

Emotive and Cognitive Simulations by Agents: Roles of Three Levels of Information Processing

Mohammad Kazemifard¹, Nasser Ghasem-Aghaee

Department of Computer Engineering
University of Isfahan, HezarJarib Street
Isfahan, Iran, 81746-73441

m.kazemifard@appliedemotion.com
aghaee@eng.ui.ac.ir

Tuncer I. Ören

M&SNet: Modeling and Simulation
Network of SCS and
SITE, University of Ottawa
Ottawa, Ont., Canada
oren@site.uottawa.ca

¹ Corresponding author. Tel.: +98 918 330 6035; E-mail addresses m.kazemifard@appliedemotion.com,
m.kazemifard@yahoo.com

Abstract

The information processing paradigm advocated by Ortony et al. (Ortony, Norman, & Revelle, 2005) integrate four functions –affect, motivation, cognition, and behavior– into three levels –reactive, routine, and reflective. However, it does not contain details of implementation. The three levels of information processing paradigm ties well with our view of two sources for inputs (or stimuli), namely external and internal inputs. This article provides an agent-based implementation of the three levels of information processing and clarifies the information flows of affect, motivation, cognition, behavior as well as perception. We simulate the three levels of information processing in a predator-prey environment. This paper shows manners in which affect, motivation, cognition, and behavior can be represented and used by agents at different levels of processing. This study contributes to understanding and processing of emotions, to three levels of information processing, and to predator-prey simulation.

Keywords: three levels of information processing, two sources of inputs, emotion, motivation, behavior, agents, predator-prey simulation

1 Introduction

Agents are autonomous software modules with perception and social ability to perform goal-directed knowledge processing over time, on behalf of humans or other agents in software and physical environments (Ghasem-Aghaee & Ören, 2003). Intelligent or *cognitive agents* have cognitive abilities such as anticipation, understanding, learning, and communication in natural language. Simulation with cognitive agents is *cognitive agent-simulation*. *Emotive agents* (Ghasem-Aghaee & Ören, 2003; Kazemifard, Ghasem-Aghaee, & Ören, 2009) have the following characteristics. (1) They have cognitive knowledge processing abilities; (2) they can have personalities and can detect personalities of others; (3) they are sensitive to emotional inputs and they can understand emotions of self, as well as of others; and (4) they can use the understood emotions (of self and/or others) for further knowledge processing and actions.

As clarified in Section 3.1 discrimination of two sources of inputs, i.e., external and internal inputs (Ören, 2001) opens new vistas in cognitive and emotive knowledge processing and ties quite well with the three levels of information processing advocated by Ortony et al. (Ortony, et al., 2005).

The paradigm of three levels of information processing, i.e., reactive, routine, and reflective levels (Ortony, et al., 2005) shows an emotion flow in which emotion is undifferentiated at the reactive level whereas it is differentiated in the reflective level. The emotional knowledge as well as emotional intelligence of agents is increasing from the reactive level to the reflective level of the three levels of information processing. In our simulation experiments, we assumed that agents contain no emotional experiences at the beginning of simulation. They just have some emotional knowledge in the reflective level. During their lifetime, they learn positive and negative affects by classical conditioning. Then, they differentiate the positive and negative affects into four primary emotions in the routine level. The three levels of information processing is a proposal and does not have the details of implementation.

In this paper: (1) we tie together the three levels of knowledge processing of Ortony et al. (2005) and two sources of inputs (i.e, external and internal); (2) implement the three levels of information processing in a predator-prey environment by elaborating in detail of possible instantiations of each level, and the relationships across these levels; prey uses the three levels of information processing to generate appropriate behaviors; and (3) we aim at presenting the functionalities of the three levels of information processing in a simulation environment and not the functionalities of a biological ecosystem. Hence, we consider different assumptions than the biological studies. For example, the prey has exercise, contact for energy, and contact for resistance behaviors or the predator does not die during the simulation. These assumptions could easily be relaxed in other simulation studies.

Section 2 describes related works; section 3 describes the background of the study including two sources of inputs and the three levels of information processing, motivation, behavior, classical conditioning, case-based reasoning (CBR), and reinforcement learning. Sections 4 and 5 present the implementation and evaluation of the three levels of information processing. Finally section 6 presents the conclusion and the perspective of our future works.

2 RELATED WORKS

There are few architectures that exhibit emotion in ways that link directly to other cognitive processes and that modulate intelligent behavior (Langley, Laird, & Rogers, 2009).

CogAff is an information-processing model proposed by Sloman (Sloman, 2001; Sloman,

Chrisley, & Scheutz, 2005; Sloman, Scheutz, & Logan, 2000), and includes three levels namely: reactive, deliberative, and reflective (meta-management). Each level encompasses perception mechanisms, central-processing mechanisms, and action mechanisms. The architecture has an alarm mechanism as well as information communications between all parts of the architecture. Alarm mechanism works centrally and is similar to the interruption mechanism. H-CogAff is a particular instance of CogAff explaining human mental phenomena. Each level supports different emotions category. “Further sub-divisions are required to cover the full variety of human emotions, especially as emotions can change their character over time as they grow” (Sloman, et al., 2005). Although CogAff and Ortony et al. (2005) are in the same spirit, Ortony et al. (2005) is a functional one and focuses on a model of affect that can change over time from proto-affect to full-fledge emotions.

CLARION has similar structure to the three levels of information processing. It is a cognitive architecture (Sun, 2006, 2009), which has two levels: the implicit level (similar to reactive and routine levels) and the explicit level (similar to reflective level). The implicit level is the bottom level and encodes implicit knowledge. It utilizes a multi-layer neural network with Q-learning to learn implicit knowledge. The explicit level is the top level and encodes explicit knowledge. It utilizes a one-shot learning to learn explicit knowledge. The bottom level and the top level exchange their learning through bottom-up and top-down learning. Each level consists of four distinct functional subsystems: action-centered subsystem to control actions, non-action-centered subsystem to maintain general implicit or explicit knowledge, metacognitive subsystem to monitor, direct, and modify the operations of all the subsystems, and motivational subsystem to provide underlying motivations for perception, action, and cognition, in terms of providing impetus and feedback. These subsystems are similar to the motivation, cognition, and behavior functions. CLARION only handles interruption through the metacognition subsystem (Sun, Zhang, & Mathews, 2006) and handles social anxiety through motivational subsystem (Wilson, Sun, & Mathews, 2010). Although the implicit level handles partially the functionalities of both reactive and routine level, considering three levels with distinct functionalities and information communication and interrupting mechanism is “a good way of thinking about the design of emotions in computational artifacts of arbitrary complexity that must perform unanticipated tasks in unpredictable environments” (Ortony, et al., 2005).

Since this study is the first implementation of the three levels of information processing of Ortony el al. (2005), we only discuss the related works in the predator-prey simulation in the rest of this section. Kestern presented an emotional model named SHAME (Scalable, Hybrid Architecture for the Mimicry of Emotions) for a system simulating the emotional state of an agent acting in a virtual environment (Kesteren, 2001). He constructed an agent-based simulation model named “GridWorld”. SHAME implements the affect function similar to the affect function in the reflective level, and the motivation and behavior functions similar to the ones in the reactive level. It utilizes a Neural Network to learn how the emotional state should be influenced by the occurrence of stimuli. Zadeh, Shouraki, & Halavati (2006) studied the possible role of emotions in mental resource management. They implemented an artificial life simulation environment called Zamin to evaluate agents’ ability to produce emotional behavior and to make better decisions. They use only positive/negative affect and approach/avoidance behavior (only the functionality of Reactive level) in a predator-prey environment Zamin (Zadeh, et al., 2006). Gras, Devaurs, Wozniak, & Aspinall (2009) present an individual-based predator-prey model using a fuzzy cognitive map (FCM) to model agent behavior. FCM allows the evolution of the agent behavior through the cycles of the simulation. It also enables the agent to evaluate its environment (e.g., distance to predator or prey, distance to grass) and its internal states. The study of Gras et al. (2009) considers affect,

motivation, and behavior into internal state at once (e.g. fear, hunger, sexualNeeds, curiosity, satisfaction, annoyance, search for prey, eating). In our study, there is distinction between each function and its functionality over the levels.

3 BACKGROUND

3.1 A comprehensive view of five types of inputs

For any knowledge processing system, it is customary to consider that inputs are generated at the environment of the system and outputs go to its environment. However, for advanced knowledge processing systems such as software agents, it is important to consider two sources of inputs, namely external and internal inputs (Ören, 2001). Table 1 systematically represents modes, sources, types, and nature of inputs. Based on their source, there are two types of inputs, namely, external and internal inputs. According to the mode of inputs, there are three possibilities: (1) passive acceptance of inputs, (2) perception of inputs, and (3) generation of inputs.

External inputs can also be named exogenous inputs, since they are generated outside of the system. Most common external inputs are *imposed* or *forced inputs*, for which, *type of access* to input can be by argument passing, knowledge in a common area, message passing, or by coupling. *Nature* of imposed external inputs can be data, forced events, sensation, i.e., data coming from sensors (and transformed from analog to digital form), as well as imposed external goals. Imposed or forced inputs can also be said to be passively accepted by a knowledge processing system.

