Cognitive Architecture to Evolve Conscious Cognitive Tasks into Common Sense Actions on Agents

K. R. Shylaja, M. V. Vijayakumar, Darryl. N. Davis and E. V. Prasad

***Abstract*— the research work describes the design of a cognitive model to demonstrate consciousness and common sense concepts on the robots to make them more situated and smart in executing their tasks assigned using cognitive approach. The work also explains how the robots convert their learned knowledge into common sense knowledge over a period of time. COCOCA (Consciousness and Common sense Cognitive Architecture) uses Global Workspace Theory (Baars,1988) and Multi Draft Model (Dennett, 1991) for consciousness, EM-One architecture (Singh,2005) for common sense critics and SMCA (Society of Mind Cognitive Architecture) for agent architecture (Vijaykumar, 2008), as metaphors. The control system designed enables a machine to build a knowledge base through conscious explicit learning of task operations. This agent after using this knowledge repeatedly on a scenario converts this into task specific common sense knowledge. The research is aiming to prove that common sense tasks are executed faster and utilize less resource than conscious tasks. The performance of agents improves if it can execute most of its routine tasks as common sense. The COCO cognitive architecture proposed in this paper is a five layered architecture with layers such as; reflexive layer, reactive layer, deliberative layer, consciousness layer and common sense layer, where the agents of each layer exhibit different level of consciousness and intelligence.**

Index Terms— cognition, cognitive architecture, consciousness, Access and Phenomenal Consciousness, common sense critics

I. Introduction

Development of conscious robots to execute highly critical tasks in critical environment requires human kind of consciousness and decision making abilities. The behaviour of human or animal is a result of conscious processes running in their minds. In human or animals the consciousness demonstrated will be either phenomenal consciousness or access consciousness [7] [8].

The phenomenal consciousness is simply a raw sense such as our experiences of feelings, emotional thoughts, taste of chocolate etc. These raw senses are also called as qualia. The access consciousness is using these phenomenal qualias to remember something or learning some topics etc. The access consciousness is how we control our behaviour because of the qualias, hence is a process of acting on things which we have already experienced [14].

Consciousness can be implemented on machines using computational model of cognitive approach [1] [3] [4] [5] which either uses a vehicle model or process model. The vehicular approach takes into consideration of how the information is represented in brain when in conscious state, where as process approach studies different control processes that are active in brain in conscious state, manipulating the information stored in our brain, This approach emphasizes on how vehicle representations are processed rather than how they look or what they are.

The cognitive science is a field of science which studies the control process running in brain to understand how a cognitive task is executed in brain to produce cognition [2] [18]. Using cognitive approach for consciousness is to give a computational model which includes a set of disciplined cognitive process running to exhibit appropriate behaviour. These cognitive processes use information structures stored in memory as knowledge base for reasoning. The information is encoded in the brain for processing to create a conscious state of experience. The brain is considered as set of information processing devices that process each sensed input to bring them into conscious awareness.[1] [3] [4] [10].

II. Psychological Study of consciousness

Consciousness has no clear definition, but is attributed to critical elements of mental life such as thoughts, feelings and volition. Though many dictionaries give definitions such as “the state of being aware, or ones own awareness about world and self” (concise oxford dictionary). The other relevant definition of consciousness that can be adapted on machines [27] is “being conscious is the ability to have subjective experiences, wishes, desires and complex thoughts and to perform flexible, self monitored purposeful behaviours.”

Manuscript received June 26, 2013; revised August 11, 2013;
K.R.Shylaja, Associate Professor is with Dr.Ambedkar Institute of Technology, Bangalore, India; Phone Number: 09900138703; email: tejushyla@yahoo.co.in; fax: ;
M.V.Vijaykumar is with New Horizon College of engineering, Professor & Head, Phone Number: (0) +99 9731443839; e-mail: dr.vijay.research@gmail.com;
Darryl. N Davis is with University of Hull, UK, Director of Research Phone Number: +44(0)1482466469; email: d.n.davis@hull.ac.uk;
E V Prasad was with JNTU, Kakinada, Rector & Prof. of CSE ; Phone Number(O) +91 884 230 0823 +91 984 957; email: profevprasad@yahoo.com

The role of consciousness in subjective experiences is to capture the mental content and mental process when in conscious thinking process, perception and feeling. These subjective experiences will affect the intentional behaviour and will be evident in one's actions.

