International Journal of advanced studies in Computer Science and Engineering
IJASCSE Volume 4, Issue 9, 2015

# Development of Swarm and Ambient Cognitive Architecture (SACA) by using Society of agents

Ashwini K,
Computer Science & Engineering, Research Student, Jain University,
Bangalore, India.

Dr M V Vijayakumar,
Computer Science & Engineering,
Research Guide, Dr Ambedkar Institute of Technology, Bangalore, India

***Abstract:*** **This paper describes the concept of Swarm and Ambient intelligence using Society of Agents in simulated grid environment. The metrics used for ambient and swarm intelligence are motivation, coordination and performance. Here agents exhibit intelligent behaviour through coordination and motivation. Ambient and Swarm Intelligence are emerging technologies in the field of Artificial Intelligence. The two important aims are, firstly to develop a self-configurable computational model using the concepts of Ambient and Swarm Intelligence. Second To investigate the concepts of Ambient and Swarm intelligence in detail with respect to motivation, coordination and performance. The proposed SACA (Swarm and Ambient Cognitive Architecture) is designed and implemented for four layers which include Reflexive-Reactive, Deliberative (BDI), Swarm, Meta Learning layer. In the proposed multiple-layered architecture, the agents exhibit simple actions like moving in the environment to the complex level actions like communicating with each other andmoving together for the same task. The group of agents finishes their assigned task and the performance and the motivation is well demonstrated in the simulated environment. It has been demonstrated that the group performance was high when they had a specific goal and their performance were high. The group's goal setting also increases the individual performance. It motivates them to achieve the goal. Therefore the performance is more when they have a well desired goal setting in their life. This paper gives an idea on how to develop a swarm and ambient intelligence in a SACA model. It is based on the four layers.**

*Keywords: Ambient, Swarm, Agents, Cognitive Architecture, BDI, Motivation, Coordination, Performance.*

## I. INTRODUCTION

Swarm Intelligence is a new emerging branch in the field of Artificial Intelligence. In 1989 G.BENI and J.WANG first introduced the concept of swarm intelligence by cellular robotics systems [1]. Swarm is group of homogenous individual agents, interact among them and with the environment. Agents are simple with limited capabilities, but by interacting with the other agents of their own kind they achieve the task. The agents follow very simple rules. Swarm Intelligence is a simple local behaviour which leads to global intelligent behaviour. The main aim of Swarm Intelligence is to increase the performance and robustness. There are many natural Swarms exist in the nature like colonies of ants, flocking of birds, honey bees. From the inspiration of these natural Swarms, many Swarm Algorithms which are developed. The social interaction of swarm there are two types namely direct interaction and indirect interactions.

1. Direct interactions: here agents interact with each other through audio and video example: birds interact with each other through sound (audio); bees interact with each other through waggle dance.
2. Indirect interaction: here agents interact with the environment, that is, one agent changes the environment and the other agents respond to change. The indirect interaction is called stigmergy. E.g.: the pheromone laid by the ants during the search of foods.

The enhancement in the field of technology has led to the development of new devices. This lead to the transformation how it connects the people in the society with the computers. Initially there were huge devices, now these huge devices are embedded in the electronic devices using the protocols such as Bluetooth and zigbee which are used in our day to day life like washing machines and etc. where even non-specialist also will be able to handle it. This lead to the removal of physical connection. This kind of technical improvement is being extended in the area called Ambient Intelligence (AMI) [2]. In Ambient Intelligence, Ambient is immediate surroundings of the agent/user. Ambient Intelligence is giving intelligence to the device or to the environment, so that environment gets the intelligence and it response to the agent needs/user.AmI is the combination of artificial intelligence and the different technologies. In AmI, Sensors act as a main device. It is used to capture the information of the surrounding area [3].

