Modeling Motivations and Emotions as a Basis for Intelligent Behavior

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Abstract

We report on an experiment to implement an autonomous creature situated in a two-dimensional world, that shows various learning and problem-solving capabilities, within the Society of Mind framework. This goal is approached from a developmental perspective, where phases in the experiment correspond broadly to cognitive stages in the development of an infant. This paper describes the first stage, the creature being a newborn whose behavior is strongly driven by motivational states—impulses to action based on bodily needs—and basic emotions—peripheral and cognitive responses triggered by the recognition of a significant event. Physiological parameters are used to model both concepts, which are seen by analogy with control systems. Motivations drive behavior selection and organization based on the notions of arousal and satiation, and the exploitation principle. Emotions exert further control by sending "hormones" that may affect the intensity of the selected behavior, enable it, or prevent it. They also influence the attentional and perception mechanisms.

Introduction

This paper present the first stage of an experiment to implement an autonomous creature with diverse learning and problem-solving capabilities. Our main emphasis is in building a complete creature able not only to survive and make rapid decisions in a dynamic world, but also showing many other competences: play, be happy, solve problems, recognize external events and the effects of its actions as pleasurable or noxious, learn from its experience, and in general "enjoy life" in its 2–D world. This goal requires an adequate framework and a solid basis to build upon.

We have adopted Minsky's *Society of Mind* (SoM) as a framework, in two senses. First, we follow its general principle that views intelligence as emerging from the interactions of societies of simple, non-intelligent agents "cleverly engineered". Second, we are implementing our creature in terms of agents and principles described in SoM. This framework is at the same time comprehensive and flexible enough to provide continuous guidance for our architecture, from the basic behavioral mechanisms to the more complex cognitive functions, leaving enough freedom to make the design and implementation of these agents an enjoyable challenge. As for the basic creature to build upon, we have adopted a developmental approach, starting with a "newborn" creature which is endowed with a certain number of innate structures and mechanism to cope with its environment, such as a complex perceptual system which embeds *a priori* notions of space and object, or a motivational and emotional system that allows it to make rapid and adapted decisions. With respect to this latter, we adhere to the idea that "the affect system provides the primary blueprints for cognition, decision, and action" (Tomkins 1984). This creature should end developing more complex and clever behavior as a result of its interactions with the world. The incremental design approach we have adopted follows also the principle underlying the subsumption architecture (Brooks 1991). To achieve more and more complex behavior, we will keep adding agents to our creature without modifying the existing ones—only their connections will grow more complex. The fact of using internal motivations and emotional states to drive the creature's behavior and learning—among other things—distinguishes our work from other developmental models such as (Drescher 1991), and from other *tabula rasa* approaches to learning.

The paper is organized as follows. Next section introduces the experimental setting chosen to implement our ideas. Then, the different agents in charge of sensing, perceiving and acting are presented, to continue with our model of (early) motivations and emotions. Finally, we draw some conclusions and assess the possibilities that this design offers as a basis for higher-level cognitive activities.

Experimental Setting

Gridland

Our simulated world is a two-dimensional grid inhabited by geometrical figures (Figure 1). Gridland's population falls into three main categories: single-cell—dot-shaped—living beings, single-cell—dot-shaped—food and water sources, and inanimate blocks of varying shapes and sizes, namely lines, triangles, squares, rectangles, and circles.

There are two species of *living beings*: Abbotts[1]—the

[1]Named after Edwin A. Abbott, whose novel *Flatland* (Abbott 1884) inspired some of the features of Gridland.