The meta awareness or meta conscious is being aware of what and why we are conscious of something. In this perspective the unconscious experiences are those mental contents that are experientially conscious of ongoing experience but are not reported.

Characterization of conscious tasks:

The consciousness is always associated with cognitive tasks that are executed, though the level of consciousness in each task may be different. The conscious cognitive tasks are characterized by conscious access, conscious thinking, conscious control and meta-conscious monitoring of self behaviour [27]. The conscious mind is a result of mental processes that are running on mental representations of ongoing events to exhibit behaviour.

A. Conscious access:

This subtopic explains how any mental process or mental content will become available for reporting on conscious activation. The global workspace theory [3] [4] [5] is one of the cognitive theory for explaining conscious experiences. Unless the conscious experiences are accessed, one can not consciously reason, plan and control its actions by making complex decisions or judgments in critical situations. Any experience to become conscious should have strength, stability and quality. The global workspace theory uses a central working memory to generate conscious experiences. The experience that persists for longer or familiar or recently experienced will have high strength and get access to the working memory to become a conscious experience.

According to Singer [24] the brain has structural and functional features. The internal representation of brain when in conscious forms a meta-level representation as structural part. These first level representations are watched by higher-order functions or second order processes. These functions analyze the performance of their protocols with the deliberative actions executed in response for incoming signals to achieve the assigned goals.

B. Conscious thinking process:

According to Block and Searle's, consciousness enables higher-order, meaning based, and truth-value preserving processing of information [7] [22]**.** The unconscious processes are simpler in execution and are based on the associations they represent in a given context.

The cognitive tasks are executed in two different ways: some of the cognitive tasks are executed based on available knowledge, facts and values. In simple terms this is based on rules and propositions stored as knowledge in the system and are called as reflective systems. The reflective systems always exhibit rational behaviours to achieve the goals as they infer from the available rules [26]. The other system is an impulsive system, which will execute mostly based on their associations and motivations. These systems always demonstrate non-reasoned actions. The unconscious semantic processing of an ongoing event is mostly executed as an impulsive action.

The consciously repeated and highly trained operations over a period of time will become automatic and are simply executed based on their association in the current context. In brief the reflective system operations after being repeated many number of times will become impulsive actions [16] [20] [25]**.** The psychological experiment conducted has proved that deeper conscious thinking on simple problems leads to suboptimal decisions compared to unconscious thinking [12].

C. Conscious control actions:

The executive functions of cognition that monitor, manage and control the conscious cognitive processes are called the conscious control actions. The main aspect of control process is to select the mental content to be loaded in the conscious working memory that is most preferred and attended consciously in an ongoing event. This selection of mental content depends on the intentionality of an agent which has a rational behind its actions. These actions are deliberately executed when its necessary preconditions arise in an event sequence. These control actions can be flexible enough to adapt in a new scenarios and can be rearranged based on new requirements.

The constraints of conscious operations are:

- At any given point one can be conscious of limited number of elements in given environment, hence they have a limited capacity.
- All conscious controls are executed in serial and you can't parallel process multiple events consciously [19].
- The conscious actions require lots of effort and focus hence they are metabolically costly [11].

The mental process in mind can self adjust their operations depending on the contextual conditions and execute [9]**.** Hence in following scenarios the unconscious action control can be preferred:

- If there is possibility for an agent to autonomously control its actions in a given environment. The automatic behaviours are often executed unconsciously [6] [13] [28].
- If there are unconscious goals in the frame of mind when an agent is executing a goal related tasks such as cooperate, achieve and remember.
- The unconscious goals are possible if the goals are pre-formulated and standard and can be activated automatically.
- These goals can be used when there is no requirement on novelty of goal achievement and their behavioral sequence is predetermined.
- When the consequence of its action sequence is not important and does not affect the performance of the agent or the system as a whole.
- Unconscious goal activation is preferred only in certain conditions and cannot achieve the flexibility and potential of conscious goal achievement in all environments.

Meta conscious Monitoring Process:

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The conscious process running in mind and the mental content during their execution is monitored by a higher level control process called metacontrol process to take the system into meta conscious or Meta awareness state. This process can map the current content of the conscious working memory with the current goals assigned to an agent for achieving. If there is a deviated content found in working memory it can report to the control system to execute an introspection process [27].