Along with the Sensor,AmI also involves the other devices like ultrasonic devices cameras and microphones. The working of AmI is, in the first model the sensors are used for acquiring the data or information from the surrounding environment. But the sensor does not check whether the data is correct or valid. The second model is storage, handling and maintain the data. The third model is intelligent model. It is at high level. This model is mainly responsible for understanding the particular language; it also performs the multi-agent based modelling. This component is then used by the top layer model[4].

The marriage between the Freudian and the Turing revolutions was an unhappy marriage which resulted to the birth of cognitive science. Cognitive science is an interdisciplinary field, which focuses on the study of mind or thought process of brain. The word Cognition is "The *process of obtaining knowledge through thought, experience and senses"*. Later it leads to the developments of mathematical theory of communication and cybernetics. It was first come in natural science of information. By 1930, Sigmund Freud came up with the idea that most of the operations of mind are hidden in the layer of sub-consciousness. The problem of such mental problems (Psychoanalysis) had grown based on guessing and the context is unscientific. So the scientific community has come up with the erroneous notion to understand the working of mind. Before 20$^{th}$ century, Camillo Golgi and Santiago Raman works led to the description of the structure of neuron and stated that the neuron is the fundamental functional unit of the brain [5].

John von Neumann one of the greatest scientific geniuses of 20th century has worked on the theory of neural science and has first developed the Cognitive Architecture. The Cognitive architecture is a theoretical entity, that build an integrated theory and explains the human cognition and performance.Cognitive architecture used for a specific task, supplied with the task specific knowledge is called as a cognitive model. Everything in the surrounding is the man made machine, to understand the working mechanism of these machines, it is important to study the mind or the thought process of the brain.

According to the Neumann any cognitive architecture should satisfy the following 3 layers:

1. Reflexive Layer: Reflex action is basically derived from human and animal biological neuromuscular action. The reflexes are built-in mechanisms where action can occur quickly, before thinking.
2. Reactive Layer: Reactive agents are having more flexible control mechanism. Here agents are more goals oriented. So agents in this layer behaviors across integrated actions.
3. Deliberative Layer: Deliberative or BDI (Belief-Desire-Intention) agents developed on the behaviors used in the reflexive and reactive agents. The deliberative actions are planned and coordinated in terms of the agent, its internal state, its motivations and its perception of resources in the environment. Mind is made of many small processes; these are called deliberative or mental agents. Each mental agent by itself can do some simple things. Deliberative agents reasons about their own tasks and plans [5].

## II. SYSTEM ARCHITECTURE

The SACA(Swarm Ambient Cognitive Architecture) architecture is designed by considering the SMCA (Vijay Kumar, 2008) as a base. The SMCA is 6 tier and 5 column architecture as shown in the figure 1. This provides the basic explanations. The SMCA is group of individual agents performing the different individual actions. But the SACA is a group of individual agents performs same actions.

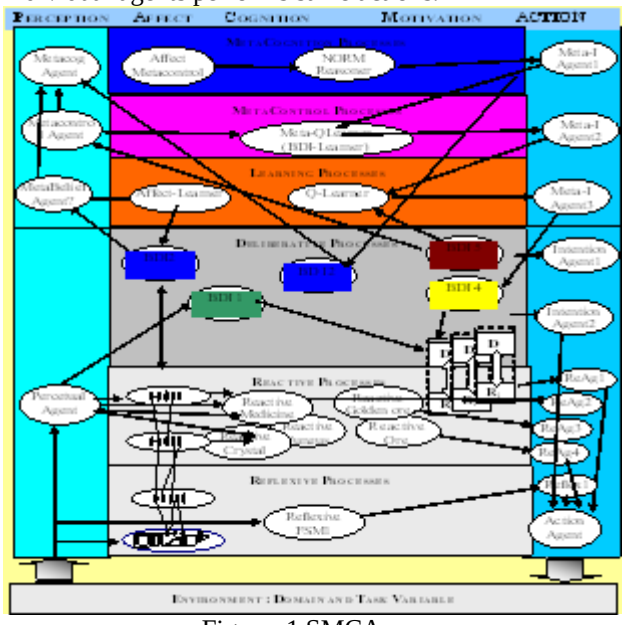



Figure: 1 SMCA

SACA model is 4 tier and 5 column model as shown in the figure 2 used to implement the various cognitive issues like planning, reasoning, thinking, problem solving, decision making and etc. At every

