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An Emotion and Temperament Model for Cognitive Mobile Robots

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ABSTRACT: *This paper describes a model of emotions and temperaments (or personalities), and how to implement it in cognitive mobile robots. Emotions such as fear, anger, sadness, happiness, disgust, and surprise can be modeled theoretically, and vary due to reinforcers such as rewards and punishments. The model incorporates exponential decay of the reinforcement effects, so without continual reinforcers the emotion will return to their steady-state values. It is shown that emotions and temperament are coupled through the theory. The constants used in the model of emotions are related to the temperament of the robot. The main five temperaments discussed include Extrovert/ Introvert, Neurotic/Rational, Conscientious/Careless, Agreeable/Disagreeable, and Open/Reticent. The emotion and temperament engine (ETE) developed here has been incorporated into SS-RICS, which is a cognitive architecture developed at the Army Research Laboratory and tested in both mobile robots and in simulators.*

1. Introduction

Mobile robots are not currently designed with temperaments or emotions, which is referred to as Affective Computing [Picard (2000)]. Temperament (or personality traits) and emotions are not the same thing. Temperaments are traits that an individual animal possesses that are innate and typically fixed for that animal's life. Emotions vary continuously, sometimes on small time scales. In animals, temperament and emotion (and variations across groups) are as important to survival as cognition. They are crucial to the animal's survival, and will make robots more effective also (LeDoux, 2000).

There are five main types of temperament in humans and other animals, often called the Big Five (Digman, 1990): Extrovert vs. Introvert, Neurotic vs. Rational, Conscientious vs. Careless, Agreeable vs. Disagreeable, and Open vs. Reticent

When we design and build autonomous robots we do not generally think of these varying across the group, but a heterogeneous mix of traits in a group will make the group more successful. In addition, unlike in biology where these traits are relatively fixed over the life of the organism, these could be varied in intelligent mobile robots.

While people do not completely agree on a complete list of emotions, Damasio (1994 and 2010) discusses six "universal" emotions: Fear, Anger, Sadness, Happiness, Disgust, and Surprise

Plutchik (2001) discusses the same six emotions, but also includes "trust" and "anticipation." He also describes how there can be varying levels of each emotion in his emotion wheel. Ekman (1999) describes 15 basic emotions. The six (or eight) emotions are common across animals [Braithwaite et al (2013)] and cultures. The approach used herein could easily use more or fewer emotions. Damasio refers to emotions as automated programs for action that have been created through evolution. Emotions are related to reward, punishment, drives, and motivations. There are typically negative and positive emotions, and they are tied to reinforcers (rewards, punishments, lack of reward, and lack of punishments), see Gray (1990), Rolls (1990), and Rolls (2013).

While some investigators have studied affective computing in robots, there are very few studies which incorporate temperament and emotions into mobile robots. And the ones that do exist, do not properly distinguish temperament from emotions (e.g. Barteneva et al, 2007 and Canamero, 2005). Gray (1990) discusses the connection between emotions and cognition. Groups of mobile robots with a mix of personality and emotions will be more effective and have increased mission success. An interesting anecdote relates to the well-known robot soccer competition. One of the researchers remarked that the robots play in the same manner at the start of the game as at the end, whereas a human would play very differently in the last few minutes of the game, especially if they were losing. Another example is group behavior. In nature there are many examples of groups (ants, fish, rats, humans, etc.) that are very effective, and the groups usually include a wide variety of personality types.

This paper discusses how to incorporate emotions and temperament into cognitive architectures such as ACT/R, Soar, and SS-RICS. The emotions are basically state variables, and the robot will behave differently depending on which emotion it is experiencing. The temperaments, as described below, are fixed characteristics of the robot (although, unlike in animals, we could vary them in time).

2. Cognitive Software

The work described here uses the Symbolic and Sub-symbolic Robotics Intelligence Control System (SS-RICS), although we have used the SOAR cognitive architecture (Laird, 2008) on mobile robots in the past (Hanford and Long, 2014).