According to William James consciousness is a mental life that manifests inner experiences and constantly changing mind states that form a stream of consciousness, which can be aware of and can be interacted to others. He stated two characteristics of consciousness; the first one is selective attention, where the decision of either selecting or ignoring some of the sensed data in the environment; the second one is fringe of consciousness, where the rightness or familiarity of actions experienced, which can be called as introspection and are not fully conscious processes[21].

Conscious awareness is the processes that persist for longer and acquires influential state over time. These control process are usually for rehearsal, recall, review and redesign our own activities. Baar's define conscious awareness as an experience that" can be reported and acted upon with verifiable accuracy, under optimal reporting conditions are reported as conscious.[3]"

III. Computational models of Consciousness

Cognitive science provides theories for designing computational models of mind. The conscious and unconscious experiences are represented as psychological processes in our brain. The principle of cognitive psychology treats each cognitive process as an operation on a set of neurons.

The cognitive theory can model computational conscious processes as mental process such as; information processing, knowledge representation, storage, retrieval, activation and knowledge transformation. The brain is considered as a collection of semi independent information processing devices and they are parallel in executing their mental tasks. These processing devices of the brain share and contribute their processed information with other mental tasks running in other parts of the brain [3] [4] [21].

Minsky (2006) describes our mind as a collection of many subsystems called resources. The mental activities such as anger and love are the result in change of states of some of these resources. The effect of anger is actually created by turning on some of the resources while turning certain other resources off. Consciousness is actually collection of such mental activities which are executed in serial one after the other. Our mind uses most recent memories in conscious state, which are described in abstract, symbolic or verbal description. To respond consciously, our mind uses models that are created and updated frequently in our mind for every object in the environment.

According to Baars Global workspace Theory (GWT) the brain is considered as a collection of multiple independent processing networks. There is a central global working memory through which these processes communicate with each other. According to Global workspace theory the data received by sensory organs is broadcasted to all parts of the brain for simple and flexible processing [5] [21].

Dennett (1991) proposes another Psychological contribution for conscious experiences called MDM (Multi Draft Model) [10]. According to MDM, the brain receives inputs from multiple sources with multiple interpretations from different sensory organs for an ongoing event in the environment. Over a period of time some of these inputs influence the degree of information that can be generated in other parts of the brain. As the degree of influence increases, these inputs become conscious experiences [10]. To select the conscious inputs from these multiple interpretations, MDM applies Higher-Order Theory. The MDM rejects the concept of "Cartesian Theatre concept of Consciousness" proposed by Baars [3]. Dennett also rejects the concept of qualia in MDM. He argues that the qualia's are properties of consciousness and are not a form of consciousness or a phenomenal consciousness.

IV. Newly proposed COCOCA (Consciousness and common sense cognitive architecture)

The COCOCA is a 3-column and five layer architecture proposed for demonstrating consciousness features and common sense critics in social and mental realm on machines. The architecture is influenced by SMCA (Vijaykumar, 2008), EM-One (Singh, 2005) and CAMAL (Darryl, 2000). The layers of this architecture define incremental control systems for robots that show different levels of capabilities.

The first level control system exhibits simple reflexes such as avoid hitting the wall, avoid obstacles. The second level control system is reactive in nature and demonstrate conscious features like attention, characterization, perception conscious features. The third level is BDI layer which builds a desire, Intension set for a robot that drives the control system. The next layer is conscious layer which demonstrate the highest level or complex cognitive tasks which requires conscious reasoning and decision making.

The highest level layer is common sense layer which works at the meta conscious level where the robot is conscious of what it is conscious of common sense actions.

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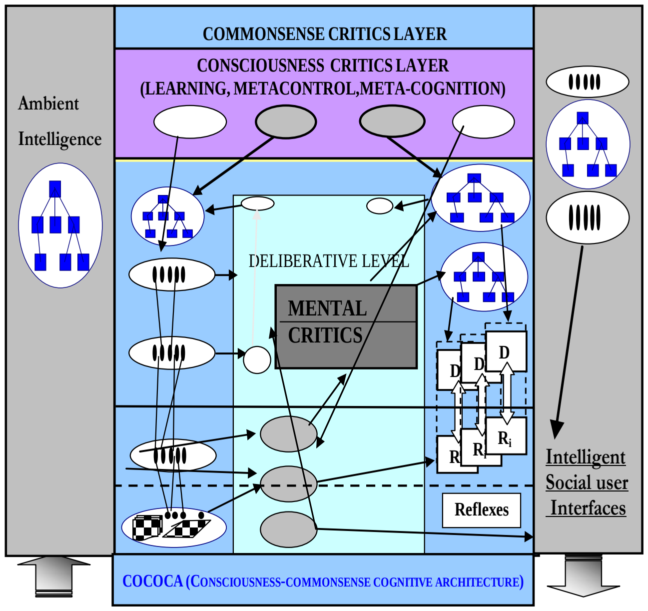

Fig. 1. COCOCA architecture

The architecture used for building control system works efficiently both in competitive environments as well as in collaborative or coordinated environment. In competitive environments the robots compete with each other to collect maximum resources and in collaborative environment they coordinate with each other to collect the maximum resource in minimum time duration.