Table 1. Sources, modes, types, and nature of inputs
and their relationships with three levels of information processing
(Adapted from (Ören, 2001))

Source of input	Mode of input	Type of input	Nature of input	Type of knowledge processing
External input (Externally generated input - i.e., exogenous input)	Passive acceptance	Imposed or forced input (Passive acceptance of external input)	Nature of input: - Forced <i>Data (facts)</i> - <i>Forced Events</i> - Sensation (converted sensory data: from analog to digital; single (or multi sensor–sensor fusion)) - External goals (imposed goals) Type of access to input: argument passing, knowledge in a common area, message passing, coupling.	Reactive and routine knowledge processing
		Perceived external input	- Perception (interpreted sensory data and detected events) -- includes: decoding, selection (filtering), recognition, regulation - Perceived goals	
	Perception	Evaluated external input	- evaluation of inputs (acceptability) - evaluation of source of inputs (reliability, credibility) - evaluation of goals behind inputs to discriminate ostensible and real reasons of inputs	Reflective knowledge processing
		Perceived internal input	- Introspection (self-reflection) (perceived internal facts, events; or realization of lack of them)	
Internal input	Internal generation	Endogenous input (Generation of internal input)	- Anticipated facts and/or events (anticipatory systems) - Internally generated questions - Internally generated hypotheses by: -- Expectation-driven reasoning (Forward reasoning) (Bottom-up reasoning) (Data-driven reasoning) -- Model-driven reasoning - Internal goals (<i>internally generated goals</i> by teleogenic systems)	Reflective knowledge processing

A second type of external input is *perceived input* where the knowledge processing system, instead of passively accepting inputs, actively perceives the external inputs. One of the characteristics of software agents is the ability of perception. Hence, perceived external

inputs are very natural for software agents. Perceived external inputs include: (1) perception (i.e., interpreted sensory data and detected events) which includes decoding, selection (filtering), recognition, and regulation; and (2) perceived goals.

The third type of external inputs is evaluated external inputs, which encompass (1) evaluation of inputs (for acceptability), (2) evaluation of sources of inputs (for reliability and credibility), and (3) evaluation of goals behind inputs to discriminate ostensible and real reasons of inputs.

Internal inputs can be perceived or generated. Perceived internal inputs are based on introspection or self-reflection of a knowledge processing system and can be: perceived internal facts, events, or realization of lack of them.

Endogenous inputs are by definition generated by the knowledge processing system and consists of (1) anticipated facts and/or events (by anticipatory systems), (2) internally generated questions, (3) internally generated hypotheses by expectation-driven reasoning or by model-driven reasoning, and (4) internally generated goals by teleogenetic (or goal generating) systems.

Hence, there are five types of inputs: (1) imposed or forced inputs, (2) perceived external inputs, (3) evaluated external inputs, (4) perceived internal inputs, and (5) internally generated inputs. As shown in Table 1, they can be grouped in three modalities: (1) passive acceptance, (2) perception, and (3) internal generation; and in two sources (1) external inputs and (2) internal inputs. As will be seen in Section 3.2, the clarification on the modes, sources, types, and nature of inputs tie quite naturally with the three levels of information processing.

3.2 Three levels of information processing

Ortony et al., proposed a general functional model for organisms (Ortony, et al., 2005). This is centered on three levels of information processing: reactive, routine and reflective, each of which being elaborated across four relatively independent functions which are: affect, motivation, cognition, and behavior.

1. *Affect* is related to value and what the organism feels.
2. *Motivation* is related to action tendencies and what the organism needs and wants.
3. *Cognition* is related to meaning and what the organism knows, thinks, and believes.
4. *Behavior* is related to the organism's actions and what the organism does.

In this structure, the affect is undifferentiated in reactive level whereas it is differentiated at the reflective level (Ortony, 2009). The term affect is a superordinate concept that subsumes feeling and emotion (Ortony, et al., 2005). Feelings are readouts of the brain's registration of bodily conditions and changes and emotions are interpreted feelings (Ortony, et al., 2005). The schematic of the three processing levels adapted from Ortony et al. (2005) is depicted in Figure 1.

Figure 2, also adapted from Ortony et al. (2005) is redesigned to clarify existence and relationships of the four functionalities represented by: A: Affect, B: Behavior, C: Cognition, and M: Motivation; as well as by P: Perception. Only Affect, Behavior, and Motivation exist at all three levels. As expected, P: Perception does not exist at reflective level and C: Cognition does not exist at reactive level. Details of the information flows are given at Figure 4-6. To be consistent with Ortony et al. (2005), the output of B: Behavior at reflective level is coupled to routine level.

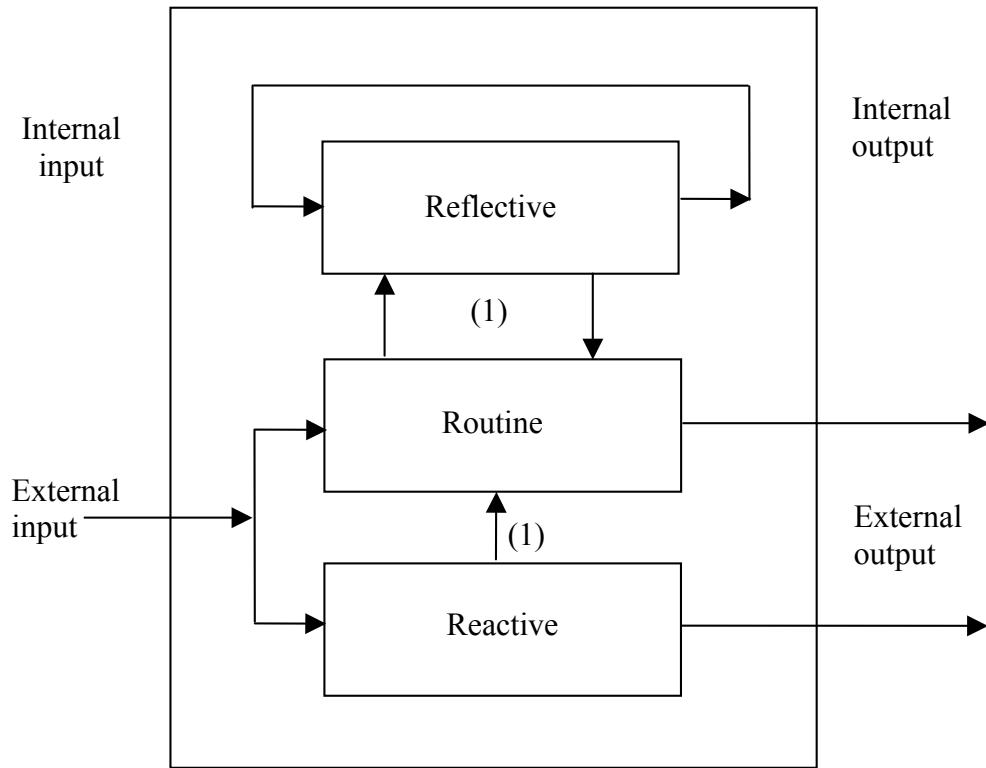


Figure 1. Three levels of information processing (reactive, routine, and reflective) and two sources of inputs and outputs (external and internal)
 (adopted from Ortony et al. (Ortony, et al., 2005))

(1): When transition from reactive level to routine level occurs, routine level responds to the environment directly but when transition from routine level to reflective level occurs, reflective level send responses to routine level. A transition is caused by an interruption.

The **reactive level** includes perception, affect, motivations, and approach/avoidance behavior. The affect function includes only proto-affect with positive and negative values. Proto-affect directs survival behaviors (Kelley, 2005). Negative proto-affect protects the organism from danger and positive proto-affect associated with appetitive behaviors such as search for grass (Kelley, 2005). There is no cognition at this level.

The **routine level** includes perception, affect, motivations, approach/avoidance behaviors, and cognition. The affect function includes four primitive emotions:

1. *Joy*: occurrence of a desirable stimulus
2. *Distress*: occurrence of an undesirable stimulus
3. *Hope*: prospect of a desirable stimulus
4. *Fear*: prospect of an undesirable stimulus

According to Ortony et al. (Ortony, et al., 2005) expectation is an important parameter at this level. If the current situation does not deviate from expectations, it is handled by the routine level. If it does, it is handled by the reflective level. The responses of the routine level are faster and less accurate, while those at the reflective level are slower but more accurate. Ortony et al. (2005) also stated that the cognitive resources of routine level are not sufficient

to interpret the feeling as full-fledged emotions. The full-fledge emotions exist only in reflective level. There is no feedback at this level.

The **reflective level** includes affect, motivations, approach/avoidance behaviors, and cognition. It includes joy, distress, hope, and fear; they are more elaborate than the similar emotions in the routine level. The affect function also includes four other emotions:

1. *Satisfaction*: confirmation of the prospect of a desirable stimulus
2. *Disappointment*: disconfirmation of the prospect of a desirable stimulus
3. *Relief*: disconfirmation of the prospect of an undesirable stimulus
4. *Fear-confirmed*: confirmation of the prospect of an undesirable stimulus

The reflective level can interpret full-fledge emotions in terms of goals, standards, and attitudes (Ortony, Clore, & Collins, 1988). We have considered only goal-based emotions in this study. This level cannot directly perceive nor act in the world. Rather, it operates on the percepts obtained from routine level and acts indirectly on the world by influencing the operation of the lower levels.