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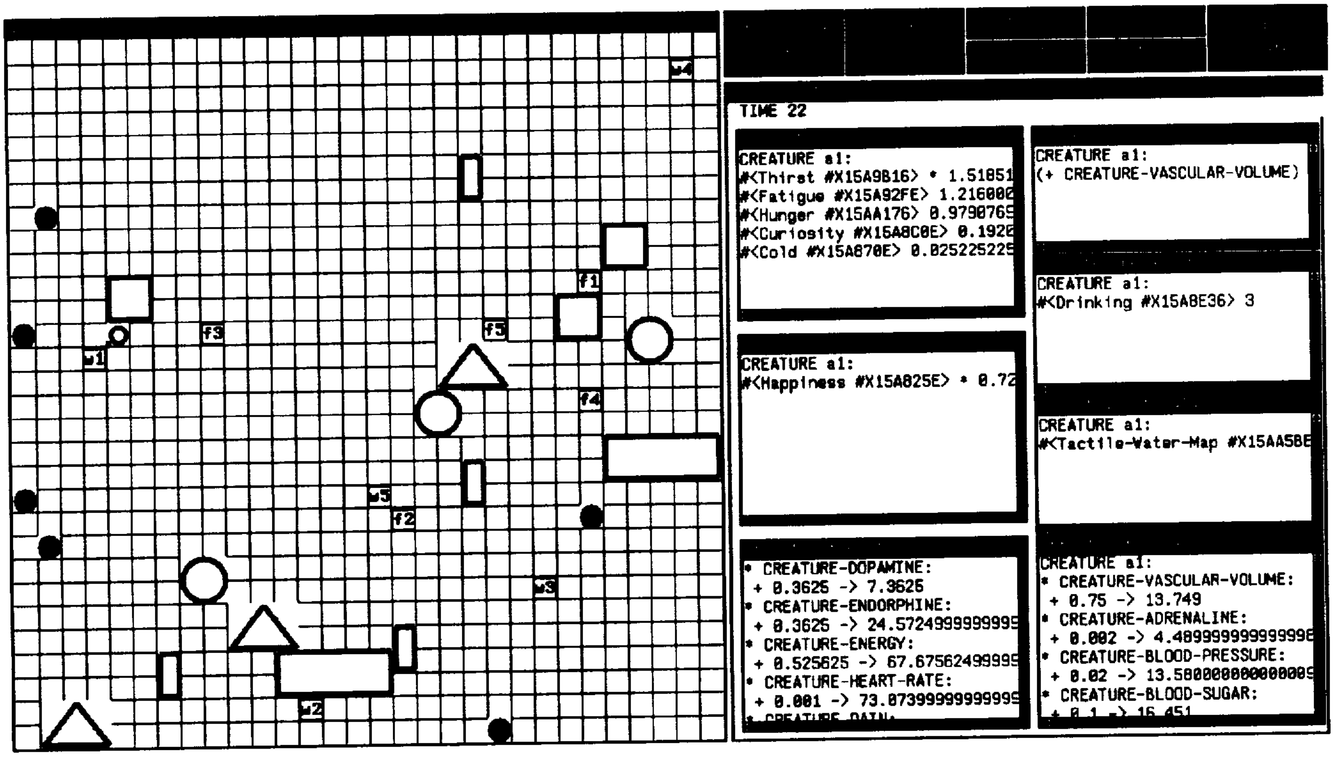

Figure 1: A snapshot of Gridland. Abbotts are white "dots" with a black spot in one corner—their eye. Black dots are Enemies.

smart guys, and therefore the protagonists of our story—and Enemies. In the remaining of the paper we will talk interchangeably of "Abbott" as an individual and of "Abbotts" as a species. Enemies have a simple fixed behavior: they wander around without hitting blocks, they eat and drink every time they find food and water, and they also try to eat Abbotts and to each other. An Enemy's bite is a source of pain both for Abbotts and for other Enemies. *Food and water* sources are oddly distributed in the grid. Once exhausted, they disappear and regenerate at a different (random) location. *Blocks* cannot move by themselves. They act mainly as obstacles during the navigation task, although Abbotts can also move them around while playing. Gridland is represented in an array, the elements of which are six-dimensional vectors containing numeric information about the physical features present in the corresponding cell:

- Gravity level, increasing downwards by one a row.
- Occupancy—empty (0), full (1), or partially full cell (2).
- Hardness of the object contained in the cell—a value ranging from 0 (empty cell) to 4.
- Brightness of the object in the cell—between 0 and 9.
- Surface—list of cells occupied by an object. This feature is not accessible to living beings, but used to moved things around in the animation.
- Amount of organic matter—a number between 0 and 5, where 0 corresponds to empty cells and inanimate blocks, and 5 to healthy Abbotts and Enemies, and to intact water and food sources. Any value in between corresponds to injured individuals or to partially consumed food or water.

Table 1 characterizes Gridland's inhabitants in terms of these features, which allow living beings to perceive them as physical objects.

Entity	Surf.-Occ.	Hard.	Bright.	Amt.
Water	1-partial	1	1	5
Food	1-total	2	2	5
Abbotts	1-total	3	8	5
Enemies	1-total	3	9	5
Lines	2-total	4	3	0
Circles	4-partial	4	4	0
Triangles	1-t., 5-p.	4	5	0
Squares	4-total	4	6	0
Rectangles	8-total	4	7	0

Table 1: Characterization of Gridland's inhabitants.

