# How to Determine the Utility of Emotions

**Matthias Scheutz**
Artificial Intelligence and Robotics Laboratory
Department of Computer Science and Engineering
University of Notre Dame, Notre Dame, IN 46556, USA
mscheutz@cse.nd.edu

## Abstract

In this paper, we describe a new methodology for determining the utility of emotions. After briefly reviewing the status quo of emotional agents in AI, we describe the methodology and demonstrate it by showing the utility of "anger" for biologically plausible foraging agents in an evolutionary setting.

## Background on Emotions and AI

Evidence from psychology (Frijda 1986; Izard 1991; Scherer, Schorr, & Johnstone 2001), neuroscience (Damasio 1994; LeDoux & Fellous 1995; Panksepp 2000; Hamm, Schupp, & Weike 2003), and ethology (Lorenz & Leyhausen 1973; McFarland 1981) suggests that emotions play several crucial roles in biological organisms. Especially in humans, they seem to be deeply intertwined with cognitive processing (e.g., they can bias problem solving strategies in humans (Bless, Schwarz, & Wieland 1996; Schwarz ) or help to evaluate a situation quickly (Kahneman, