Comparative Analysis of Cognitive Architectures for Impact of Non-deliberative Learning on Rationality of Agency

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Summary
This paper describes the importance of unconscious, non-deliberative processes and learning in planning and decision making of software agency in critical, unexpected situations. Real time planning is one of most debatable research areas in agency that mainly emphasis on the role of focused, controlled deliberative processes and learning, and come under conscious regime of mind. It restricts the rationality of cognitive agent with narrow domain knowledge to cope with challenging environment and also confines the scope of AGI to meet human's level intelligence. Therefore importance of unconscious, non-deliberative processes in real time planning and decision making cannot be discounted to make human like conscious software agents. Humans have great ability to promptly and precisely learn and react to meet daily life activities and handle challenges successfully with rational decisions. Neuroscience, folk psychology and Cognitive Psychology provides the evidence that unconscious, non-deliberative processes such as intuition and automaticity developed gradually from continuous learning and experiences, and run parallel with deliberative process. These unconscious, non-deliberative processes also play integral role to take rational decisions in novel, critical environments.

Key words:
Cognitive Architecture, Deliberative Processes, Non-deliberative processes, Rationality, Intuition, Automaticity, Unconscious cognition, Comparative Analysis.

1. Introduction

One of the main characteristics of cognitive agent is capability of decision and choice by analysing different options associated with relative risk and reward [1], [2], [3], [4]. It is significant feature of human's daily life that based on learning and leads to adaptive behaviour with evolution. Many psychological processes such as attention, perception, memory, learning, evaluation and reasoning are involved in judgement and choice processes to recover information related to current goal or task from memory and external sources.

Reasoning plays important role to retrieve more suitable information with the help of rational choice process which gives meaning to choose more appropriate way to take better decisions [1], [5], [6]. Rationality is vital aspect of human's cognition and leading characteristics of decision making process. It is responsible to change in decision choice process with continuous learning, restructuring, evolution and adaptation. Therefore it increases the chance to achieve current goal.

In term of cognitive agency, humans have persuasive brain which represents both reflective, consciously awareness and explicit processing system as well as reflexive, unconscious, automatic and implicit processing system [7]. Evaluative conditioning associated with reasoning and rule-based logic, performs well in conscious, explicit processing system. Because conscious processing system integrates multiple and diverse sets of information to validate the cost-benefit analysis of complex, critical decisions based on preferences, judgements and decisions among multiple choices. Thus conscious, reflective, explicit processing plays important role in logical reasoning and analytical thinking. Similarly in software agency, logical reasoning generates some new ideas or plans from knowledge or information which is taken from already experienced rules.

The main emphasis of artificial general intelligence (AGI) is to build conscious, life like, general purpose, artificial autonomous agents with multidimensional properties to cope with unexpected, novel situations that is inspired from ability of humans to work in variety of domains [8]. According to Wang AGI focuses to analyze the information processing of human mind, necessities of cognition and importance of learning to bring human's like intelligence in artificial autonomous agents [9]. It is further elaborated as AGI system must be general-purpose in nature as to deal novel problems which never visualize before. The autonomous system according to principle of AGI must be capable to take rational decision with continuous, incremental learning and effectively utilization of knowledge, and also must be capable to achieve goal with insufficient knowledge and resources.

In acquaintance for human level intelligence, an autonomous agent must be capable to deal different challenges based on logical reasoning, also understand the semantic content of language with incremental learning and move around obstacles in working environment [10].

The intelligent agent should be able to observe, interact and learn from its current environment and also from other agent's experiences and rewards [10], [11]. Then must have capacity to use its learning to develop skill, solve more complex problems while considering future

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problems related to it with planning and decision making in dynamic environment.

Therefore, to meet AGI challenges many computational versions based on different cognitive features such as memory, multiple sensors, emotion, perception, reasoning, attention, learning, planning, decision making and problem solving are trying to incorporate within an artificial autonomous agent to take it towards cognitive agency [12]. Every design to build different computational models based on keen study of cognitive scientists and cognitive-neuro scientist on information processing of human's mind to develop more rational and intelligent cognitive software agent, and also improving gradually by applying different cognitive measures.

According to research scope few of them are LIDA, CLARION, and QuBIC are discussed in detail and have different cognitive measures to perform routine tasks and to deal critical, novel, unexpected situations.