V. Cognitive cycles of COCOCA agents

The sense-plan-act cycles of COCOCA robots are designed in two levels: conscious cycle and common sense cycle.

Conscious cognitive cycle:
The robots when exposed to new environment they tend to be more conscious and learn the environment. The cognitive cycle showed in fig 2 shows the different stages of cognitive cycle that the robot adopts to execute conscious tasks. The robot receives the input through the sensors system that will be temporarily stored in sensor buffer. The inputs are laid out in buffer for perceiving the input signals, once they are perceived they will be interpreted to understand how these inputs can be manipulated to achieve the goals. Reasoning is done to choose one of the option out of multiple options available. Based on this the best action sequence is selected and executed by the robot. The feedback of these actions will check if the current action has affected the performance of the robot to get a better result, such actions are learnt.

Common sense cognitive cycle:
The robots after being explored in new environments and achieve the task assigned build a set of learned knowledge. This knowledge base after being repeatedly used to execute the task assigned becomes a expertise and will be moved into a common-sense-knowledge. This knowledge is stored in a different procedural memory in a semantic representation. The robots will enter a common sense cognitive cycle when they see a repeated pattern of input from the sensing system. The common sense cognitive cycle shown in fig. 3 below has only 3 stages: sense, perceive and act as it works in a feed-forward loop. The action at this stage is simply executed on perception and doesn't require reasoning or understanding what has been perceived.

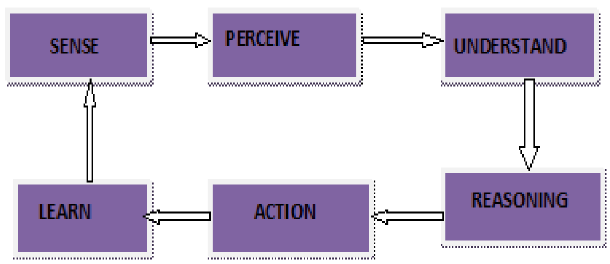

Fig. 2. Cognitive cycle of Conscious tasks of an agent

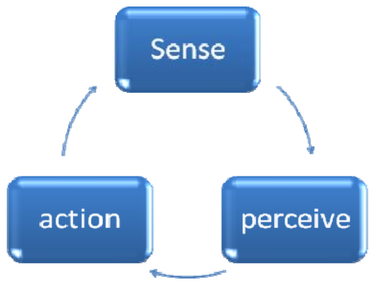

Fig. 3. Common sense cognitive cycle

The robots reaching this stage of cognitive cycle will perform better compared to robots running in conscious cycle. The next chapter discusses about the scenarios and test cases created to analyze the performance of these cognitive cycles.

VI. Designing of control system for COCOCA agents

The research work proposes a cognitive architecture to implement and test consciousness on robots and compared against human consciousness levels. The layered architecture [17][15][23] of COCOCA agent has five layers such as; reflexive layer, reactive layer and deliberative layer, consciousness layer and the topmost being common sense layer.

The uppermost layer has common sense of social interactions and task specific knowledge base, which are executed in subconscious level to improve the performance of the agent or robot. The attention based and imagery based approach of consciousness is used to implement consciousness on machines, where it is addressed how a bot prioritize the sensed information and make it a conscious sensation using attention and how it controls its actions based on consciously sensed stimuli is imagery approach.

The COCOCA architecture designed to implement consciousness uses Global Workspace Theory [4] to

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consciously perceive the high priority dynamic changes taking place in the environment using attention based approach. The robots run the cognitive cycle of stimuli-cognition-response cycle to understand the minute changes in the environment and generate a plan based on the high priority of stimuli sensed in the environment.