layer there are agents with behaviours, which react to the problems of that layer. At each layer the agents shows many intelligent behaviour which are combination of many simple behaviours. The SACA model includes reflexive-reactive, deliberative, swarm, meta-learning agents. The SACA architecture describes the collective behaviour of simple and intelligent agents. The agent uses cognition to metacognition throughout the process to show the intelligent behaviour. Consider the scenario of the ambient environment shown in the figure 3. The simulated agents also called as actors are represented as circle shapes. The agents are created by using the Prolog graphics. There are two different parameters exist in the environment: (1) Agents energy, (2) Performance. The energy parameter considered in the environment for agent is food and is shown in the small green square shape. The performance parameter for the agent in the environment is demand and is shown in the small white circle shape. Diamond is also called as a goal parameter. All the parameters are created using the Prolog graphics.

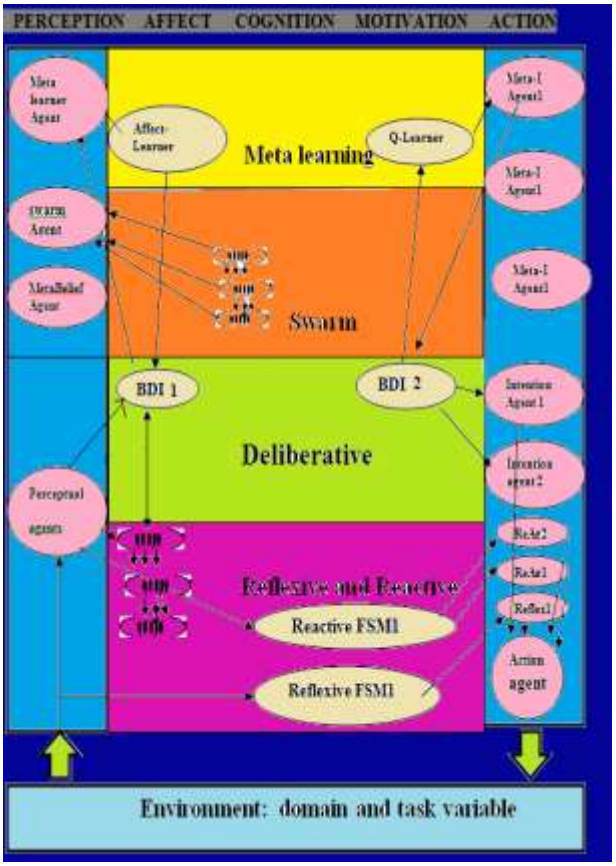



Figure: 2 SACA

The agents in the environment work together to exhibit different control mechanisms and techniques. The agents within SACA architecture demonstrate activities for their planning, reasoning, decision making, problem solving and self-reflection. By using many different metrics, the agent behaviour can be analysed. The major metrics are interaction with environment, agents and with its parameters, competition with respect to collection of diamonds and the energy utilization at every cycle.