Creatures as Societies of Agents

A creature consists of societies of agents of many different types. We will adopt the broad definition of agent given in (Minsky 1985, p. 326): "any part or process of the mind that by itself is simple enough to understand—even though the interactions among groups of such agents may produce phenomena that are much harder to understand." An agent can thus be considered as a function that maps percepts into actions (Russell & Norvig 1995), where an action can be an observable activity that affects the external world, or turning another agent on of off. This notion of agent promotes system decomposition by activity—a pattern of interactions with the world (Brooks 1991). The notion of agent is to be

```
(defclass agent ()
  ((name ... :initarg :name)
   (owner ... :initarg :owner)
   (stimulus ... :initarg :stimulus)
   (activation ... :initarg :activation)
   (state ... :initform 0)))
```

Figure 2: General characterization of an agent.

seen by opposition to that of an agency (Minsky 1985, p. 326)—"any assembly of parts considered in terms of what it can accomplish as a unit, without regard to what each of its parts does by itself." The agent/agency distinction parallels the inside/outside view of a system. Our purpose is to engineer societies of agents in such a way that they look as clever, goal-oriented agencies or intentional systems (Dennett 1978) to an external observer. We define an agent (Figure 2) by: a name; an owner—the creature to which it belongs; an incentive-stimulus to which the agent responds, that can be a list of physical features, a physiological parameter, or another agent; an activation level—a real number; and state—0 (inactive) or 1 (active, when its stimulus has been perceived). Enemies are much simpler creatures than Abbotts, and they only have nine agents:

- Three sensors: an internal pain sensor, and two 8-bit tactile sensors—one that indicates the presence or absence of objects on each of the eight cells surrounding it, and another that indicates the amount of organic matter on each of its neighboring cells.
- One motor map: a 4-bit vector that indicates the presence or absence of an object on each of the four directions where it can move—to its left, right, top, and bottom.
- Two effectors: a foot and a mouth.
- Three behaviors: walking, eating, and withdrawing.

In the remaining of the paper, we will describe Abbott's agents. Besides agents, a creature also has a set of physical properties, already presented, and a set of physiological variables that define its bodily state.

Implementation

The microworld and the creatures inhabiting it have been implemented on a Sparc station using Harlequin Lucid Common Lisp. The different blocks, food and water sources are randomly placed when the scenario is first initialized. The interface (Figure 1) allows the user to select the number of creatures of each species, to choose the execution mode—automatic, for a number of steps to be set by the user, or stepwise—to stop or interrupt the execution, to reinitialize the creatures' physiological parameters both during a run or between two scenarios, and to inspect the internal state of the different agents composing the creatures. In addition, for each Abbott, it shows the evolution of the action selection mechanism and the motivational and emotional states controlling it—the agents which are active with their corresponding activation level or intensity, and the effects they have on the creature's bodily state—at every time step.

Parameter	Init. val.	Set point	Variab.
Adrenaline	10	10	± 5
Blood pressure	12	12	± 4
Blood sugar	30	20	± 10
Dopamine	10	10	± 5
Endorphine	20	20	± 10
Energy	120	100	± 50
Heart rate	75	75	± 25
Pain	0	0	± 2
Respiration rate	8	8	± 7
Temperature	37	37	± 3
Vascular volume	25	20	± 10

Table 2: Physiological variables used to define Abbott's bodily state.

Sensing, Perceiving, and Acting

Since our world is dynamic and unpredictable, our creatures must sense it "continuously"—very often—and in a non-trivial way. In particular, we do not provide our creatures with any labeled percepts. Also, many different agents process sensory information at different levels. This information is not merged into a central locus, but kept very distributed, as it will be used by different agents at different levels and in different ways, depending on their nature and connections.