3.3 Motivation

In this study, the motivations are activated by affects and internal stimuli. For our study, we adapted the Maslow's hierarchy of needs (Maslow, 1943) and Reiss's motivation theory (Reiss, 2004).

Maslow's hierarchy of needs (Maslow, 1943) includes five needs from low level to high level: physiological, safety, social, esteem, and self-actualization. We have conjectured physiological and safety needs (primary drives (Sun, 2009)) in the reactive level's motivations, and safety need and social need (high-level primary drive¹ (Sun, 2009)) in the routine level's and reflective level's motivations. Then, we placed the Reiss's motivation in the Maslow's hierarchy.

Reiss's motivation theory (Reiss, 2004) relates the motivations to feelings and includes sixteen motivations. We used five of them namely:

1. *Eating* which is desire to eat. After it is responded, agent feels satiation. Eating is essential for survival, and we consider it as the physiological need.
2. *Romance* which is desire to sex. It is a response to lust and we consider it as the physiological need.
3. *Tranquility* which is desire to avoid fear and the prey run away from danger (the predator). After it is responded, prey feels safe and relaxed. We consider the *tranquility*, as the safety need.
4. *Physical exercise* which is desire to exercise muscles. As stronger prey is less vulnerable to predators' attack compared to weaker, ill or injured one, we consider the *physical exercise*, as the safety need.
5. *Social contact* which is desire for companionship. A prey feels fun after social contact and the prey shares its energy, resistance, and learning with another prey. We consider the *social contact* as the social need.

¹ There are justifications for high-level primary drive in Sun (2009).

3.4 Behavior

We have implemented our study in a predator-prey environment. Only prey has planned behaviors. All the behaviors consume one unit of energy except the “rest behavior”, which consumes no energy. The behavior function encompasses the following:

1. *Search for conspecific*: a prey searches to find another prey when there is no prey in its range of vision.
2. *Approach to prey*: a prey moves toward another prey in its range of vision.
3. *Mate*: a prey mates with a conspecific where the conspecific is beside the prey.
4. *Search for grass*: a prey is searching to find grass when there is no grass in its range of vision.
5. *Approach to grass*: a prey moves toward grass in its range of vision.
6. *Eat*: a prey eats the grass located beside it.
7. *Opposite direction*: a prey moves in opposite of previous direction. It is a reactive behavior motivated by tranquility.
8. *Exercise*: a prey increases its resistance. This behavior has no movement.
9. *Contact for energy*: a prey shares its energy and learning (classical conditioning data and Q-Table) with another prey.
10. *Contact for resistance*: a prey shares its resistance and learning (classical conditioning data and Q-Table) with another prey.
11. *Escape*: a prey moves to minimum negative affect direction. It is a high level behavior in response of tranquility.
12. *Rest*: a prey does not move and has no energy consumption.
13. *Think*: a prey is suspended and acts “no behavior”.
14. *Search*: a behavior is randomly selected from a behavior repository. This behavior is used only in reflective level to augment exploration.
15. *No behavior*: a prey has no move but it consumes a unit of energy. This is not an actual behavior. When a prey has no behavior for act (because of low knowledge), it generates a “no behavior”. It is similar to “rest” and “think” behavior but not identical. “Rest” is a behavior that prey selects it by decision-making process. “Think” is used in reflective level to show this level is slow. Whenever a prey uses reflective level to respond a situation, it generates a “Think behavior” firstly then it responds to the situation by a behavior.

3.5 Learning

In our simulation, the prey agent is going to live as much as it can. It does not have any knowledge about the environment at the starting of the simulation. It needs to learn how to live in this environment and which behavior or emotion can be emerged in a particular situation. Adaptability to changing circumstances is a key feature of living creatures (Savage, 2010). Hence, the goal of a prey in learning in this study is to be adaptable to its environment not modeling the behaviors of the other objects in the environment. The prey learns by classical conditioning to have positive affect related to conspecifics and grass and negative affect related to predators in its environment and learns how to react them. Then, it can use these experiences to learn more complex things. For example, if there are some predators, grass, and conspecifics in range of vision of a prey, the prey can have some reactions: escape from predators (negative stimulus), approach to grass and conspecifics (positive stimuli). The prey needs to learn which reaction is the best in this situation as well as which emotions can emerge in this situation. If there is a situation in which the prey can select two or more behaviors, it selects one of them by a mechanism and gets a reward/punishment from the environment (reinforcement learning). It also can compute an emotion for the situation by a

computational emotional model. The situation and the selected behavior as well as the emotion can be stored as a case by which the prey can respond to similar situations in future (Case-Based Reasoning).

In this paper, we utilized a distinct leaning method for each level of the three levels on the basis of the Ortony et al. (Ortony, et al., 2005). Easiness of the implementation was the criterion in selecting learning methods; hence, we selected the familiar methods in the machine learning. In the *reactive* level, proposals of Ortony et al. are: habituation and classical conditioning. We selected classical conditioning. In the *routine* level, the proposals are: operant and some classical conditioning, and Case-Based Reasoning. We selected Case-Based Reasoning. In the *reflective* level, the proposals are: conceptualization, analogical, metaphorical, and counterfactual reasoning.

Since the learning methods of these levels need more elaboration, we skip the implementation of these methods in this paper. Implementation of the learning methods of the reflective level needs many considerations so that we left it for our future studies. We will discuss about this issue in the conclusion section. We utilized the reinforcement learning for the cognition function of the reflective level only and for the affect function we utilized a computational emotional model with fuzzy methods.

Although a one-to-one mapping of learning mechanism to each level may need a lot of justifications, we did it to make the model computationally feasible. It is “undecided about exactly how to conceptualize the distribution of these phenomena across levels” (Ortony, et al., 2005). The evaluation of different learning methods for each level is another work for future.

3.5.1 Classical Conditioning

It is a form of associative learning proposed by Pavlov (Pavlov, 1960). It associates a natural stimulus with a neutral stimulus. It includes four principle concepts:

1. *Unconditioned Stimulus (US)* triggers a response naturally and automatically.
2. *Unconditioned Response (UR)* is an unlearned and innate response to an US.
3. *Conditioned Stimulus (CS)* is a neutral stimulus
4. *Conditioned Response (CR)* is a learned response to an earlier neutral stimulus.

If the CS and the US are repeatedly paired, the CS associates with the US and the organism produces CR to the CS.

3.5.2 Case-Based Reasoning (CBR)

It is a form of instance-based learning. CBR uses the solutions of the similar past problems to solve a new problem. CBR’s process includes four steps (Aamodt & Plaza, 1994):

1. *Retrieve* the most similar case for a given problem.
2. *Reuse* the solution(s) of the case to solve the given problem.
3. *Revise* the solution to adapt for the given problem.
4. *Retain* the successful adaptation knowledge and the given problem as a new case.

3.5.3 Reinforcement Learning

It is a machine learning method in which an agent can learn to select optimal actions to achieve its goals (Mitchell, 1997). After the agent performs an action, it received a reward, or punishment. Since the Q-Learning algorithm does not need training data, we use the Q-Learning algorithm in this study. The Q-Learning algorithm uses a Q-Table for learning. $Q(s,a)$ represents an entry of the Q-Table in which “s” represents a state of environment and

“a” represents a performed action. In traditional reinforcement learning, an agent perceives states in an environment and performs actions. The agent gets reward/punishment in response to the selection being made. We have used emotions of the agent as states and behaviors as actions in this study; hence, agents generate their own reward/punishment (Marinier & Laird, 2008). In this study, the following process has been considered for Q-Learning:

- initialize all the entries with a big negative number.
- do forever
 - select an action a in state s with ϵ -greedy
 - receive the reward/punishment r
 - observe the new state s'
 - update the $Q(s,a)$ as in Eq.1:

$$Q(s,a) \leftarrow (1 - \beta) * Q(s,a) + \beta * (r + \gamma * \max_{a'} Q(s',a')) \quad (1)$$

◦ $s \leftarrow s'$

In both “contact for energy” and “contact for resistance” behaviors, partners share their learning in the way that the younger prey replaces its classical conditioning data and Q-Table with the ones in the older prey. They don’t share their CBR in respect that it can be obtained from the data of classical conditioning and Q-Table.