SS-RICS is intended to be a theory of robotic cognition based on human cognition. Additionally, a thrust of SS-RICS has been on the integration of theories within the field of cognitive psychology - primarily theories of knowledge representation and organization. The field of knowledge representation in cognitive psychology has been embattled in a struggle to quantify knowledge structures as either symbolic or subsymbolic (Kelley, 2003). Symbolic knowledge is characterized as static, discrete, and conscious. Language is a symbolic representation of knowledge. Subsymbolic representations of knowledge has been characterized as dynamic, distributed, and unconscious. Typically, perceptual or motor skills are characterized as subsymbolic knowledge. Riding a bicycle can be characterized as subsymbolic knowledge. Within SS-RICS, these two representations of knowledge are not mutually exclusive, but instead, lie on either ends of a cognitive continuum (Kelley, 2003). SS-RICS is a hybrid cognitive system that allows for a continuum of knowledge that includes both symbolic as well as subsymbolic constructs. It is believed that this integrated approach is the best way to represent the complete spectrum of cognition.

The Army Research Laboratory[1]s (ARL) Human Research and Engineering Directorate (HRED) developed the Symbolic and Sub-symbolic Robotics Intelligence Control System (SS-RICS) beginning in 2006 (Kelley, 2006). SS-RICS is a rule based production system, robotics control system inspired by the cognitive architecture, the Adaptive Character of Thought - Rational (ACT-R) (Anderson and Lebiere, 1998). Development of the system has leveraged heavily from biological and human capabilities for navigation, action and selection, and memory decay.

Long and Kelley (2010), described how robots could become conscious by building on current approaches to cognitive modeling, emotions and temperament will help in this endeavor. One of the most recent advances in SS-RICS has been the incorporation of a memory system that mimics human-type dreams to consolidate memories (Kelley, 2014).

SS-RICS is organized into three layers all utilizing a basic unit of knowledge, or working memory element, called facts. Facts are composed of a tuple: which is name, type, and slots. For example, a fact might contain information such as: (Location234 color value=red). In this example, Location234 is the name of the fact, the type of the fact is "color" and a slot, which has the name of "value" is defined as "red".

One layer serves as the Long Term Memory (LTM), and in practical terms, it is a relational database or a semantic network. As of this writing we are using a variation of ConceptNet (Liu and Singh, 2004) and have made some progress integrating ConceptNet into SS-RICS. ConceptNet allows SS-RICS to relate similar objects to each other (i.e. dogs and cats are similar) and allows SS-RICS to query the database for information about objects. For example, we can query ConceptNet and find that “Sweet” is a “PropertyOf” “Apple”.

The second layer within SS-RICS is the production system, which serves as the executor and Working Memory (WM) component of the architecture. The production system executes goals by matching rules to facts within working memory (not LTM). We are currently working on processes which pull information from LTM into WM by using spreading activation (Anderson and Lebiere, 1998). For example, if the robot defined a goal of going through a door, the robot would pull goals and facts from LTM associated with going through a door, as well as other goals, for going down halls and maneuvering in rooms. Note that this requires goals and rules to have activation to be stored as memories; this is different from ACT-R which doesn’t assign activation values to productions.

The third layer is the sub-symbolic layer. The sub-symbolic layer serves as the perceptual component of SS-RICS. The key aspect of the perceptual layer is that all of the sub-symbolic processors are running in parallel and can be chained together for serial or hierarchical operations. For example, a processor that receives data from a range sensor generates memories representing geometric line segments which it then passes to a line processor to be merged into a higher level line memory. For resource allocation adjustments processors may also be turned on and off at runtime as necessary. This makes SS-RICS relatively scalable in terms of real time processing. The sub-symbolic layer provides information to the production system in a continuous fashion represented as facts. As SS-RICS is developed, newer sub-symbolic systems can be added or removed as necessary. We have tried to make this component as modular as possible.