Sensors

A sensor is "an agent whose inputs are sensitive to stimuli that come from the world outside the brain" (Minsky 1985, 11.1). Abbott has three kinds of sensors—somatic, tactile, and visual. *Somatic sensors* provide Abbott with information about different aspects of its own body. Two of them are devoted to proprioceptive input: the position of the eye—one of the four corners of Abbott's body—and the motor direction—top, left, bottom or right. The rest monitor the variables defining its bodily state (Table 2). Besides providing the value of their incentive stimulus—the variable they track—these agents also define a range within which this stimulus should be kept under normal conditions, report on the difference between the actual parameter value and the parameter set point—its ideal value—and measure the intensity of the change at every time step. External *tactile sensors* output a 9-bit vector reporting on the value of their respective incentive stimulus on each of the eight surrounding cells, plus the cell occupied by Abbott. This has four tactile sensors: the gravity, occupancy, hardness, and organic amount sensors. Abbott's single eye supplies information about object features in a 5×5-cell, 90-degree area. The eye can be moved to any of Abbott's corners. There are *two visual sensors*, the output of which is a list of integers: a brightness sensor, and distance sensor that calculates the (square) distance of obstacles with respect to the eye.

Recognizers

Recognizer agents are higher-level processors of sensory data. Their output thus carries some information on complex objects, rather than on isolated features. A recognizer is "an agent that becomes active in response to a particular pattern of input signals" (Minsky 1985, 19.6). The only type of recognizers used at this stage are object recognizers. Abbott uses two object recognizers—a tactile recognizer, and a visual recognizer. These agents use an ART–1 neural net (Carpenter & Grossberg 1988) to perform the recognition task. We have arbitrarily set the size of the output (recognition or categorization) layer of both networks to 20 units, although only a few of them are currently used. The tactile recognizer has eight input units, corresponding to the elements of a vector that binarizes and merges data from two tactile sensors—occupancy and hardness. The visual recognizer has four input units, corresponding to a binary vector that translates information stemming from the brightness sensor.

ART–1 unsupervised, vector-clustering, competitive learning algorithm presents several advantages that make it an adequate choice for recognizers:

- Its learning algorithm requires only one pass through the training set to learn a category (with fast learning). It is therefore perfectly suit for a dynamic world, where one-shot learning and recognition can present many advantages for adaptation.
- These nets provide a good solution to the stability/plasticity dilemma, as they automatically switch between learning and recognition modes. This way, the possibility that Abbott keeps dynamically learning new object categories remains open.
- The vigilance threshold allows to easily establish in advance[2] the number of categories that the network will learn given a certain training set. This amounts to endowing the agent with an *a priori* perceptual structure that determines how it will group lower-level percepts into higher-level concepts—the kinds of objects it will be able to know.

Recognizers incorporate two additional features:

- The ability to forget the less frequently used categories when the memory is full, allowing for new learning.
- A mechanism that resets the network's forward and backward weights to their initial values and that changes (lowers or raises) the vigilance threshold as instructed by the attentional mechanism, depending on the emotional state of the creature. Accordingly, the recognizer agent will perform its task at a different granularity level—coarser if the threshold is lowered, finer if it is raised—giving rise to a completely different categorization of the world.

Since the only input these agents understand are binary vectors, they cannot communicate directly with sensors—they do it through the agency of direction-nemes. Recognizers' output consists of the index of the output unit that became active upon recognition (or learning) of a given stimulus pattern.

[2] A second parameter that can be used, as we have done here, to compute the forward weights so as to prevent that a vector that is a subset of another be classified in the same category—what Grossberg calls "self-scaling" of the forward weights—is as critical to the classification performance as the vigilance threshold.

Direction-nemes

Direction-nemes are agents associated with a particular direction or region in space (Minsky 1985, 24.6). Abbott has eight direction-nemes: top, top-left, left, bottom-left, bottom, bottom-right, right, and top-right. Each of them can only read the information in one of the positions of the vector that constitutes the output of the different sensors it can communicate with. It translates this information—an integer—into a format that can subsequently be used by other agents, namely recognizers and maps—a binary vector. They also perform some sensory association: tactile information concerning the occupancy and hardness features of each cell are assembled in a single vector. Direction-nemes corresponding to Abbott's corners store two sensory patterns observed at that particular spatial region: the tactile and the visual vectors. Those located in the horizontal-vertical axes store only tactile patterns. These patterns undergo a further process that we would be tempted to call "interpretation" except for the fact that its result is completely meaningless for direction-nemes. Each of them sends its stored patterns to the corresponding—tactile or visual—object recognizers, which return the index of the winning output neuron.

The effect of these agents is that Abbott can only perceive and act on the world within a spatial framework, i.e., all the external objects and events have a spatial stamp inherently associated with them.