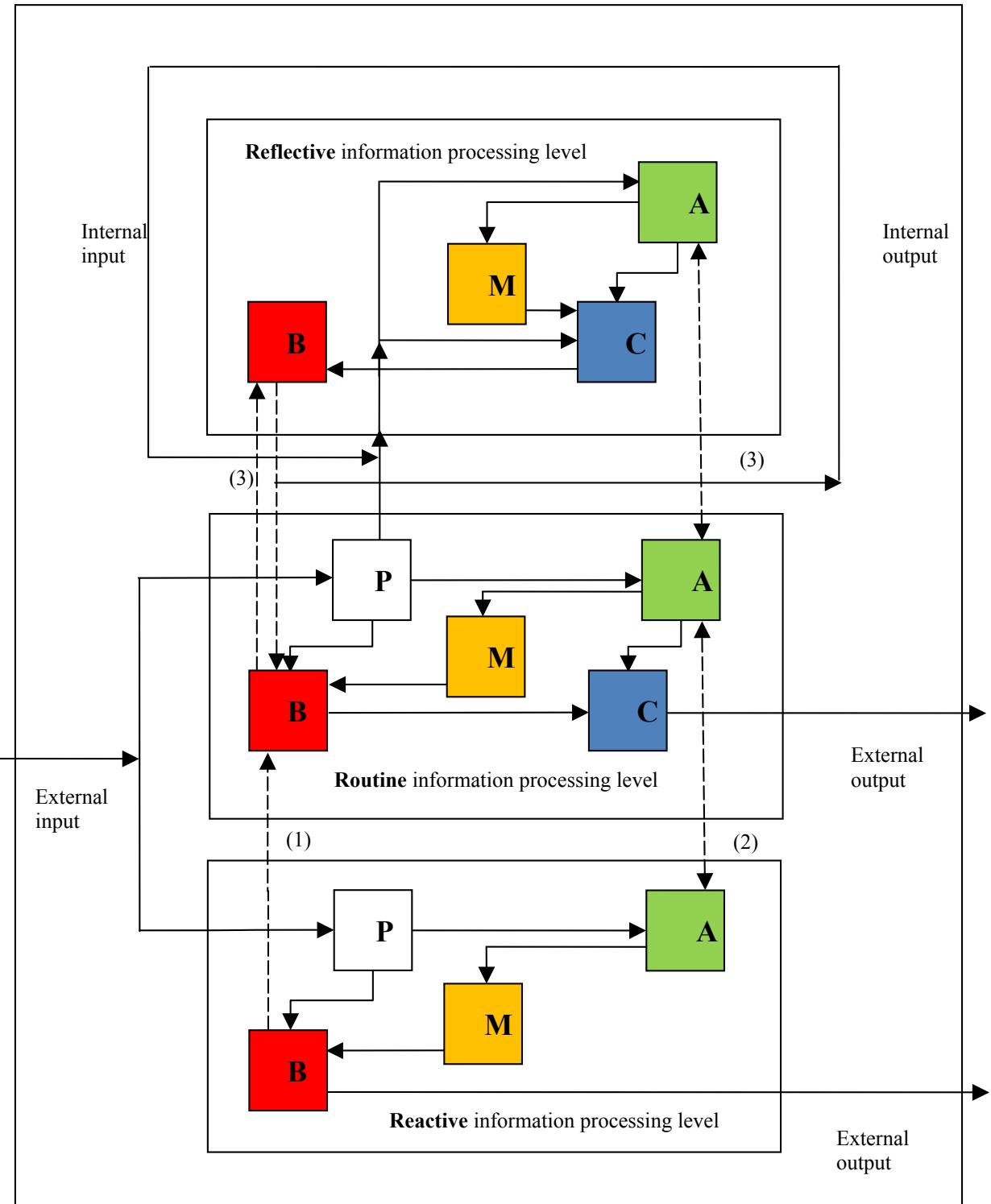


Figure 2. Three levels of information processing in the predator-prey system.

(Adopted from Ortony et al. (Ortony, et al., 2005) and redesigned to clarify existence and relationships of each of the four functionalities represented by: A: Affect, B: Behavior, C: Cognition, M: Motivation; as well as P: Perception. For example in the reactive level, P influences A and B. It means A and B use the data of P). Only Affect, Behavior, and Motivation exist at all three levels.

In the reflective level, internal output comes from B of reflective level and connects to output of P of routine level as internal input. This internal input will be used in the next cycle of the simulation.

- (1): Transition from reactive level to routine level occurs in behavior function if it cannot select a behavior.
- Routine level responds to the environment directly.

(2): Affect function of the routine level also exchange information with affect function of the reactive level but there is no transition (It is not in the Ortony et al. (Ortony, et al., 2005)).

(3): Transition from routine level to reflective level occurs in affect and behavior functions if current situation deviates from expectations. In other words, the affect and behavior functions in routine level cannot generate an emotion or find a behavior for the current situation. Since reflective level cannot have external output, it sends responses to routine level. When transition from the behavior function of routine level to the behavior function of reflective level occurs, the behavior function of reflective level uses its related functions to respond.

4 IMPLEMENTATION

In the implementation, we extended the code of Sabelli and Kovacevic (Sabelli & Kovacevic, 2007) and adopted it to our study¹. They constructed a multi-agent simulation model “Wild West”. This simulation model was used for the biological research of predator-prey. Their model includes three types of agents: grass, buffalo (named prey in our study), which eat the grass, and cowboys (named predator in our study), which eat or attack the buffalos. Buffalos and cowboys die when their energy is exhausted. Grass is reproduced with a rate in each cycle of the simulation. Herein environment, both the buffalo and the cowboys have random behavior.

In our simulation, predators don't die. While the prey population increases, the predator population increases and grass population decreases. Hence, the prey life is going to be hard. Hence, the prey with a good plan can live longer in this environment. Each prey has a resistance parameter indicating the capacity of the prey to protect itself against predators' attack. The predator attacks a prey and gets a part of the prey's energy. The energy of the attacked prey reduces on the basis of its resistance. When a prey or predator with full energy (we named it mate starter) locates beside another conspecific, they mate. The result of mate is an offspring. The offspring of the predators doesn't inherit anything from its parents. The offspring of prey inherit its energy from the mate starter. Mate increases the resistance of both parents and decreases energy of the mate starter. Wherein all the preys die, the simulation ends. Predators move randomly and the prey uses the three levels of information processing. Both prey and predators move only one block of simulation area in each cycle of the simulation. The prey sees and moves in eight directions (Figure 3). The range of prey's vision is six environmental blocks. Prey avoids negative emotions, and it plans to generate positive emotions. In the following sections, we discuss the implementation of each level. We hypothesized that the priority of all the affects, motivations, and behaviors are equal. If there is more than one behavior for act, the behaviors are appended to a behavior repository and each level has a distinct mechanism to pick one of them.

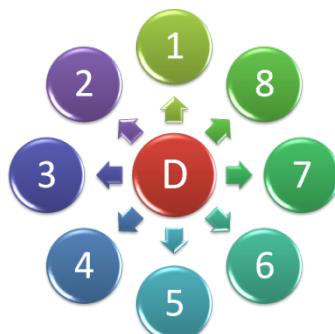


Figure 3: The eight directions of prey's vision and moving

¹ The implementation is downloadable from <http://www.appliedemotion.com>

4.1 Elaboration on the three levels of information processing

Figure 2 that we adapted from Ortony et al. (Ortony, et al., 2005) shows a sketch of our view about the three levels of information processing. We elaborated and redesigned the original figure on the relations between the functions of each level as well as structure and intra communication of the levels. In our versions of this figure, we clarified existence and relationships of each of the four functionalities represented by: A: Affect, B: Behavior, C: Cognition, M: Motivation; as well as P: Perception. Only Affect, Behavior, and Motivation exist at all three levels.

Figure 4-6 show the internal structure of each level by a sequence diagram in which the diagrams represent what and when the interactions between the functions occur. In these diagrams, *numbers* show sequence of the functions and the *arrows* between the lifelines represent messages being sent between the functions.

In the reactive level, we utilized pattern matching and classical conditioning methods for responding to percepts and the proto-affect generation respectively. In the routine level, we utilized the Case-Based Reasoning (CBR) method for responding to percepts and generating corresponding emotions. In the *reflective level*, we utilized reinforcement learning and fuzzy systems to generate behaviors and emotions.

There is an interrupt and information communication between the levels. In this study, the difference between interrupt and information communication is that when a function communicates information with higher levels, it generates a response and sends the information for justification only. But when the function communicates interrupt with higher levels, it doesn't know any response and sends an interrupt to higher levels and the processing transits to the higher level.

Perception function gets –as a forced input– the data of all objects in the range of vision by message passing. The data are type (prey, grass, and predator) and position of each object. Perception function also perceives external inputs and organizes percepts' information as an array in which each percept encompasses the direction (Figure 3), distance, and type of a perceived object. In the routine level, the behavior function precedes cognition function and in the reflective level, the cognition function precedes the behavior function (Ortony, et al., 2005).