LIDA (Learning Intelligent Distribution Agent) is an autonomous software agent based on many psychological theories of cognition like deliberation, volition, sophisticated action selection, non-routine problem solving, metacognition, atomization, and self-awareness [8], [13].

It is major advancement to develop cognitive agent based on study of information processing in mind as it said to be cognitive theory of everything [14], [13]. Deliberation takes place in LIDA over multiple cognitive cycles and is a conscious process to plan, decide and schedule in goal directed behavior. The deliberative process is supported by reasoning, logic, emotions and motivation to evaluate the possible plans in term of scenarios and choose the best one. In LIDA, deliberative process is done by deliberative codelets and evaluation process is accomplished by codelets.

CLARION is generic, dual process computational cognitive architecture based on wide variety of psychological processes [15]. It said to be dual process as to distinct the importance of explicit and, implicit processes, and also try to find the relation between these two different types of process, come under conscious and unconscious regime of mind to develop cognitive software agent. It is broad unified theory of mind with hybrid architecture based on two main cognitive assumptions representation and learning.

QuBIC (Quantum and bio-inspired intelligence and consciousness) is a cybernetic-based cognitive architecture based on the idea to establish unified solution for the development of machine consciousness from theory to modelling l [16]. It is further expand as to developmental framework represents cognitive agents/machines based on cybernetic philosophy of consciousness and machines.

The research on conscious, deliberative processing and learning in software agency is still not matching the criteria as information processing in human's mind. It requires more research on controlled, deliberative processing by analyzing further aspects of information processing in mind. Similarly there is lot of research required based on different tests and psychological, cognitive science evidences to understand the role of unconscious, implicit, non-deliberative process such as intuition and automaticity to minimize the difference in real time judgement, planning and decision-making in cognitive agents.

2. Literature Review

Generally, to choose and pursue goal by analyzing different facts and preferences even with minimum knowledge and experience, come under deliberation- the conscious, rule-based, effortful processing of mind. Different theories and models of goals and goal directed behavior such as goal-setting theory, theory of reasoned action and self-efficacy theory are focusing on the significance and role of conscious thought or consciousness to construct and seek the goal [17], [18], [19]. Many steps are involved in the process to choose and pursue goal based on feasibility and desirability as measure multiple options, considering different strategies and plans associated with many sub-goals to achieve them, compare and evaluating the current goal with other goals while regularly monitor the environment to adapt strategy according to current situation. All these processes are done by many psychological processes which are slow, controlled, rule-based and deliberative, and come under conscious regime of mind to pursue goal. This conscious goal pursuit behavior results to skill acquisition after some learning iteration in same environment.

2.1 Learning

Learning is adaptive in nature and associated with gradual building and acquisition of knowledge that results to maintain particular skill patterns (such as driving a car, riding etc.) [20] [21]. Therefore learning can be defined as the process of skill acquisition with continuous practice or experience that involves in change of behavior. Behavioral patterns develop gradually with every learning iteration and continuous experience. It is further described as in initial stage, explicit knowledge developed and consider as important step to skill acquisition that leads to develop associations in deliberative goal pursuit process [22]. But continuous practice after some period of time results to develop number of iteration procedures which make skill less dependent on conscious, explicit knowledge while become more automatic, effortless and unconscious.

2.2 Knowledge Acquisition and Skill Development

Skill development is associated with execution of specific action-patterns during learning process phase [23]. Such as driving, writing etc. depend on conscious, influential learning of sequence of actions but after some practice, there is gradual reduction in conscious control. After some time with frequent practice, a skill become overlearned and results to bring changes in motor areas. These changes help to execute specific motor actions which work below conscious awareness in consciously goal pursuit behavior.
According to Masters, skill acquisition is a gradual process that passes from different phases as cognitive, conscious through associative to an autonomous phase [24]. In initial stage, the performance is irregular, slow and need more effort or practice because at this stage knowledge is rule-based and explicit, on the other hand performance becomes fast, effortless and smooth on autonomous phase because it based on non-verbalize implicit knowledge.
Expertise of any domain acquired knowledge consists of both physical and cognitive skill which established after ample repetition and learning [25]. Physical skill developed from physical expertise of procedural tasks while cognitive skills are depend on cognitive processes of analytical thinking, analysis and decision making that support procedural tasks. Rule-based, controlled, conscious, experimental learning transform into knowledge and then into experience which results to pattern generation related to cognitive skill acquisition and perform unconsciously with gradual reduction of attentional resources [26].