Maps

Maps closely resemble picture-frames (Minsky 1985, 24.7)—a type of frame whose terminals are controlled by direction-nemes, and that is particularly suited to representing certain kinds of spatial information. Like picture-frames, maps are fed by direction-nemes; all maps share the same terminals, i.e., the same direction-nemes. Unlike picture-frames, each map is specialized to represent only one type of information, as it is reactive to a single stimulus. The main reason for this design choice is that maps act as incentive stimulus for motivations and behaviors, and therefore we don't need—or want—a general map that centralizes all the high-level sensory information. Maps incentive stimuli are binary vectors of the same type as those produced by direction-nemes. Abbott has two main categories of maps—tactile and visual, according to the nature of their stimulus. Maps contain binary terminals or slots corresponding to the different spatial positions they are concerned with—eight for tactile maps, four for visual—which indicate the absence or presence of the map's incentive stimulus at each position. To obtain this information, maps communicate with recognizers and direction-nemes. Each map sends its incentive stimulus to the corresponding (tactile or visual) recognizer as training signal, and the recognizer outputs the index of the winning output unit. The map then compares this index with the corresponding one stored by each of the direction-nemes it can communicate with. If the index is the same, the stimulus has been observed at that particular location and the concerned slot is set to one. Maps turn themselves "on" as soon as one of their slots is "on". The information at each terminal is finally assembled in a binary vector—an 8-bit vector in the case of tactile maps, a 4-bit one in that of visual maps. Abbott has five tactile maps—occupancy, water, food, living-being, and block maps—and six visual maps—the same as above except that the living-being-map is substituted by a visual-enemy-map and a visual-abbott-map.

Effectors

Effectors are agents that perform motor actions in the external world, with given intensities and directions. Abbott has three effectors: a hand, a foot, and a mouth. Each of them can perform a motor action in response to another agent's activation call—a behavior or an affective state. Hand's motor actions are open, close, push, and pull. Foot's motor actions are go-up, go-left, go-down, go-right (all with varying intensities), and stop. The mouth's only action is ingest.

Behaviors

Our behaviors resemble to the notion of competence modules in (Maes 1991). As in her case, we distinguish between consumatory and appetitive behaviors. Behavior agents correspond to consumatory behaviors—those contributing to the balance of resources that ensure a creature's self-sufficiency—while appetitive behaviors are realized by managers agents. Behaviors implement goal-achieving systems (McFarland 1995)—a system that can recognize a stimulus or goal (or at least change its behavior) when it encounters it, but the process of arriving at the goal is determined by the environment. According to McFarland (p. 421), "the main characteristic of goal-achieving behavior is preprogrammed recognition. The goal is achieved by being at the right place at the right time and recognizing this state of affairs." A behavior (Figure 3) is thus an agent characterized by: a preprogrammed incentive stimulus; a certain intensity and direction determined by both, environmental and internal factors; an effector with which the behavior can communicate; and a list of effects that the execution of the behavior has on the creature's physiological parameters, the first of which is the main effect of the behavior. The execution of a behavior either increases or decreases the values of diverse physiological parameters at every time step by an amount that is dependent on the behavior and proportional to its intensity. A behavior can be executed only if: (a) it has been selected by the motivational/emotional state of the creature; and (b) its incentive stimulus is being observed, i.e., the corresponding agent (map or sensor) is in an active state. When this second condition does not hold, the motivational system will either look for another behavior that can equally satisfy the current need, or call another agent that can make the incentive stimulus become active—a manager.

The fact of using the state of a map agent as incentive stimulus has important consequences with respect to how the affective state of the creature can affect its performance. Since the emotional state influences the way Abbott categorizes the world—by decreasing or increasing the vigilance threshold of recognizers—a tactile block map can become active in the presence of an Enemy, for instance, when it is "confused". Abbott would then, say, try to sleep on it, be bitten by the Enemy, and therefore feel pain. Abbotts (and Enemies) also feel pain whenever they try to execute a behavior in a way that is not allowed by the physics of the world, e.g., eat blocks or sleep on top of a triangle. Abbott's

```
(defclass drinking (behavior)
 ((effector :initform 'mouth)
  (stimulus :initform 'tactile-water-map
  (effects :initform
    '((+ creature-vascular-volume)
      (+ creature-adrenaline)
      (+ creature-blood-sugar)
      (+ creature-endorphine)
      (+ creature-energy)
      (- creature-temperature)
      ...))))
```

Figure 3: An example of behavior—drinking

Behavior	Stimulus	Main Effect
Attack	living-being	− adrenaline
Drink	water	+ vascular volume
Eat	food	+ blood sugar
Play	block, Abbott	+ endorphine
Rest	top flat block	+ energy
Walk avoiding obstacles	free space	+ temperature
Withdraw	pain	− pain

Table 3: Abbott's main behaviors.

current behaviors, their incentive stimuli and their main effects are shown in Table 3.