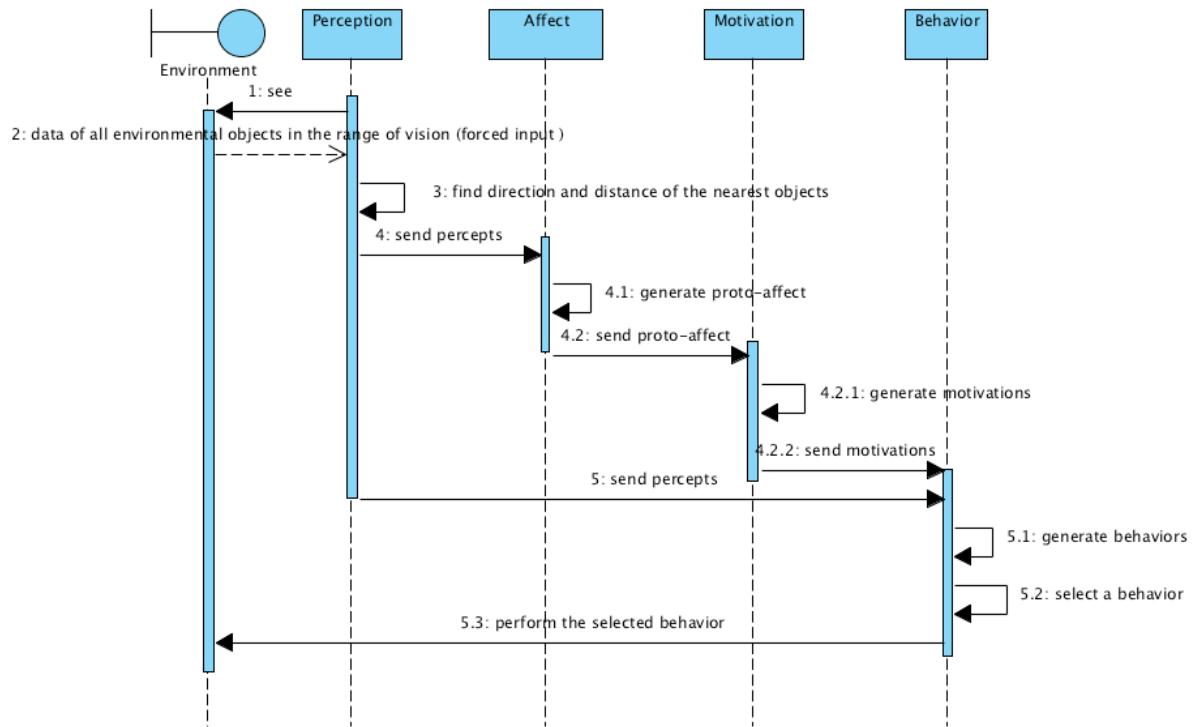


Figure 4: Reactive level sequence diagram

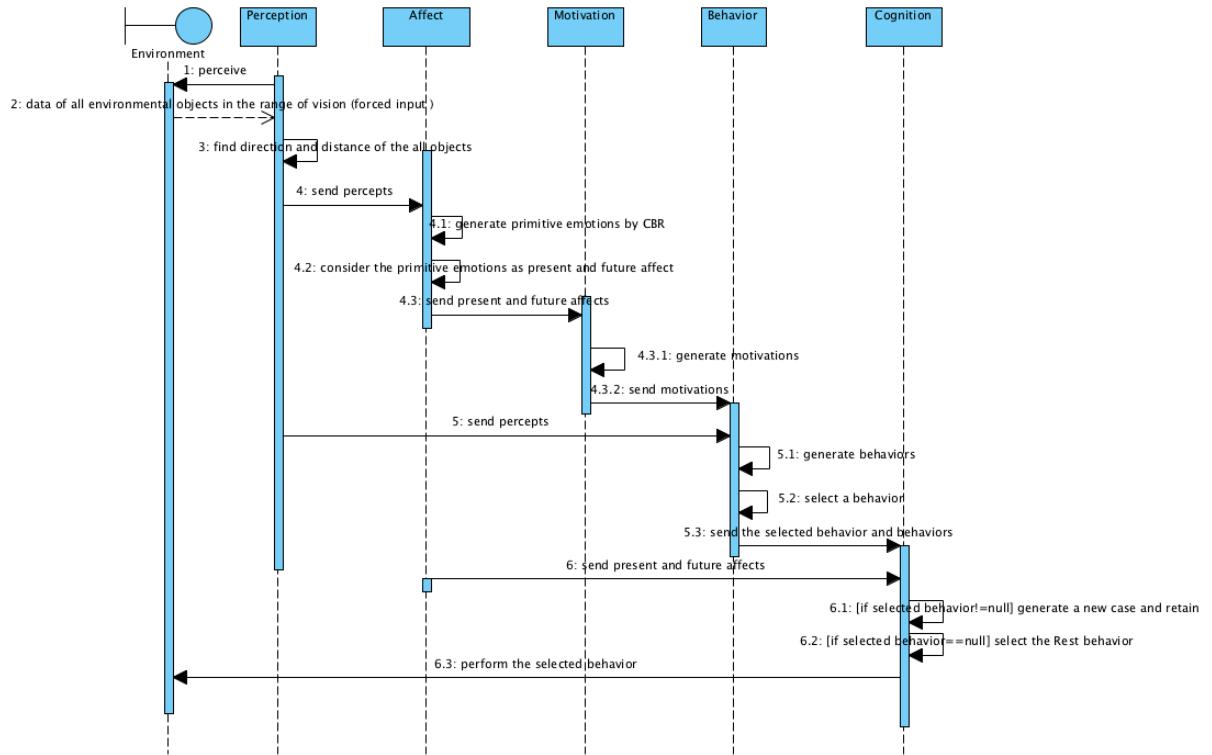


Figure 5: Routine level sequence diagram

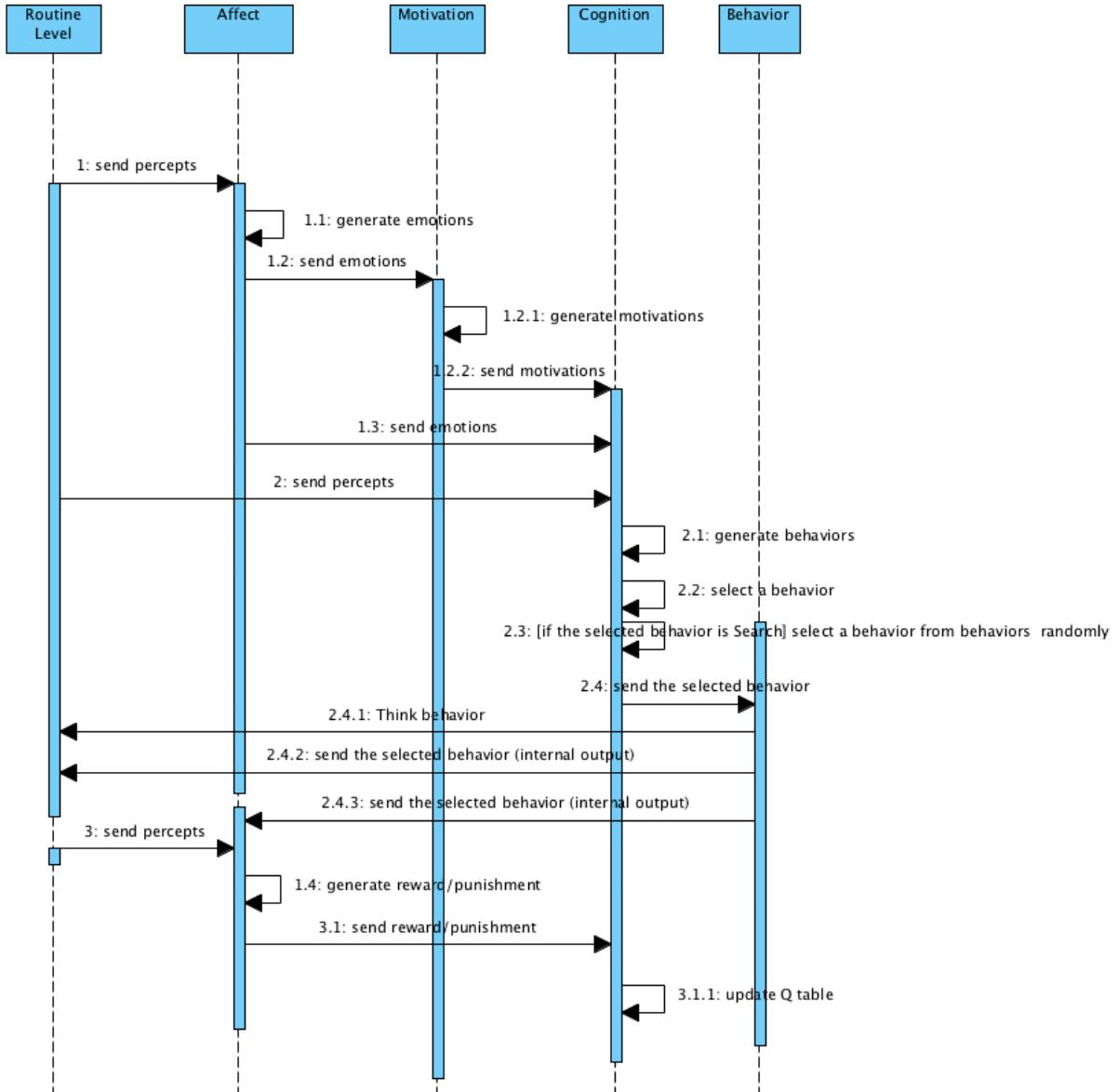


Figure 6: Reflective level sequence diagram

4.2 Reactive level

At reactive level, prey has a focused and limited perception of external inputs. It filters data and only perceives information of the nearest prey, predator, and grass around itself.