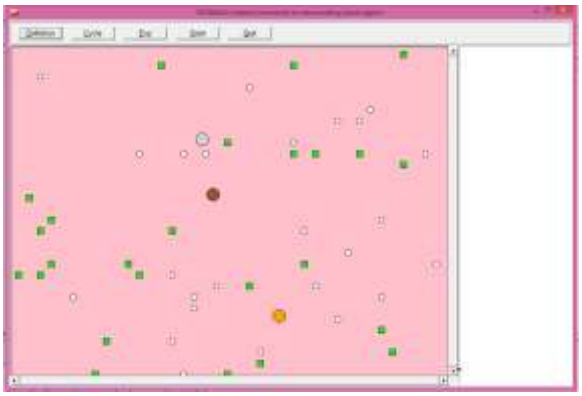


Figure 3: Simulated environment

SACA model has reflexive-reaction, deliberative, swarm, and meta-learning agents. The reflexive agent at the reflexive layer has the reflexive behaviour of action based on the environmental conditions. The reactive agent at the reactive layer shows the goal oriented behaviour. The agent at this layer are more focused on the goals and hence shows reactive actions such as shortest route, coordinated actions in between agent and parameters in the environment.
The deliberative agent at deliberative layers are more focused by able to have control over its internal state and highly focused towards the goal. Swarm agents are group of agents collectively performing the task. Agents at this layer exhibit the motivation and coordination. Meta learning is used for adoptive BDI models. The BDI model is associated to the deliberative level of the architecture. The Meta learning mechanism used for controlling the BDI models belong to the top level of the SACA architecture. The metrics used by the BDI agent is psychological and goal oriented behaviour decision making variables. The BDI agents control its pattern of behaviour with respect to time and energy.

## III. RESULTS

The experiment results show the performance of the swarm agents in ambient environment. The results will demonstrate that communication along is not sufficient for individual performance in a group but even the behaviour of an individual plays the roleie motivation. The results of these experiments will provide the basis solution or partial solution for the

issues stated in this paper. SACA architecture is designed to check how individual agents will behave in a group, how agents behaviour will have on impact on the group performance. Agent behaviour can be analysed using different metrics like competition, life expectancy and the social interaction with respect to environment and its parameter. The simulation demonstrates the complex interaction between different type of agents, agents behaviour with respect to use of energy and time to make decisions. The SACA results are simulated for

1. Performance of swarm agents with respects to number of diamonds collected.
2. Life expectancy of swarm agents with respect to number of cycles lived.
3. Energy distribution of swarm agents: at each cycle how agent's energy is getting decreased and on consumption of food how the energy of on agents is getting increased.
4. Comparison of performance of agents and thus concluding the highly motivated agent and less motivated agent.

The cycle is fixed for all the agents. Here in experiment the number of cycles considered is 500 and initial energy for each agent is 100 units.Number of food considered is 25 pieces and diamonds 25 pieces. Each agent is experimented for the same cycle, same initial energy, same resources like food and diamonds. Input value of each parameter is defined the configuration file. The output file gives the details of each agent. This file includes number of cycles lived, collection of each parameter as shown in the figure 4. The results of each agent is systematically tested and calculated based on their life expectancy and the performance.

```
Selected data is
File name = ashwini-graphs-july21st.txt
Maximum cycles = 500
Obstacles = 0
Intial energy = 100
Food      =    25
Diamond   =    25
```

| Cycle | Name | Type | Age | Energy | Food | Diamond |
|---|---|---|---|---|---|---|
| 1 | reflexive_edge | agent1 | 1 | 100 | 0 | 0 |
| 2 | reflexive_edge | agent1 | 2 | 98 | 0 | 0 |
| 3 | reflexive_edge | agent1 | 3 | 96 | 0 | 0 |
| 4 | reflexive_edge | agent1 | 4 | 94 | 0 | 0 |
| 5 | reflexive_edge | agent1 | 5 | 92 | 0 | 0 |
| 6 | reflexive_edge | agent1 | 6 | 90 | 0 | 0 |
| 7 | reflexive_edge | agent1 | 7 | 88 | 0 | 0 |
| 8 | reflexive_edge | agent1 | 8 | 86 | 0 | 0 |
| 9 | reflexive_edge | agent1 | 9 | 84 | 0 | 0 |
| 10 | reflexive_edge | agent1 | 10 | 82 | 0 | 0 |
| 11 | reflexive_edge | agent1 | 11 | 80 | 0 | 0 |
| 12 | reflexive_edge | agent1 | 12 | 78 | 0 | 0 |
| 13 | reflexive_edge | agent1 | 13 | 76 | 0 | 0 |
| 14 | reflexive_edge | agent1 | 14 | 74 | 0 | 0 |
| 15 | reflexive_edge | agent1 | 15 | 72 | 0 | 0 |
| 16 | reflexive_edge | agent1 | 16 | 100 | 1 | 0 |
| 17 | reflexive_edge | agent1 | 17 | 98 | 1 | 0 |