Managers

Manager agents—or societies of agents—implement very simple skills that can be seen to correspond to appetitive behaviors in the ethology literature, i.e., behaviors that make more likely that the conditions that allow to satisfy a basic need—the presence of a stimulus—hold. Examples of manager agents in (Minsky 1985) are Find, Get, Put, Grasp, etc. Abbott's main managers are the finder, look-for, and go-toward agents. Contrary to behaviors, managers do not have preprogrammed recognition of an incentive stimulus; rather, we have implemented them by taking advantage of the *exploitation principle*,"the act of one agency making use of the activity of another agency, without understanding how it works" (Minsky 1985, 4.5, 16.7). Managers can respond to any stimulus—or rather simulus (16.8)—that another agent "tells them" to attend to, or in other words, makes them "hallucinate". In our implementation, this simulus has the form of one or several agents—maps or sensors—that the manager will try to turn into an active state. Therefore, manager agents exhibit a goal-directed behavior (McFarland 1995), that is guided by an explicit representation of the goal to be achieved. Managers are exploited by proto-specialists, and they can exploit other managers, behaviors, or simple motor actions. This use of the exploitation principle allows us to avoid having to program a different behavior for each of the potential incentive stimuli (e.g., go-toward-food, go-toward-water, etc.), without however making use of classical variables. Indeed, ours can be seen as a form of "active" indexical-functional or deictic representation (Agre & Chapman 1990).

Primitive Affects

In the next section we briefly examine some theories concerning motivations and emotions in biological systems that have served as a source of inspiration for our design. Then, we present how SoM approaches this topic, to describe in subsequent sections the practical implementation of some of these ideas in Abbott.

A model of affects?

In a first approximation, motivations seem to be concerned with internal needs related to survival, whereas emotions are general terms used to design a complex set of phenomena at different levels—autonomic, visceral, skeleto-motor, cognitive, and social. If the nature and role of motivational states seem to be rather well agreed-upon, those of emotions are problematic.

Motivational states. Motivations are inferred internal states postulated to explain the variability of behavioral responses that cannot be exclusively accounted for by observable stimuli. These states or drives constitute urges to action based on bodily needs related to self-sufficiency and survival. Neurobiology attempts to reduce the problem of motivation to that of a complex reflex regulated by excitatory and inhibitory control mechanisms in response to multiple stimuli, some of them internal, some external. In general, motivations can be seen as homeostatic processes which maintain a controlled physiological variable within a certain range. An error detector generates an error signal—the drive—when the value of this variable does not match the ideal value or set point, which triggers inhibitory and excitatory controlling elements to adjust the variable in the adequate direction, such as feeding, drinking, or fleeing behaviors. Motivation varies as a function of deprivation. Like classical homeostatic systems, it involves arousal and satiation. External—incentive—stimuli, both innate and learned, are also able to motivate and drive behavior. Motivational states have three functions (Kandel et al.1995): (a) a directing function—they steer behavior toward, or away from, a specific goal; (b) an activating function—they increase general alertness and energize the individual to action; and (c) an organizing function—they combine individual behavioral components into a coherent, goal-oriented behavioral sequence.