2.3 Role of Unconscious in Goal-Directed Behavior

It is stated that unconscious information processing has substantial influence in expert judgement, reasoning, planning and decision making as experts in particular domain handle the critical situations [27], [28]. A skilled person or expert has better understanding to cope with critical, emergency situations on based of previous learning experiences and rapidly establish the schema with intuitive judgements in which course of actions emerge to mind with negligible intentional effort to support explicit reasoning and planning that leads to take rational decisions. According to Dijksterhuis unconscious is not bounded with capacity limitation issues therefore extensive amount of information integrate unconsciously to think about vital matters in critical situations [29], [30]. It is stated as unconscious shows availability of much more information and its representations of multiple alternatives in memory which lead to superior judgements with quality planning and decisions in complex critical situations. Shen and colleagues describe that goal directed behavior is mainly consists of both deliberative and automatic (unconscious, non-deliberative) processes (Shen, Wyer Jr., & Cai, 2012). Cognitive agency is generally conscious about goal directed processes but motor actions perform automatically (unconsciously) to support that conscious, deliberative processes towards successful achievement of particular goal.

2.4 Automaticity

The composition of motor actions lead to automaticity which is product of learning as based on previous experiences [31], [32]. Every practice or learning experience results to gradual reduction of attentional resources, therefore automaticity is consider as fast, efficient and effortless while runs parallel with other deliberative, controlled, explicit processes. Automaticity is further observed (or study) as plans of actions are automatically related to particular goal that is consider as projected to pursue. Therefore with the activation of goal, the habitual plan is automatically activated to achieve the particular goal, there is no conscious guidance to plan or follow goal [31]. According to Bargh et. Al. automaticity represents the control of human's psychological processes by external events or stimuli to make judgements, choices and decisions to deal current situation or follow a goal without being consciously aware of such control [33]. One of significant feature of automaticity is autonomy, as once a process is started by triggering stimulus from environment or by intentional choice then it runs till completion even in the absence of conscious monitoring [34].

2.5 Intuition

One of important aspects of automaticity is associated with intuition to make quick, unintentional and automatic influence on choice and decision making [33]. Intuitive decision mode plays major role to deal complex tasks due to its extensive information processing capacity to manipulate among multiple reasons with negligible information processing cost [35], [36]. Intuition is recognized to be one of most significant cognitive processes and can be defined as the process having capacity to act or decide even without following a particular routine or rule while work with minimal attentional resources or unconsciously [37]. It represents fast reactions in form of judgements and decisions, therefore comes with effective outcome in complex, unexpected, crucial situations. It assists the effective and quick performance of tasks such as in game playing where intensely requiring quick reaction time, similarly lives saving, emergency situations faced by medical practitioners in hospitals, fire fighter and piolets in air aviation with rapid response to handle such time constrained, unexpected, complex and urgent problem solving scenarios even without being involve in conscious,

deliberative analysis and introspection of such situations to save human's lives [37].In such critical, emergency scenarios, the decision makers must be expert of their particular field because they able to apply rich cognitive resources without involving in general awareness of the situation while novices feel to consciously involve to decide various plans and related course of actions which results in lower performance or failure to meet challenges [37].Intuitive decision mode in particular field is activated through gradual learning and experiences, and also depends on associative pattern recognition processes [38]. The intuitive ability of an expert or skilled person is directed from substantial number of patterns held in long term memory. It is also directed from their ability to identify silent and critical environmental cues, and then rapidly match those cues with generally occurring patterns which leads to develop associations and come up with effective decisions to solve complex problems.
Therefore automaticity and intuition work below conscious awareness while run parallel with conscious, deliberative goal pursuit behavior, and help to take rational decisions in complex, novel situations that represents self-regulation and adaptation in cognitive agent.

3. Comparative Analysis of Cognitive Architectures

The main emphasis of this research is to meet the challenges of AGI to develop more human like conscious, rational, adaptive cognitive agent. Therefore, detail comparative analysis of few existing architectures is provided in upcoming sections to represent the importance of unconscious regime of mind with significant cognitive parameters such as implicit process, automaticity, intuition and skill acquisition, and their role in unexpected, complex problem solving.