We have used fear conditioning (LeDoux, 1996; Pavlov, 1960), a form of classical conditioning, to generate the proto-affect. In fear conditioning, the organism learns to fear new stimulus. We have extended the fear conditioning by which not only it works for fear (negative affect) but also it works for hope (positive affect). In our study, the principle concepts of classical conditioning are defined as follow:

- The Unconditioned Stimuli (USs) are:
 1. attack stimulus,
 2. eating stimulus, and
 3. mate stimulus.
- The Unconditioned Responses (URs) are:
 1. fear attack (negative affect),

- 2. hope eating (positive affect), and
- 3. hope mate (positive affect)
- The Conditioned Stimuli (CSs) are:
 - 1. predator stimulus,
 - 2. grass stimulus, and
 - 3. prey stimulus.
- The Conditioned Responses (CRs) are:
 - 1. fear predator (negative affect),
 - 2. hope grass (positive affect), and
 - 3. hope prey (positive affect).

In this study, a Conditioned Stimulus (CS) associates with an Unconditioned Stimulus (US) at the first paring. The proto-affect is generated by Conditioned Responses (CRs). Each prey includes the Unconditioned Stimulus (US) and Conditioned Stimulus (CS) as innate knowledge. For example, a prey is attacked (Unconditioned Stimulus-US) by a predator (Conditioned Stimulus-CS) for the first time. Since the prey fears attack (Unconditioned Response-UR), the pairing of Conditioned Stimulus (CS) with Unconditioned Stimulus (US) causes that the prey fears predators (CR). Hence, when the prey sees a predator (negative stimulus), it gets negative affect (fear).

Prey includes a sensitivity parameter indicating prey's responsiveness to a stimulus. It is a numerical parameter initialized with prey's vision. It means that the prey responds to a six blocks distance stimulus initially. After computation of proto-affect, reactive level informs the affect function of the routine level. If the affect function of routine level finds an inconsistency between its computation and the proto-affect value, it informs the reactive level to increase or decrease the value of the sensitivity.

This level includes eating and romance as physiological motivations and tranquility as a safety motivation. Both eating and romance are related to the energy level, and they are motivated internally when the energy level of the prey is lower/upper than a limit. The eating is also motivated wherein the proto-affect is positive, and the tranquility is motivated wherein the proto-affect is negative.

The reactive level uses percepts and motivations to select a behavior (Table 2). The proto-affect influences behaviors indirectly. It influences the motivations and the motivation influences the behaviors. This level uses a pattern matching method if its behavior repository contains more than one behavior. There are two situations in which the reactive level interrupts the routine level:

1. If it has two or more behaviors in the behavior repository and the behavior repository doesn't match with any behavior patterns, it interrupts the higher levels to select one of them. Each behavior pattern includes both the behaviors of the behavior repository in one of previous states that the prey interrupted the routine level for selection and the response of the routine level.
2. For "search for grass" and "search for conspecific" behaviors, it interrupts the higher levels to find the direction of searching. There is no mechanism in this level to find the search direction.

Table 2: A prey selects a behavior by considering the motivations and percepts in the reactive level.

Motivation	Perception	Behavior
tranquility	predator	Opposite direction
eating	no grass	Search for grass (interrupted the routine level for correct direction)
eating	grass	Approach to grass
eating	grass is here	Eat
romance	no prey	Search for conspecific (interrupted the routine level for correct direction)
romance	prey	Approach to prey
romance	prey is beside	Mate

4.3 Routine level

At the routine level, prey has a broad perception of external inputs. It perceives information of all the prey, predators, and the grass in the range of vision.

As clarified in section 3.2, we named joy/distress as present affect and hope/fear as future affect. Both present and future affects include two values: positive (joy and hope) and negative (distress and fear). We use similarity parameter to measure the expectation violation. Herein, the routine level handles a situation if the situation's similarity with previous cases is high; otherwise, the reflective level handles it. The Euclidean distance is used for similarity measurement. The values of present and future affect are generated by “present CBR” and “future CBR” respectively. Solutions in the “present CBR” are joy and distress emotions and in the future CBR are hope and fear emotions. A case of the “present CBR” includes type of stimulus (attack, mate, or eat), current energy, and current resistance (i.e., if a prey is attacked by a predator, the prey’s energy is 5, and the prey’s resistance is 0.02, the prey’s emotion is distress). A case of “future CBR” contains the percepts’ distance, current energy, and current resistance (i.e., if a prey perceives three predators in distance 3 (negative stimuli), a prey in distance 2 (positive stimuli), the prey’s energy is 50, and the prey’s resistance is 0.7, the prey’s emotion is hope. Since the prey has high energy and resistance in this case, it does not fear the predators but with low energy and resistance, it fears the very near predators). If a prey learns the positive and negative stimuli with classical conditioning, the “future CBR” works properly. The weight of nearer percepts is higher than far percepts. If there are no similar cases ($\text{similarity} \geq 0.5$) with a new situation, the routine level interrupts the reflective level to find the emotion of the agent in the situation. The “present CBR” or “future CBR” retains the response of the reflective level and the new situation as a new case.

Table 3: Selection of motivations on the basis of the internal states and affects in *routine level*
 (The dash (-) represents “don’t care”. It means, the motivations are independent of the values of those cells)

Internal State	Affect	Motivations
-	future affect is negative	tranquility
-	present affect is negative	physical exercise
-	future affect and present affect are positive	social contact and physical exercise
resistance ≥ 0.5 or energy $>$ Mate_Limit (high energy) or energy $<$ Energy_Limit (low energy)	-	social contact

This level includes tranquility and physical exercise as safety motivations and social contact as the social motivation. The motivations are selected on the basis of the affect function and the internal states (Table 3). In Table 3, the tranquility is motivated wherein the future affect is negative and it doesn't care the values of internal state. When the present and future affects are positive, both social contact and exercise are motivated. When the resistance is greater than or equal 0.5, social contact is motivated and the values of the present and future affect are not taken into account. The prey wants to have social contact and share its energy with others when its energy is high. It wants to have social contact and looks for another prey, when its energy is low. This is useful when there is no grass and the prey can be alive by communication. With respect to the rules of Table 3, several motivations may be motivated.

On the basis of the percepts and motivations, a prey selects a behavior (Table 4). Since behavior function of the routine level is proactive not reactive, it does not need to cover all situations in Table 4. The affect function also impacts the behavior. If both present and future affects are positive, the rest behavior is appended to the behavior repository. The direction of the interrupted “search for conspecific” and “search for grass” from reactive level is set to least negative future affect direction. If there is more than one behavior in the behavior repository, a “behavior CBR” selects a behavior. The present and future affects, behaviors in behavior repository, and interrupted behaviors from the reactive level make a case. If “behavior CBR” finds a behavior, the behavior is adapted by new direction. If there is no similar case for this new situation, the reflective level is interrupted to respond. After behavior selection, the cognition function processes the solution, and the new case, and retains it. If there is no behavior in response, a “rest behavior” is responded.

Based on psychological literature, attention is focused on local details in negative affect and on global details in positive affect (Ortony, et al., 2005). Hence, prey considers only the nearest predator when it has negative affect and considers all predators when it has positive affect (i.e., in “search for grass” or “search for conspecific”).

Table 4: A prey selects a behavior by considering the motivations and the percepts at the routine level.

Motivation	Perception	Behavior
physical exercise	-	exercise
social contact	prey is beside	contact for energy and contact for resistance
social contact	prey	approach to prey
social contact	no prey	search for conspecific
tranquility	predator	escape

4.4 Reflective level

This level has internal input and output. In this study, this level only perceives internal input –perception of routine level and its internal output. It includes social contact and physical exercise motivations. The satisfaction, disappointment, relief, and fear-confirmed emotions motivate the social contact motivation. The relief emotion motivates also the physical exercise and produces the “rest behavior”. These emotions are generated by the following rules (Ortony, et al., 1988):

IF	Previous emotion	IS	Hope
AND	Current emotion	IS	Joy
THEN	Emotion	IS	Satisfaction
IF	Previous emotion	IS	Hope
AND	Current emotion	IS	Distress
THEN	Emotion	IS	Disappointment
IF	Previous emotion	IS	Fear
AND	Current emotion	IS	Joy
THEN	Emotion	IS	Relief
IF	Previous emotion	IS	Fear
AND	Current emotion	IS	Distress
THEN	Emotion	IS	Fear-Confirmed

In this level, we have considered the joy/distress emotions as the occurrence of a desirable or an undesirable stimulus and the hope/fear emotions as the prospect of a desirable or an undesirable stimulus. The values of the joy and distress emotions are computed regarding the desirability/undesirability of the stimulus (attack, eat, and mate). We have

utilized the model of GEmA. (Kazemifard, Ghasem-Aghaee, & Ören, 2006; Kazemifard, Ghasem-Aghaee, & Ören, 2010) for computing the desirability/undesirability of a stimulus. On the basis of this model, we have considered two goals: save resistance with importance 0.2 and save energy with importance 0.8. Both goals are related to the survival goal. The impact of a stimulus on a goal is computed as follow:

$$\text{impact}(\text{stimulus}_i, \text{goal}_j) = \text{achievement}(\text{goal}_j)_{\text{after}} - \text{achievement}(\text{goal}_j)_{\text{before}}$$

On the basis of the model, impact is a value between -1 and 1. The desirability of a stimulus is computed as follow:

$$\begin{aligned} \text{desirability}(\text{stimulus}_i) = 0.8 * \text{impact}(\text{stimulus}_i, \text{"save energy"}) + \\ 0.2 * \text{impact}(\text{stimulus}_i, \text{"save resistance"}) \end{aligned}$$

The $\text{desirability}(\text{stimulus}_i)$ is a value between -1 and 1. Stimulus_i is desirable if $\text{desirability}(\text{stimulus}_i)$ is positive and it is undesirable, if $\text{desirability}(\text{stimulus}_i)$ is negative.