Emotional states. The status of emotions is far from being clear. The development and expression of an emotion seems to imply three major components (Kandel et al.1995): (a) the recognition of an important event; (b) a conscious emotional experience in the cortex that mediates outgoing signals to peripheral structures; and (c) reflexive autonomic and visceral responses. Diverse theories have been proposed according with the causality relation they establish between the second and the third of these elements, but basically all of them agree in seen emotion as a "story" that the brain concocts to explain bodily reactions, Schachter-Damasio's "constructive" hypothesis (Schachter 1964; Damasio 1994) being the most widely accepted nowadays. The mechanisms that put in relation the different components of emotions are less well understood than those of motivations, as it is their role in behavior selection and adaptation. The homeostatic model does not seem completely adequate in this case, in particular the notions of arousal and of activation as its indicator. Contrary to activation theories, that state a mere correlation between the amount of hormone released, amount of neural excitation, and amount of emotional arousal, (Pribram 1984) proposes emotional activation as an indicator of a change in configuration of neural and endocrine activity with respect to the habitual stable baseline of the organism. As for its relation to motivational states, he attributes to each mechanism a complementary role in homeostasis—while motivation is concerned with the operations of appetitive processes that try to activate action as a response to deprivation, emotion is derived from processes that try to stop ongoing behavior, i.e., it is concerned with satiety processes of reequilibration. Tompkins views emotions as the primary innate biological motivating mechanism, since drives have insufficient strength as motives and need to be amplified by affects: "The affect system is the primary motivational system because without its amplification, nothing else matters, and with its amplification, anything else *can* matter. It thus combines urgency and generality" (Tomkins 1984, p. 164). This generality of time, object, intensity, and density of emotions are not the consequence of learning, but rather the structural innate features that make learning possible. But if emotions show this generality, what accounts for the activation of different affects? He proposes three variants of a single principle: stimulation increase, which activates both positive and negative affects such as startle, fear, and interest; (high) stimulation level, which only activates negative emotions such as distress or anger; and stimulation decrease, which only activates positive emotions such as joy.

Proto-specialists

Infants seem to have very few and clearly differentiated emotions, which are mostly related to basic bodily needs. They seem to be always in one well-defined state, that demands all their attention. They also switch states and activities very easily, as if unable to maintain their attention in one activity for a long period in the face of novel stimuli or new internal needs. These primitive emotional states Minsky calls proto-specialists—"genetically constructed subsystems responsible for some of an animal's "instinctive" behavior" (Minsky 1985, 16.3). Proto-specialists control what happens in an infant's brain. As children grow older, the context and their own experience teaches them to control these proto-specialists and to feel and behave as appropriate in every circumstance. In Abbott we have distinguished between two types of proto-specialists—motivations and emotions—as they present some differences with respect to action selection and control.

Motivations

We have basically adopted the homeostatic approach to model motivations. As shown in Figure 4, these agents are characterized by: a controlled variable, the set point and the normal variability range of which are defined by the corresponding sensor that tracks its real value; an incentive stimulus that can increase the motivation's activation level, but cannot trigger it; an error signal or drive; and a satiation

```
(defclass hunger (motivation)
 ((controlled-variable :initform 'blood-sugar)
  (stimulus :initform 'visual-food-map
  (drive :initform '(+ blood-sugar))
  (satiation :initform
   '(+ set-point variability))))
```

Figure 4: A motivation example—hunger.

Motivation	Drive
Aggression	decrease adrenaline
Cold	increase temperature
Curiosity	increase endorphine
Fatigue	increase energy
Hunger	increase blood sugar
Self-protection	decrease pain
Thirst	increase vascular volume
Warmth	increase temperature

Table 4: Abbott's motivations and their drives.

criterion. Table 4 shows Abbott's motivations with their corresponding drives.

Each motivation for which its feedback detector produces an error signal receives an activation level proportional to the magnitude of the error, and an intensity calculated on the basis of its activation level. Emotions can modify these levels, as we will see in next section. The motivation with the highest level becomes then active, and tries to organize the creature's behavior so as to satisfy its drive. First, it will look for the behavior(s) that can contribute most to its satisfaction—those whose main effect coincides with the drive. If none is found, it will select a list of behaviors that can contribute to it to a lesser extent. If more than one behavior is selected, all of them are kept to try to opportunistically execute the first whose incentive stimulus is observed. If the behavior(s) cannot be executed, its sends a failure message back. Then the motivation activates the finder agent, providing it with its own stimulus—the agent that the finder must try to turn active—and the intensity of the urge, which will be transmitted by finder to the agents it switches on—other managers, behaviors, or motor actions. In the case the behavior becomes active, its is executed with a given intensity—that of the urge—which has an impact on the values of some physiological variables. The way in which the behavior contributes to the satiation of the drive (and to the modification of other variables) depends on the intensity with which it is executed. For some behaviors, such as withdraw or attack, the intensity determines the strength of the motor actions; for others, the duration of the behavior—how many time steps it will last, provided that no external event (e.g., an Enemy's bite) or internal body state make other motivation more urgent. After an interruption, a creature can return to its previous motivation if it is still strong enough.