SS-RICS is currently designed to interact with a robotic platform via an interface which defines the required operations and properties needed for SS-RICS to operate the robotic asset and interact with its sensors. This interface allows SS-RICS to communicate with any robotic system which has an implementation that fulfills the interface. We currently have implementations of the interface for Mobile Robots Pioneer platform of robots, the SRV-1 robot, the iRobot PackBot and Clearpath's Husky A200. SS-RICS was designed and developed using both managed and unmanaged C++ using Microsoft Visual studio 2003, 2008 and 2010.

A flowchart of the system being used here is shown in Figure 1. The emotion engine was added to SS-RICS as a subsim, and the emotions and the currently most active emotion are available as state variables.

3. Emotion and Temperament Model

The survival of animals (including humans) depends on emotions and temperament. Robots with emotions and temperaments will also allow better interactions with humans. In addition, teams of animals (including humans) are more effective when the groups have a mix of temperaments. This has been shown true for robots (Eskridge et al, 2014), cockroaches (Planas-Sitja et al), fish (Mittelbach et al, 2014), ants (Pinter-Wollman, 2012), spiders (Pruitt and Keiser, 2014)), humans (Pieterse et al, 2006; Moynihan and Peterson, 2004), sheep (Michelena et al, 2009), and other animals. Also, Eskridge and Schlupp (2014) state:

> *The combination of different personalities within a group and the associated roles assumed by different members have been found to improve the overall success of the group (Couzin et al., 2005; Dyer et al., 2009; Modlmeier and Foitzik, 2011; Modlmeier et al., 2012). Studies have shown that these personality differences can be stable and maintained over time (Dal et al., 2004; Oosten et al., 2010)."*

The model used herein builds upon the model for happiness by Rutledge et al (2014):

$$Happiness(t) = w_o + \sum_{j=1}^{t} \gamma^{(t-j)} \left(w_1 CR_j + w_2 EV_j + w_3 RPE_j \right)$$

where Happiness ranges from 0 to 100 and:

CR = Certain Reward (e.g. 10)
EV = Expected Value (e.g. 10)
RPE = Reward Prediction Error (e.g. 10)
w_o = Steady state value of happiness (e.g. 50)
w_1 = Magnitude of change (e.g. 0.52)
w_2 = Magnitude of change (e.g. 0.35)
w_3 = Magnitude of change (e.g. 0.80)
γ = Rate of decay (e.g. 0.72)

The model has exponential decay given by γ. If the subject chose a certain reward (CR), then EV and RPE were zero. If the subject chose a gamble, then CR was zero. They also state:

> *"Conscious emotional feelings, such as momentary happiness, are core to the ebb and flow of human mental experience. Our computational model suggests momentary happiness is a state that reflects not how well things are going but instead whether things are going better than expected."*

The model used here is guided by the above model, but modified to fit the task of incorporating emotions and temperament into cognitive mobile robots. This task is not gambling oriented, but instead involves the robot experiencing rewards or lack of rewards as it goes about it's work.

The model for emotion developed here is:

$$Emotion(t)_i = w_{o_i} + \sum_{j=1}^{t} \gamma_i^{(t-j)} \left(w_{1_i} R_{ij}^{+} + w_{2_i} R_{ij}^{-} \right)$$

where there are now six emotions (Fear, Anger, Sadness, Happiness, Disgust, Surprise), each denoted by the subscript i, and there is exponential decay of rewards also. The emotions change with time. The subscript j denotes a time instance. R^+ and R^- denote positive and negative rewards, respectively. So emotion is a vector of length six, but could easily be smaller or larger to accommodate different sets of emotions. Each emotion varies from 0 to 100, which is analogous to Plutchik's (2001) color wheel.

To determine the current emotional state of the robot, the emotion with the maximum value is chosen, i.e. a winner take all approach as used in Breazeal and Brooks (2003).