Figure 4: Result file

Based on the statistical data assigned for each agent, the experiments are conducted. To compare a result of each agent, the following statistics were collected: life expectancy, diamonds collected. The agent's total performance is calculated based on number of diamonds collected and based on life expectancy. The experiments conducted many number of times, by considering the same input. The final results graphs are consider by taking the best data out of the experiment conducted. The data will be plotted on the excel sheet. Then the graphs are generated. The schematic diagram is shown in the figure 5.

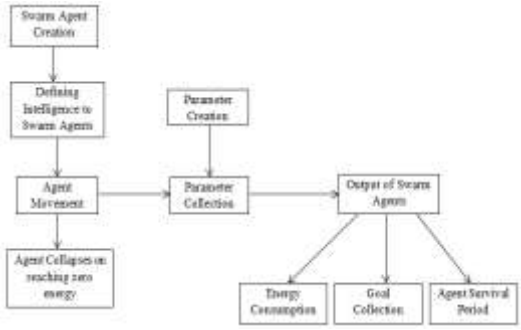
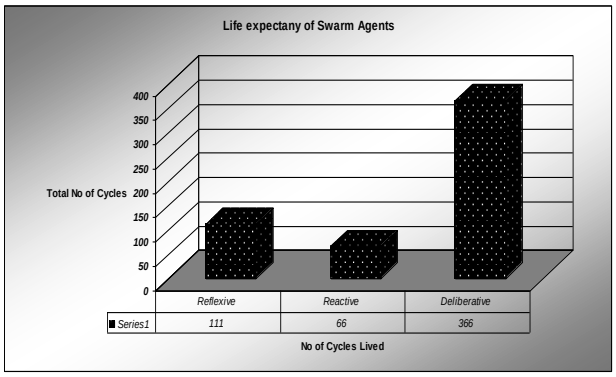



Figure 5: Schematic Diagram

First the swarm agents are created. Then the intelligence is defined for each swarm agents. After creation of swarm agents the parameters are defined for the agents. Then the agents will move towards the parameters to collect them. Output of swarm agents are determined based on the energy consumption, goal collected and the survival of the agent. On the agent's energy reaching to zero the agent will die.

*A.LIFE EXPECTANCY OF SWARM AGENTS*

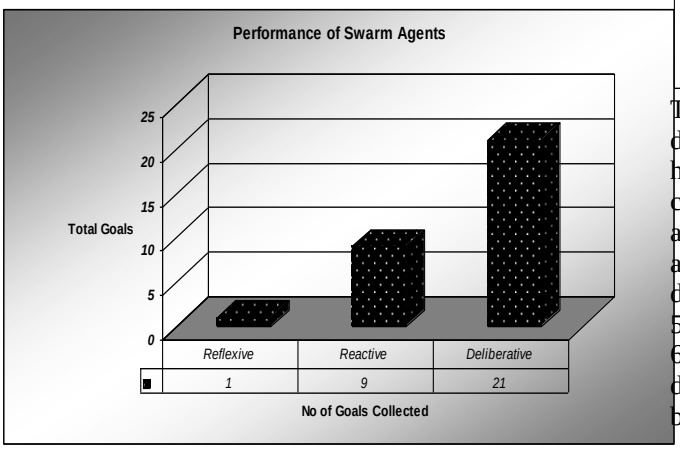
Life expectancy is defined as how long the agents survive in the environment for fixed energy.