We have used a fuzzy method to generate the fear and hope emotions with the following fuzzy variables:

distance, is the space-between a prey and its percepts (Figure 7).

effect, is the impact of the percepts on the future desirability (Figure 8).

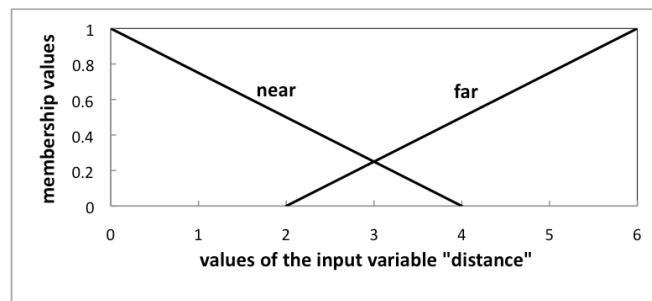


Figure 7: Fuzzy membership function of the distance

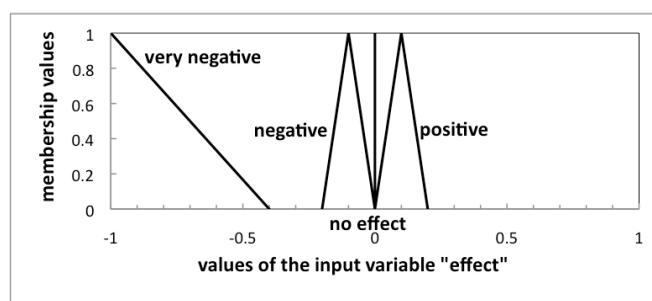


Figure 8: Fuzzy membership function of the effect

The following fuzzy rules are used to get effect of percepts on the emotions. Fuzzy union of the effects, which is between -1 and 1, computes the value of the future desirability. Positive values indicate the value of hope and negative values indicate the value of fear. The

prey learns by classical conditioning in the reactive level where predator is negative stimulus and prey and grass are positive stimuli.

IF	Predator's distance	IS	Far
THEN	Effect	IS	Negative
IF	Predator's distance	IS	Near
THEN	Effect	IS	Very Negative
IF	Prey's or Grass's distance	IS	Near
THEN	Effect	IS	Positive
IF	Prey's or Grass's distance	IS	Far
THEN	Effect	IS	No effect

Since this level can have feedback of behaviors, the cognition function utilizes a reinforcement learning method for behavior selection. We have utilized a Q-Learning algorithm with $\beta=\gamma=0.8$ and $\epsilon=0.2$ for this function. Aggregations of present affect (joy/distress) and future affect (hope/fear) in the reflective level are used for reward and punishment. The joy, distress, hope, and fear emotions are used for states (four states). To increase the rate of exploration and learning, we have considered a “search behavior”. Whenever the “search behavior” is selected, a behavior is randomly selected from the behavior repository. The result of cognition is sent to the behavior function for performing. Since this level is slow, the agent waits one cycle of simulation for responding to a situation and the behavior function responds a “think behavior” to show the waiting before responding the selected behavior.

5 EVALUATION

The predator-prey world is a grid with 51*54 blocks. First, we run the simulation with the reactive level (mode 1); and then the routine level and reflective level are added (mode 2). In mode 1, the behavior interruptions are responded by “no behavior” and the other interruptions are not responded. For the evaluation, we have run the predator-prey simulation 20000 times in each mode. In the Table 5, the initial parameters of the simulation are shown.

Table 5: The initial value of the simulation parameters
(psc=Per Simulation Cycle)

Parameter	Value
Number of prey	100
Number of predators	25
Total initial grass	259
Grass grow rate ⁴	2 psc
Resistance Rate	0.01
Maximum energy that each prey can take	40
Maximum energy that each predator can take	40
Initial energy for each prey ⁵	[0,40)
Initial energy for each predator	20
Energy taken from prey	10
Energy taken from grass	10
Energy which each predator uses each tick	0
Energy which each prey uses each tick	1
Energy each predator uses for mate	27
Energy each prey uses for mate	27

⁴ Since after cycle=1000 the grass grow rate is 0 to prevent an infinite simulation, the improvement in expansion of life span in mode 2 is low considering the considerable increase of complexity of the behavioral model of the preys compared to mode 1.

⁵ Initial energy for each prey is a random number between 0 to 40.

Table 6: The reported items after running of each mode (each mode runs 20000 times)

Items	Description
AVE_TICK_TIME	Average cycle number of the runs
MAX_LIFE_TIME	Maximum life time of prey in the runs
MIN_LIFE_TIME	Minimum life time of prey in the runs
AVE_EATEN_GRASS	Average of eaten grasses by prey per each run
PER_EATEN_PREY	Percent of eaten prey by predators
AVE_ATTACKED_PREY	Average number of attacked per each prey
PER_DEAD_PREY	Percentage number of prey that died due to energy exhaustion
AVE_PREY_MATE	Average of prey mates per each run
AVE_PREDATOR_MATE	Average of predators mates per each run
AVE_NO_BEHAVIOR	Average of situations which prey has no behavior per each run
AVE_SOCIAL_CONTACT	Average of social contacts per each run
AVE_SENSITIVITY	Average of sensitivity parameter in reactive level through the runs

After the runs of each mode, the data of Table 6 are reported. Each run of the simulation ends when there is no prey in the environment. AVE_TICK_TIME averages number of cycles that each run ended. In each run, there is a prey that lives the most. MAX_LIFE_TIME keeps the maximum lifetime among the runs. Hence, since there is a prey that lives more than the AVE_TICK_TIME, MAX_LIFE_TIME may be greater than AVE_TICK_TIME. Results of the simulations of the two modes are reported in Table 7. The average of run cycles and lifetime is more in mode 2 than mode 1; hence, the AVE_EATEN_GRASS and AVE_PREY_MATE are higher in mode 2. Due to the increasing resistance of the prey (i.e. by exercise behavior) in mode 2, when predators attack the prey, get a part of the prey's energy, and increase their energy, the prey is still alive. Predators use this energy for mate; hence, the AVE_PREDATOR_MATE, PER_EATEN_PREY, and AVE_ATTACKED_PREY in mode 2 are higher than mode 1. In the mode 2, the prey saves energy (e.g. rest behavior); hence, the PER_DEAD_PREY is lower than the mode 1. In the mode 1, preys move to opposite direction in predator stimuli and they cannot approach to grass; hence, this mode has lower PER_EATEN_PREY and higher PER_DEAD_PERY. AVE_ATTACKED_PREY shows that each prey had 0.05 attacks in mode 1 and 0.66 attacks in mode 2. Only the mode 2 has social behaviors, and there is not any "no behavior". Hence, AVG_NO_BEHAVIOR in mode 2 and AVG_SOCIAL_CONTACT in mode 1 are zero. Due

to the longer lifetime in mode 2, there is more time to justify the sensitivity parameter; hence, the AVE_SENSITIVITY is lower in mode 2 than mode 1.

Table 7: The results of the simulations in Mode 1 and Mode

Reported items	Mode 1	Mode 2
AVE_TICK_TIME	143	1454.74
MAX_LIFE_TIME	4661	11682
MIN_LIFE_TIME	1	1
AVE_EATEN_GRASS	280.11	494.14
PER_EATEN_PREY	17.28	41.50
AVE_ATTACKED_PREY	0.05	0.66
PER_DEAD_PREY	82.72	58.50
AVE_PREY_MATE	30.4	80.97
AVE_PREDATOR_MATE	1.24	30.12
AVE_NO_BEHAVIOR	3189.35	0.0
AVE_SOCIAL_CONTACT	0.0	2141.55
AVE_SENSITIVITY	6	5.36

Table 8 represents average number of each behavior selection per each run in mode 1 and mode 2. The number of “eat behavior” in

Table 8 is higher than the number of the AVE_EATEN_GRASS in Table 7 in respect that the grass may be eaten by another prey in the same time. The sum of the number of “contact for food” and “contact for resistance” behaviors selection in

Table 8 is higher than the AVE_SOCIAL_CONTACT in Table 7;-prey A wants to have social contact with prey B but prey B moves to another place at the same time and it is not beside the prey A anymore; hence, prey A can’t have social contact.