One of the very interesting aspects of this model is that it can also model temperament (i.e. personalities) through the constant terms. Temperaments do not vary in time. A temperament matrix T_{ij} can be defined as:

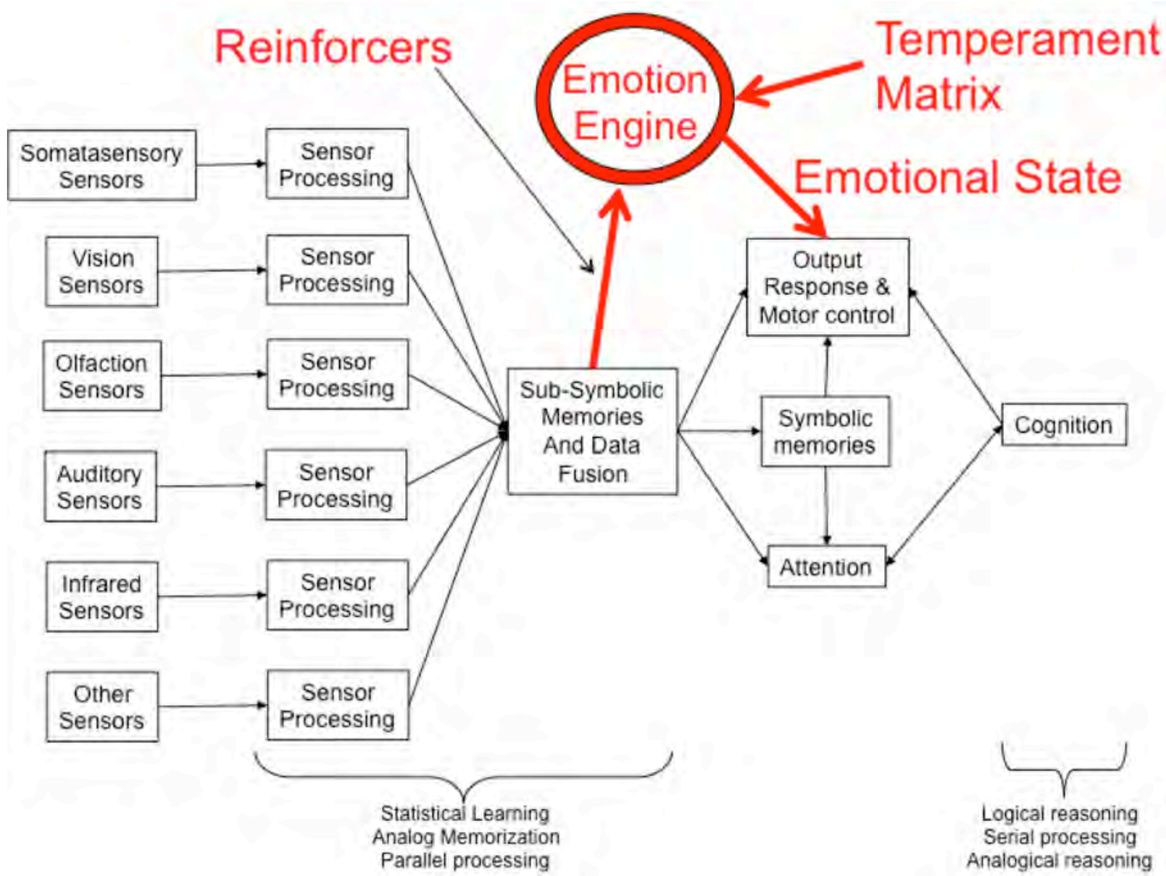

Figure 1. Flowchart of system.