The results of this experiment shows that reflective agent has lived for 111 cycles reactive agents has lived for 66 cycles and the deliberative agents has

lived for 366 cycles out of 500 cycles. So the deliberative agents maintain a higher level of count, which concludes that deliberative agents have lived for longer time in the environment than reactive and reflexive agent. Deliberative agents are more efficient in managing their energy levels and exhibit intelligent behaviours. Deliberative agent has more control and self-reflection catalyst.

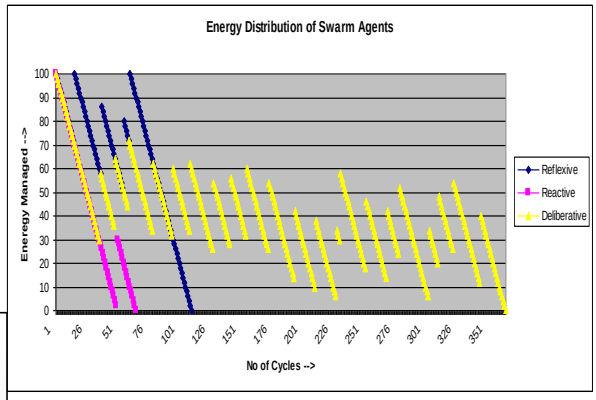
*B.PERFORMANCE OF SWARM AGENTS*




The result shows that Reflexive agent has collected one diamond. Reactive agent has collected 9 and the deliberative agent has collected 21 diamonds out of 25 diamonds in the environment. Since deliberative agent has collected more diamonds, thus concludes, the agent decision making capability at the threshold value. This result shows that the deliberative agent can reason about their change of aims, sense their state and achieved their goals thus exhibiting decision making and intelligent behaviour.

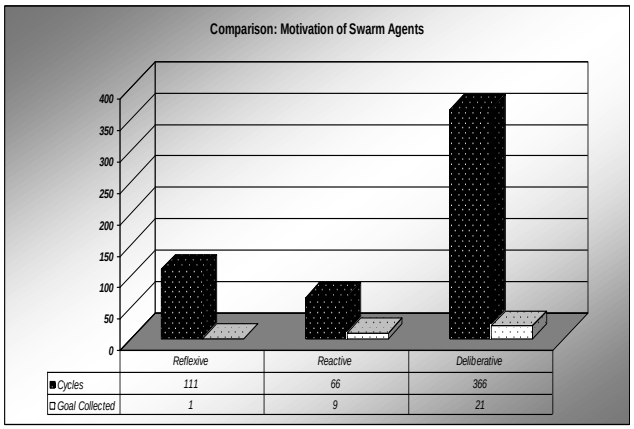
Decision making level is switching to food when it is hungry i.e. when its energy decreases below to threshold value and when it is normal energy, it switches to goal (collection of diamonds) demonstrate psychological and intelligent behaviour.

*C.ENERGY DISTRIBUTION OF SWARM AGENTS*




The result of this experiment shows the energy distribution of each agent at every cycle. Each agent has the predetermined energy i.e. 100 units. The configuration is defined as for energy move of an agent, the agent loses its energy by two units. All agents start with energy 100 units. The results say the deliberative agents manage to live 366 cycles out of 500 than reflexive with 111 cycles and reactive with 66 cycles. Deliberative agent has exhibited optimal decision making capabilities near the decision boundary.