The study shows that human are highly intelligent animals and the human mind has multi directional consciousness of multiple aspects in the environment in super conscious state[1]. The conscious level of human will attain high level of consciousness while executing critical task or newly learnt skills. These consciously learnt tasks when frequently executed by everyone will become task specific common sense. Human tends to execute these routine common sense tasks in subconscious mind. The control system designed for COCOCA robots or agents perform based on the same principles. As human performance varies depending on his inner emotions called as qualia or phenomenal consciousness even COCOCA robots behaviour control system controls its actions based on inner sensations.

The memories such as Procedural Memory (PC-MEMORY), Episodic Memory (EP-MEMORY), Declarative Memory (DC-MEMORY) are effectively used to store agent's knowledge as shown in fig 4.

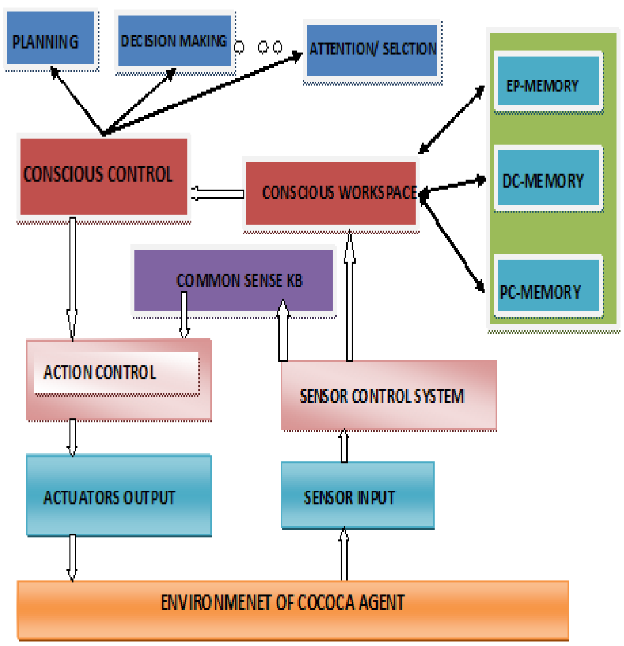

Fig. 4. Control systems for COCOCA agents

VII. TEST CASES FOR DEMONSTRATING CONSCIOUSNESS AND COMMON SENSE ON MACHINES

The scenarios are created for demonstrating how to demonstrate conscious tasks on machines. The norms and policies help the agents learn the repeated patterns of actions and learn them as common sense.

"The agent in perception state perceives that in its perceptual range there are multiple goal parameters at different distance"

In the above scene the agent focus its attention on categorizing the objects in the environment to different groups and perceive the nearest one. The agent is reactive and exhibit rationale behaviour to collect the resource.
The control system in perceptual state reads the input from senses and lays it buffer to perceive its affect on its current goal assigned. The goal parameter has the highest priority hence it will process that information consciously and go for further processing of these inputs to calculate the distance of each parameter. The action control system then creates the appropriate action plan to accomplish this goal.

"The robot perceives that it has obstacles in three possible turns towards the goal direction"

In the above scenario the agent has learnt that it has to avoid obstacle and find the alternate path for the goal. During obstacle avoidance it uses common sense cognitive cycle and turn towards the direction where there is a move possible. To find a path from the current position towards the goal state it runs conscious cognitive cycle.

In common sense cognitive cycle, it senses an obstacle and perceives that it cannot reach the goal state in that direction. Hence its action system turns the robot towards the next random direction in which there is a move possible. In conscious cognitive cycle it runs A* algorithm to consciously find a path towards the goal state.

The memory model used in the above scenario: the action for avoiding obstacle is defined semantically in transient memory; in conscious cycle it uses declarative, procedural memory to find a shortest path. It will recollect if the shortest path from this location to goal state is already found and learnt.

VIII. CONCLUSION

The research paper gives an approach to design cognitive model for demonstrating consciousness and common sense actions on machines. The proposed cognitive architecture has 5 layers and 3 columns with micro behaviours at the lowest levels such as reflexive and reactive layer. The deliberative layer implements goal oriented BDI model for agents. The top most two layers are consciousness critics' layer and common sense critics' layer with high level intelligence.

The agents construct rules as knowledge in conscious cognitive cycle during learning phase. These learnt knowledge after repeated execution will be moved into transient memory stored as semantic associations. The paper has given an approach to design a control system of different levels for robots.

The paper has given a set of test cases scenarios which can be experimentally demonstrated to measure the performance of robots when in consciousness or in common sense cognitive cycles.

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