$$T_{ij} = \begin{bmatrix} w_{0_1} & w_{1_1} & w_{2_1} & \gamma_1 \\ w_{0_2} & w_{1_2} & w_{2_2} & \gamma_2 \\ w_{0_3} & w_{1_3} & w_{2_3} & \gamma_3 \\ w_{0_4} & w_{1_4} & w_{2_4} & \gamma_4 \\ w_{0_5} & w_{1_5} & w_{2_5} & \gamma_5 \\ w_{0_6} & w_{1_6} & w_{2_6} & \gamma_6 \end{bmatrix}$$

Few previous papers have so clearly delimited the difference between modeling emotions and modeling temperament. For animals temperaments are fixed in time [Mendl, (2010)], but for robots we would be able to easily change the robots temperament (or personality) by just changing this matrix. It should be possible to model the big five temperaments presented earlier (Extrovert/Introvert, Neurotic/Rational, Conscientious/Careless, Agreeable/Disagreeable, and Open/Reticent) using the above matrix.

The simplest form of the temperament matrix would have all the rows the same (all the emotions vary in the same way), i.e.

$$T_{ij} = \begin{bmatrix} 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \end{bmatrix}$$

where for simplicity representative values from Rutledge et al (2014) have been used. As shown above the rows of this matrix relate to: fear, anger, sadness, happiness, disgust, and surprise; respectively. All 24 values in the temperament matrix can be varied however. For example, if we wanted a robot that was usually angry, did not remain happy very long, and was easily surprised, we might use:

$$T_{ij} = \begin{bmatrix} 50 & 0.52 & 0.35 & 0.72 \\ 75 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.72 \\ 50 & 0.52 & 0.35 & 0.40 \\ 50 & 0.52 & 0.35 & 0.72 \\ 60 & 0.70 & 0.35 & 0.72 \end{bmatrix}$$

The complex relations between the temperament matrix and the robot behavior still need to be investigated in more detail.

As mentioned above, SS-RICS is capable of modeling symbolic and sub-symbolic features. The Emotion and Temperament Engine (ETE) developed here is a sub-symbolic program (a "subsim") in SS-RICS, and can be called by the production system.

4. Results

Three simulations have been run in SS-RICS using different temperament matrices. The matrices are shown in Figure 2. The first case has a temperament that is on average angry. The second one is typically happy, and the third case is fearful on average. These tests were run on a simple maze shown in Figure 3. All the robots started at the same point and ended when it reached the UltimateGoal, as shown in Figure 3. Within the maze there are items the robot might perceive (food, danger, and gruesome items). The food makes the robot happy and it tends to linger in those areas. When the robot first sees danger it is surprised, and then it becomes fearful. It will also try to avoid danger by backing up and turning away from it. The gruesome items will tend to make it disgusted. In tests 1 and 3 the robot only finds food once, but in test 2 the robot sees food twice. For these tests, happiness and sadness are considered related. So when happiness increases, sadness decreases. Also, in test 1 the robot becomes afraid twice since it sees danger twice. The three graphs in Figure 4 show the paths taken by the robot in the three different tests cases.

The emotional states, as functions of the number of time steps, are shown in Figure 5. In all three cases there is a spike in surprise, but it declines quite rapidly, since γ_6 (for surprise) is a small number (0.30). In the first graph (for the angry robot), it shows it starts out angry, then is surprised for a short time, then becomes fearful, then goes back to angry as the fear wears off, and then it becomes happy as it finds the food near the end of the test.

The tests performed here were simple proof-of-concept tests, more complex tests are being conducted now. The three tests conducted were for three different temperaments (or personalities). The results show that each temperament required a different number of time steps to complete the mission (Angry: 343 steps, Happy: 507 steps, and Fearful: 531 steps). When the robot is happy or fearful, it's progress towards the goal will be reduced. So it does make sense that the angry robot will reach the goal faster.