*D.COMPARISON OF SWARM AGENTS*

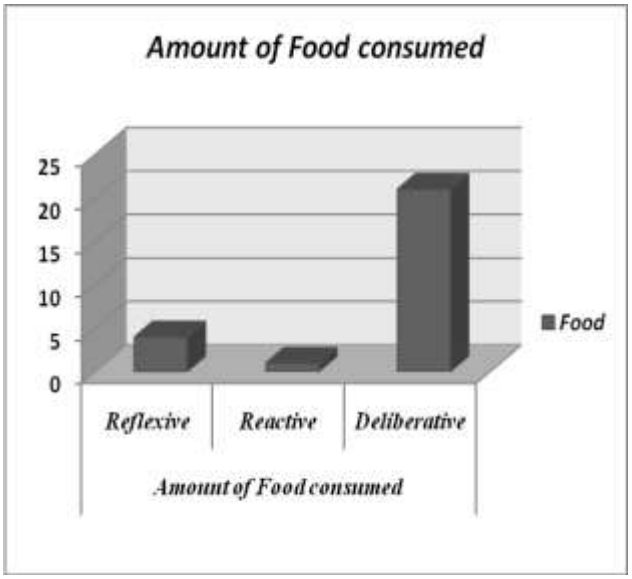



The results say that initially, the agents had the same amount of energy 100 units. After running the experiment, the deliberative agent has performed for 366 cycles out of 500 cycles and as collected 21 diamonds out of 25 diamonds. The reactive agent has performed for 66 cycles and collected 9 diamonds. The reflexive agent has performed for 111 cycles and collected one diamond. Since the deliberative agent has collected higher percentage of diamonds and performed for longer cycle then reactive and reflexive, the deliberative agent is highly motivated agent than reactive and reflexive. The reactive agent has performed for 66 cycles and has collected 9 diamonds than reflexive, reactive agent is motivated than reflexive. In comparison with all three types of

agents, Deliberative agents are highly motivated, Reactive agent is medium motivated and Reflexive agent is less/0 motivated. This result shows that the deliberative agent can reason about their change of aims, sense their state and achieve their goals. This concludes that deliberative agent has complex intelligent behaviours.

Deliberative agents has complete control in managing food and goal, try to balance motivations. Deliberative agents collect more goals and manage higher life expediency than other agents. This results shows deliberative agent has more control and self-reflection catalyst. Thus stating that deliberative agent this highly motivated than other agents and improve the performance.

*E.FOOD CONSUMPTION BY THE AGENTS*




The graph shows the agent decision making capabilities at the threshold value. If an agent has more than the threshold value energy, then agent collects diamonds. If an agent has less than the threshold value energy, then agent goes and collects food from their hunger condition. From the properties of the agents, since reflexive agent cannot differentiate the resources in the environment, we assume reflexive agent will consume more food than BDI agent. In the experiment, the reflexive agent has consumed 4 foods, reactive agent has consumed 1 food, and deliberative agent has consumed 21 foods.

Reactive agent is focused on only collecting diamonds without concentrating on its internal state. So it has only collected 1 food. Reactive agent does not exhibit the decision making nature. Deliberative agent actions are planned and coordinated in terms of the agent, its internal state, its motivations and its perception of resources in the environment. So when its energy is less than the threshold value, the agent collects the food to maintain its energy level, so that agent can perform for longer time. Since deliberative agent is highly motivated towards the goal and has high decision making quality, agent collects more food at every hunger level.

## IV. CONCLUSION

The proposed architecture is developed from SMCA. Developed SMCA does not support communication. SACA architecture is developed from the inspiration of natural swarms, hence communication is an important aspect in SACA. A low level communication is implemented in SACA between the group of agents. In SACA, group of agents works for same task. Group performance is high when agents had a specific goal. Performance in SACA is high, because individuals are more responsible of their task when they work in group.

## V FUTURE SCOPE

Further research can be made on development of high communication concepts on to robots. This can be tested on the real world than on the simulated agents in the testbed. Proposed architecture has three agents with eight behaviours. This can be extended with some more complex skills. Further research can be made on the different learning mechanisms used by the agents and implementing different learning mechanisms as part of SACA, and experimenting SARSA (State-Action-Reward-State-Action) learning algorithm on group of agents. SACA architecture can be extended by adding some more behaviour for each of the layer like perceptual behaviours. SACA model can be extended further into different application areas such as military, construction fields, agricultural field, etc. Further research can be made on adding the expert system to the SACA.

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