LIDA is empirically based on biological, neuropsychological and psychological theories and principles, therefore it can be considered as suitable for underlying foundational cognitive architecture of AGI [13]. Its architecture embodied partially connectionist and partially symbolic that represents concepts model for Global Work Space Theory (GWT) [39]. Unconscious processes in GWT are represented as theatre audience and bright spot light is conscious. Small dedicated processes intend human cognition at unconscious level. It is based on cognitive (CC), neural (NC) and functional (FC) correlates of consciousness as shown in Table 1. The design architecture of LIDA streamlined on notion of cognitive cycle which inner structure is well defined.

CLARION is major advancement to develop more human like rational cognitive agent with dual-representations of conscious, explicit and unconscious, implicit processes based on many psychological processes to meet the gap of information processing in mind [15]. The design architecture of CLARION consists of cognitive correlates (CC), neural correlates (NC) and metaphysical correlates of consciousness as shown in Table 1. At unconscious, implicit level processes are done through reinforcement learning using back-propagation neural network. CLARION focuses to explore and analyses implicit and explicit processes to design behavioral patterns which can lead to generic model of personality [40], [41]. At implicit level, it represents importance of instinct and intuition in personality development while one of important development is implementation of drives to generate new motivations which associated with explicit goal representations. It shows personality can be fundamentally based on instincts which results from motivation and related processes in humans. On basis of various tests and simulation, CLARION tried to measure the importance of instinct and intuition in personality development which is basically a broad term with multiple parameters in case of individual, individual differences, socio-cultural experiences and its influence on learning of individuals [41].

Table 1: Conscious Machines with respective measures of Correlates and Unconscious Cognition

MC	PC	FC	NCC	CC	Un-conscious Cognition	Mechanics	Meta-physical
LIDA		Y	Y	Y		Classic	
CLARION			**Y**	**Y**	**Y**	Classic	**Y**
QuBIC	**Y**	**Y**	**Y**	**Y**	**Y**	Cybernetic	**Y**

QuBIC is vital attempt to understand human cognition and information processing in mind as based on cybernetic philosophy of consciousness and intelligence [16]. By incorporating all correlates of consciousness rather focusing on classic representation, it provides singular cognitive architecture for machine consciousness to align the elements of cognitive knowledge domain (CKD). QuBIC provides cybernetic cognition for machine consciousness derived from unified theory of mind (UMT) and extent it to unified theory of mind for machine consciousness (UTMMC), which leads to develop QuBIC model and associated developmental framework, and also major advancement to design artificial mind agent.

4. Role of Unconscious, Non-deliberative processes in Cognitive Architecture

As the main focus of AGI to develop conscious, rational and adaptive cognitive architecture inspired from information processing of human's mind. Therefore main focus of this research to represent importance of unconscious, non-deliberative, implicit processes such as

intuition and automaticity developed gradually from learning and knowledge in skill acquisition process while consciously pursue a goal, and their role in judgements, planning and decision making in routine task/ goal performance as well as to deal complex critical, unexpected novel situations.

As consciousness is one of fundamental aspects of human cognition. Therefore there are different theories of human consciousness based on different knowledge domains. Different theories are formulated to develop machine consciousness by covering different parameters of human consciousness to meet the vision of AGI to develop cognitive agent that can be able to solve complex problems and take rational decisions.

LIDA based on GWT derived from many psychological and neuro evidences to measure the importance of conscious events in cognition while makes it functional consciousness. Design architecture of LIDA represents extensive spectrum of cognition from low level perception/action to high level reasoning. Architectural components of LIDA empirically based on neural and cognitive correlates of consciousness as represented in table1, but limited role of unconscious cognition. CLARION is vital attempt to take initiate to address unconscious processes while it consists of neural, cognitive and metaphysical correlates of consciousness. Both cognitive architectures are not addressing the all possible correlates of consciousness and also bounded the role of unconscious processes as well. Research on machine consciousness is mostly based on classical physics before development of QuBIC model. QuBIC is major development to model maximum correlates of consciousness necessary to simulate conscious mind which represents broad spectrum of cognitive abilities such as learning, motivation, memory, dream and self. The design architecture of QuBIC separated into conscious and unconscious regime of mind which further categorise into different cognitive measures with dual representation as memory system, motivational system, behavioral system, decision execution system and meta-cognition. Involuntary actions, reflexive actions and instinctive processes are regulated in unconscious layer of QuBIC, and also deal with physical correlates (PC) of consciousness along with implicit memory, emotion and knowledge, unconscious decisions and their enactment, and different meta-cognitive functionalities. Unconscious layer regulates the basic drives to generate new motivation and performs deed-assessments and various meta-cognitive functions such as synchronization of conscious and unconscious processes, memory management, performance evaluation and regulation of cognitive modules and learning. It leads to priority switching between conscious and unconscious processes in QuBIC model. By addressing maximum conscious correlates in QuBIC as compared to LIDA and CLARION see table 1, it also represents the role of unconscious processes. But, still there is ample research required to understand the role of unconscious cognition in human's goal pursuing behavior by measuring different aspects of routine and challenges circumstances.