5. Conclusions

We have presented a model for both emotions and temperament that can be incorporated into cognitive mobile robots. The model used was inspired by a recent model of happiness [Rutledge et al, 2014], which includes a decay factor. With this model, robots can have personalities (temperaments) and emotions, and the personalities and emotions are coupled, as they should be. Emotions and personalities are quite different features of animals (including humans) but they are coupled. Emotions vary with time and temperament is essentially fixed. A novel feature of this model is the "temperament matrix," which allows the personality and emotions of the robot to be summarized with only 24 constants (when using six emotions). More (or fewer) emotions could be modeled easily as well. This model has been integrated into SS-RICS and tested in the SS-RICS robot simulator. Additional tests will be performed using AmigoBot and Pioneer robots. In addition, we will be testing teams of robots with different temperaments.

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$$T_{ij} = \begin{bmatrix} 50 & 0.52 & 0.35 & 0.95 \\ 52 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.30 \end{bmatrix} \quad T_{ij} = \begin{bmatrix} 50 & 0.52 & 0.35 & 0.50 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 52 & 0.62 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.30 \end{bmatrix} \quad T_{ij} = \begin{bmatrix} 52 & 0.62 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.95 \\ 50 & 0.52 & 0.35 & 0.30 \end{bmatrix}$$

Test 1 (Angry) Test 2 (Happy) Test 3 (Fearful)

Figure 2. The temperament matrices used for the three test cases.