Emotions

An emotion is an agent that amplifies (or modifies) the motivational state of a creature and its perceived bodily state. It is characterized by: an incentive stimulus; an intensity

Emotion	Triggering event
Fear	presence of enemy
Anger	accomplishment of a goal menaced or undone
Happiness	achievement of a goal
Sadness	inability to achieve a goal
Boredom	repetitive activity
Interest	presence of novel object or event

Table 5: Innate external stimuli triggering emotions.

proportional to its level of activation; a list of hormones it releases when activated; a list of physiological symptoms; and a list of physiological variables it can affect. Due to their double aspect of specific and general mechanisms, emotions cannot be activated only by innate stimuli—be they drives or external events. Emotional states can be activated and discriminated by:

- External events, either an object or the outcome of a behavior. These events can be either innate (Table 5) or memorized (not yet in Abbott).
- General patterns of stimulation which provoke different types of changes in physiological variables. This is a general activation principle, which makes that the same emotion can be felt in different circumstances. For instance, a sustained abnormal high level of any variable activates the anger agent. This way, emotions help controlling homeostatic processes characterizing motivations.
- Particular patterns of physiological variable values, which in turn allow to distinguish between emotions activated by the same general mechanism, such as fear (high heart rate and low temperature) versus interest (low heart rate).

Since Abbott is an infant, it is always in a clear emotional state. We use thus a winner-takes-all strategy for emotion selection that applies the above activation principles in the following order. An external event is the strongest one, and can decide the emotional state by itself (at this stage). If none is observed, the second one is used for selection. Since it often selects more than one possible emotion, the third one is used to discriminate. At present, the selected emotion influences the action selection mechanism in two main ways. First, it can modify–increase or decrease—the intensity of the current motivation, depending on the particular effect of the hormone it releases, and as a consequence the intensity of the behavior to be selected (e.g., an angry creature executes motor actions with more strength, as glutamate is released). In extreme cases, this can prevent the execution of the behavior. Previous work by (Brooks & Viola 1990) implementing Kravitz's model of hormonal control of behavior in lobsters (Kravitz 1988) used hormones to bias behavior selection in a six-legged robot, controlling this way the gross behavior of the robot; however, hormones did not modify individual behaviors or lower level motor actions. Second, it modifies the reading of the sensors that monitor the variables the emotion can affect, therefore altering the perceived bodily state (e.g., in an euphoric emotional state, the 'happiness' agent releases endorphine, which reduces the perception of pain).

Action Selection

The action selection loop can be summarized as follows. At every time step:

1. The activation level of all agents and their activation state are (re)set to 0.
2. Both the internal variables and the environment are sensed, objects "subliminally" recognized, maps built. Not all this information will be attended to by Abbott, but only those pieces that are relevant to its motivational state.
3. Motivations are assessed and the effects of the creature's emotional state computed. The motivation with the highest activation is selected.
4. The active motivation selects the behavior(s) that can best satisfy its drive—a consumatory behavior if the incentive stimulus is present, an appetitive one otherwise.

Conclusions and Future Work

The basic agents we have presented make our creature self-sufficient and autonomous, fit to survive in its dynamic environment, to make rapid choices that lead to the satisfaction of its needs and to take advantage of what the world offers to it, or to look for it if needed. It shows both, goal-oriented and opportunistic behaviors; it is able to keep working on a task long enough to get a need satisfied, without neglecting what is going on in the world (e.g., a hungry Abbott looking for food will stop to drink if it begins to be also thirsty and water has been detected), or other more urgent needs that could arise (e.g., Abbott will stop a certain activity to avoid an Enemy's bite if this latter is considered more important). But like a very young child, or a simple animal, this is not for very long. We would like to make this creature "grow", both by learning to control its proto-specialists in a way closer to "adult emotions", and by learning things about its world and its own behavior that allow it to acquire some more complex problem-solving skills. Affects constitute an excellent basis to build on. In particular, as far as learning is concerned, our model of emotions provides a means to have different reward and punishment mechanisms. Many more agents need to be added yet. In the first place, we need adequate memory agents that make learning possible. We have started investigating a model of memory based on K-lines (Minsky 1985, 8.1) and their related controlling agents that allow Abbott to remember previous partial mental states that were useful in a given situation for some reason. Again, motivations and emotions constitute a key factor in determining what has to be remembered and why. The implementation of this model will be our next step.

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