Table 8: Average numbers of selection of each behavior per each run in mode 1 and mode 2

Behavior	Mode 1	Mode 2
Search for conspecific	0	109.87
Approach to prey	39.2	339.13
Mate	30.34	82.90
Search for grass	0	134.51
Approach to grass	695.24	2175.49
Eat	485.96	2102.67
Opposite direction	39.91	2417.99
Exercise	0	3790.31
Contact for energy	0	1088.46
Contact for resistance	0	1097.90
Escape	0	238.64
Rest	0	5224.80
Think	0	11743.34

6 CONCLUSIONS AND FUTURE WORKS

The information processing paradigm advocated by Ortony et al. (Ortony, Norman, & Revelle, 2005) integrate four functions –affect, motivation, cognition, and behavior– into three levels –reactive, routine, and reflective. However, it does not contain details of implementation. The three levels of information processing paradigm ties well with our view of two sources for inputs (or stimuli) namely external and internal inputs. In this study, we implemented three levels of information processing coupled with two sources of inputs in a predator-prey environment by elaborating in details of the functions of each level, and the relationships across these levels. The simulation showed that the prey with functionality of all three levels could live-longer in the environment. The results of the study can be used in cognitive and emotive simulations as well as predator prey simulation.

We utilized a distinct learning method for each level of the three processing levels. The evaluation of different learning methods for each level is a future study of this paper. In a separate study, we are studying how an agent can generalize its emotional experiences (from episodic memory to semantic memory) to some general concepts and use these concepts to enrich its new experiences.

This paper shows how the agents can collect emotional knowledge from their environment and how emotion can be elaborated the three levels of information processing. This mechanism is part of an emotion understanding system. Hence, we are planning to use the three levels of information processing as part of an emotion understanding systems (Kazemifard, et al., 2009). Reliability studies in modeling and simulation are very important at three levels: validity and verification, quality assurance and failure avoidance (Ören & Yilmaz, 2009). Similarly, we plan to extend our emotion understanding system with our work on misunderstanding (Ören & Yilmaz, 2010).

In this paper we concentrated on affect and behavior functions; and utilized different learning methods and computational models for these functions in each level. There were not any computational models to compute the intensity of the motivations. It is a part of our future studies to utilize a proper computational model for the motivation function. We considered a distinct role for cognition function in the reflective level; but it played this role similar to the behavior function. We will be elaborating on the cognition function in the future studies. Fuzzy cognitive map can be used as a facility to augment the predator-prey simulation (Gras, et al., 2009). It also can be used for processing as well as representing the emotional experience of an agent.

Table 1 is a general structure for sources, modes, types, and nature of inputs and their relationships with three levels of information processing. It encompasses five types of input. We used three types of five types of input –forced input, perceived external input, and perceived internal input– in the predator-prey simulation of our study. The elaboration on the other types of input –evaluated external input and endogenous input– as well as the details of their nature remains for future studies. We tested the architecture in a predator-prey environment only. It needs to have more experiments in the other environment to reach a meaningful conclusion as well as to use all types of inputs with their detail. In the future, we will be testing this architecture in other environments also.

7 ACKNOWLEDGMENT

We appreciate Bryan Koenig and Quek Boon Kiat, in Computational Cognition for Social Systems (CCSS), Institute of High Performance Computing, Singapore Agency for Science Technology and Research (A*STAR), for their valuable comments during the preparation of this paper.

REFERENCES

- Aamodt, A., & Plaza, E. (1994). Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches. *AI Communications*, 7(1), 39-59.
- Ghasem-Aghaee, N., & Ören, T. I. (2003). *Towards Fuzzy Agents with Dynamic Personality for Human Behavior Simulation*. Paper presented at the 2003 Summer Computer Simulation Conference, Montreal, PQ, Canada.
- Gras, R., Devaurs, D., Wozniak, A., & Aspinall, A. (2009). An Individual-Based Evolving Predator-Prey Ecosystem Simulation Using a Fuzzy Cognitive Map as the Behavior Model. *Artificial Life*, 15(4), 423-463.
- Kazemifard, M., Ghasem-Aghaee, N., & Oren, T. I. (2006). *An Event-based Implementation of Emotional Agents*. Paper presented at the Summer Simulation Conference (SCSC'06), Calgary, Canada.
- Kazemifard, M., Ghasem-Aghaee, N., & Ören, T. I. (2009). Agents with Ability to Understand Emotions *Proceedings of the Summer Computer Simulation Conference* (Vol. 41, pp. 254-260). Istanbul, Turkey: SCS, San Diego, CA.
- Kazemifard, M., Ghasem-Aghaee, N., & Ören, T. I. (2010). Design and Implementation of GEmA: A Generic Emotional Agent. *Expert Systems with Applications*. doi: 10.1016/j.eswa.2010.08.054
- Kelley, A. E. (2005). Neurochemical Networks Encoding Emotion and Motivation: An Evolutionary Perspective. In J. Fellous & M. Arbib (Eds.), *Who needs emotions: The brain meets the machine*. New York: Oxford University Press.
- Kesteren, A. J. (2001). A Supervised Machine-Learning Approach to Artificial Emotions: Department of Computer Science, University of Twente.
- Langley, P., Laird, J. E., & Rogers, S. (2009). Cognitive architectures: Research issues and challenges. *Cognitive Systems Research*, 10(2), 141-160.
- LeDoux, J. (1996). *The Emotional Brain*. New York: Simon & Schuster.
- Marinier, R. P., & Laird, J. E. (2008). *Emotion-Driven Reinforcement Learning*. Paper presented at the 30th Annual Conference of the Cognitive Science Society, Washington, DC, USA.
- Maslow, A. (1943). A Theory of Human Motivation. *Psychological Review*, 50(4), 370-396.
- Mitchell, T. M. (1997). *Machine Learning*. New York: McGraw-Hill.
- Ören, T. I. (2001). *Software Agents for Experimental Design in Advanced Simulation Environments (invited paper)*. In: S.M. Ermakov, Yu.N. Kashtanov, and V.Melas (eds.) Proc. of the 4th St. Petersburg Workshop on Simulation, June 18-23, 2001, pp. 89-95.
- Ören, T. I., & Yilmaz, L. (2009). Failure Avoidance in Agent-Directed Simulation: Beyond Conventional V&V and QA. In L. Yilmaz & T. I. Ören (Eds.), *Agent-Directed Simulation and Systems Engineering* (pp. 189-217): Wiley-Berlin, Germany.
- Ören, T. I., & Yilmaz, L. (2010). Semantic Agents with Understanding Abilities and Factors Affecting Misunderstanding. In A. Elci, M. T. Traore & M. A. Orgun (Eds.), *Semantic Agent Systems: Foundations and Applications*: Springer-Verlag (in press).
- Ortony, A. (2009). Affect and Emotions in Intelligent Agents: Why and How? In J. H. Tao & T. N. Tan (Eds.), *Affective Information Processing* (pp. 11-21). London: Springer.
- Ortony, A., Clore, G. L., & Collins, A. (1988). *The Cognitive Structure of Emotions*. Cambridge, UK: Cambridge University Press.
- Ortony, A., Norman, D., & Revelle, W. (2005). Affect and proto-affect in effective functioning. In J. Fellous & M. Arbib (Eds.), *Who needs emotions: The brain meets the machine* (pp. 173-202). New York: Oxford University Press.

- Pavlov, I. P. (1960). *Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex* (G. V. Anrep, Trans.). New York: Dover Publications.
- Reiss, S. (2004). Multifaceted Nature of Intrinsic Motivation: The Theory of 16 Basic Desires. *Review of General Psychology*, 8(3), 179-193.
- Sabelli, H., & Kovacevic, L. (2007). Biotic complexity of population dynamics. *Complexity*, 13(4), 47-55.
- Savage, T. (2010). Adaptability in organisms and artifacts: A multi level perspective on adaptive processes. *Cognitive Systems Research*, 11(3), 231–242.
- Sloman, A. (2001). Beyond Shallow Models of Emotion. *Cognitive Processing*, 2(1).
- Sloman, A., Chrisley, R., & Scheutz, M. (2005). The Architectural Basis of Affective States and Processes. In J. Fellous & M. Arbib (Eds.), *Who needs emotions: The brain meets the machine*. New York: Oxford University Press.
- Sloman, A., Scheutz, M., & Logan, B. (2000). Evolvable Architectures For Human-Like Minds. In G. Hatano, N. Okada & H. Tanabe (Eds.), *Affective minds* (pp. 169-181). Amsterdam: Elsevier.
- Sun, R. (2006). The CLARION cognitive architecture: Extending cognitive modeling to social simulation. In R. Sun (Ed.), *Cognition and Multi-Agent Interaction*. New York: Cambridge University Press.
- Sun, R. (2009). Motivational representations within a computational cognitive architecture. *Cognitive Computation*, 1(1), 91-103.
- Sun, R., Zhang, X., & Mathews, R. (2006). Modeling meta-cognition in a cognitive architecture. *Cognitive Systems Research*, 7(4), 327-338.
- Wilson, N., Sun, R., & Mathews, R. (2010). *A Motivationally Based Computational Interpretation of Social Anxiety Induced Stereotype Bias*. Paper presented at the 32nd Annual Conference of the Cognitive Science Society, Portland, Oregon.
- Zadeh, S. H., Shouraki, S. B., & Halavati, R. (2006). Emotional Behavior: A Resource Management Approach. *Adaptive Behavior - Animals, Animats, Software Agents, Robots, Adaptive Systems*, 14(4), 357-380.