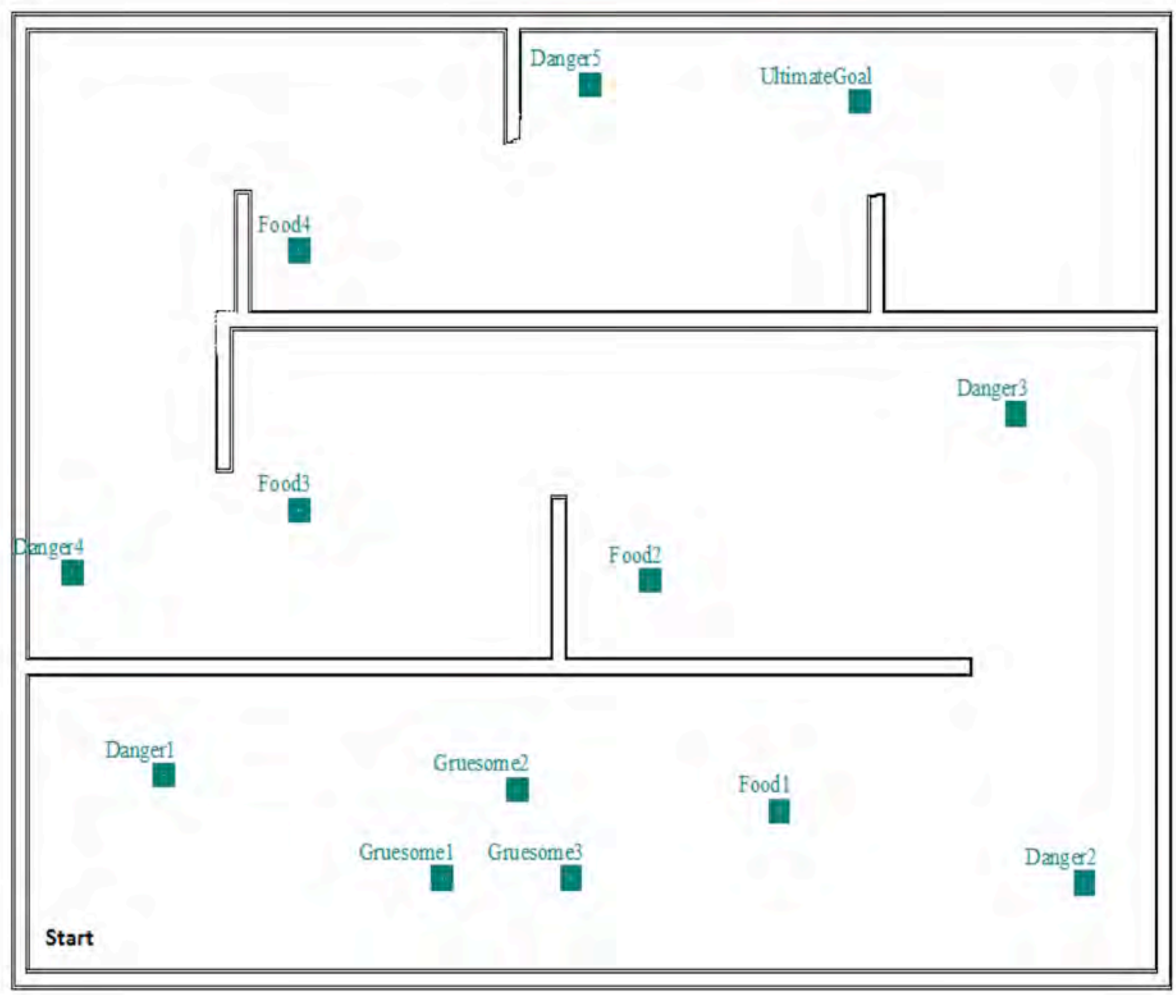
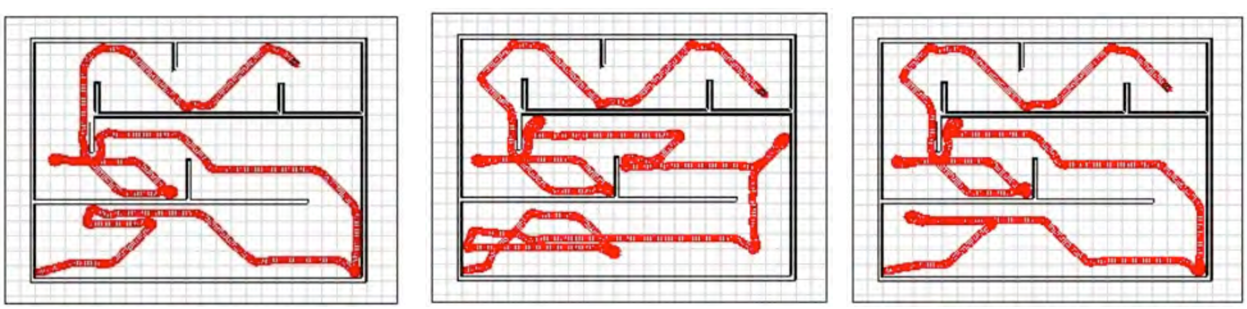
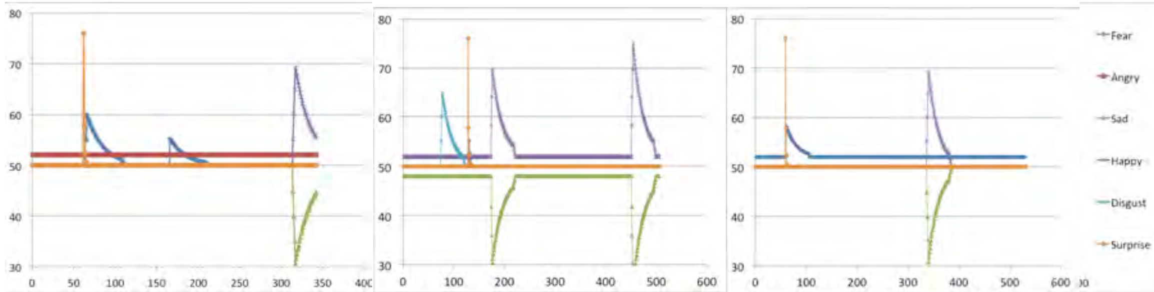


Figure 3. Maze used for tests.



Test 1 (Angry) Test 2 (Happy) Test 3 (Fearful)

Figure 4. Paths of the robot in the maze for the three tests cases.



Test 1 (Angry) Test 2 (Happy) Test 3 (Fearful)

Figure 5. Emotions as a function of time for the three test cases.

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