5. Marewski J, Schooler LJ. Constraining ACT–R models of decision strategies: An experimental paradigm CogSci. 35th Annual Conference of the Cognitive Science Society; 2013. p. 2201–6.
6. Marewski JN, Mehlhorn K. Using the ACT–R architecture to specify 39 quantitative process models of decision making. Judgment and Decision Making. 2011 Aug; 6(6):439–519.
7. Sun R. The importance of cognitive architectures: An analysis based on CLARION. J Exp Theoretical Artificial Intelligence. 2007; 19(2):159–93.
8. Helie S, Sun R. How the Core Theory of CLARION Captures Human Decision–Making. IEEE Proceedings of International Joint Conference on Neural Networks; 2011 Jul–Aug 31–5. p. 173–80.
9. Laird JE. Extending the soar cognitive architecture. Proceedings of the Conference on Artificial General Intelligence; 2008. p. 224–35.
10. Zhong Z, Yiming B, Chang D. Modeling human decision behavior with SOAR and prospect theory. International Conference on Intelligent Computing and Integrated Systems; 2010. p. 733–6.
11. Franklin S, Strain S, Snaider J, McCall R, Faghihi U. Global workspace theory, its LIDA model and the underlying neuroscience. Biologically Inspired Cognitive Architectures. 2012 Jul; 1(1):32–43.
12. Franklin S. A foundational architecture for artificial general intelligence. Proceedings of the Conference on Advances in Artificial General Intelligence: Concepts, Architectures and Algorithms; 2006. p. 36–54.
13. Snaider J, McCall R, Franklin S. The LIDA framework as a general tool for AGI. 4th International Conference Proceedings on Artificial General Intelligence; 2011 Aug 3–6. p. 133–42.
14. Faghihi U, Franklin S. The LIDA model as a foundational architecture for AGI. Theoretical Foundations of Artificial General Intelligence. Vol. 4 (Ch. 7). 2012 Sep. p. 103–21.
15. Franklin S, Madl T, D'Mello S, Snaider J. LIDA: A systems–level architecture for cognition, emotion and learning. IEEE Transactions on Autonomous Mental Development. 2014 Mar; 6(1):19–41.
16. Martin J, Sujatha S. Volitional decision making on interactivity as a result of multi–cyclic cognitive processes and emotions. Journal of Computing Technologies. 2015 Oct; 4(10):2278–3814.
17. Busemeyer JR, Townsend JT. Decision field theory: A dynamic–cognitive approach to decision making in an uncertain environment. Psychological Review. 1993 Jul; 100(3):432–59.
18. Diederich A. Dynamic stochastic models for decision making under time constraints. Journal of mathematical Psychology. 1997 Sep; 41(3):260–74.
19. Berkowitsch NAJ, Scheibehenne B, Rieskamp J. Rigorously testing multialternative decision field theory against random utility models. Journal of Experimental Psychology: General. 2014 Jun; 143(3):1331–48.
20. Diederich A, Oswald P. Sequential sampling model for multiattribute choice alternatives with random attention time and processing order. Frontiers in Human Neuroscience. 2014 Sep; 8: Article 697.
21. Erlhagen W, Bicho E. Dynamic Field Theory (DFT): Applications in cognitive science and robotics. euCognition: The European Network for Advancement of Artificial Cognitive Systems, Network Action. 2009; 057–1.
22. Wang Y, Ruhe G. The cognitive process of decision making. Int'l Journal of Cognitive Informatics and Natural Intelligence. 2007 Apr–Jun; 1(2):73–85.
23. Wang Y. RTPA: A denotational mathematics for manipulating intelligent and computational behaviors. Int'l Journal of Cognitive Informatics and Natural Intelligence. 2008; 2(2):44–62.