The implementation of unconscious, non-deliberative processes in cognitive architecture determine importance of unconscious cognition to take rational decisions and lead towards scope of AGI. Non-deliberative, implicit processes automaticity and intuition start developing gradually with every learning iteration after some constant period of time while to pursue a goal deliberately, and it is associated with skill acquisition as shown in fig 1. Therefore, every learning experience results to develop behavioral patterns in cognitive architecture. After few iterations of conscious, controlled, rule based learning results to acquire skill based on explicit knowledge.

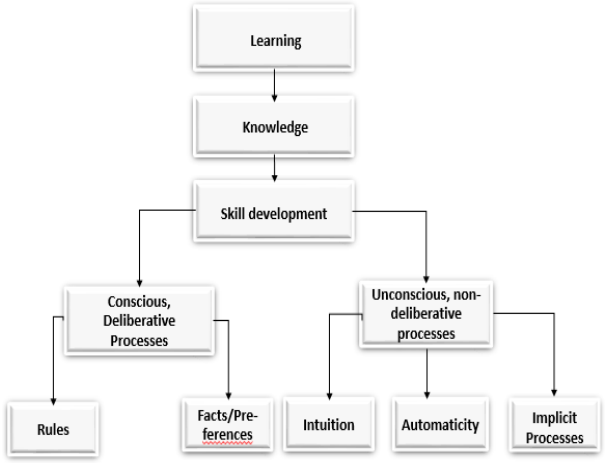

Fig. 1 The Relationship between Deliberative and Non-deliberative Processes from Learning to Skill developemnt.

At this stage, associations develop gradually with every learning iteration and role of explicit knowledge starts reducing. Therefore number of iteration procedures develop steadily and lead skill towards more automatic behavioral patterns with minimum attentional resources. Consequently implicit processes associated with relative implicit memory and implicit learning belong to unconscious regime of mind, start progressing and eventually running parallel with deliberative goal pursuit behavior. Gradual reduction of attentional resources, learning and knowledge results to develop automaticity and intuition which lead to enhance the role of unconscious. Automaticity govern many routine behaviors and actions that results to lower the burden on conscious processing. Specific goal structure such as plans of actions, routines develop gradually and then activate unconsciously with relevant situation to pursue a goal.

Similarly intuition is a result of knowledge and experiences assembled from related problem solving structures.

In critical situation, intuition helps to analyze situation with judgements based on multiple dimensions of information are cues with their respective values which work below conscious awareness but govern conscious deliberative processes to take rational decision. Role of automaticity explored the prominence of intuition to show automatic and immediate influence on planning and decisions, that lead to rational decisions associated with self-regulation and adaptation.

5. Conclusion

The detail discussion with support of literature helps to measure the importance of unconscious non-deliberative processes intuition and automaticity to take rational decisions. With reference to psychology, folk psychology and cognitive psychology unconscious cognition plays integral role to develop routine behaviours, and to plan and decide to perform daily life activities or to meet unexpected, novel situations.

According to scope of this research, the role of unconscious, implicit, non-deliberative processes-intuition and automaticity is crucial to develop cognitive architecture to take rational decisions in challenging circumstances. Continuous, iterative learning patterns leads to develop unconscious processes-automaticity and intuition in cognitive agent that reduce the role of conscious resources to pursue a goal in similar circumstances. The agent with intuitive decision mode can analyze critical situation with previous knowledge and multiple dimensions of information below conscious awareness. On the other hand, automaticity delve the importance of intuition that represent immediate and automatic influence of intuition on planning and decision while running parallel in consciously goal pursuing behavior. It leads to rationality in cognitive agent with adaptive behavior.

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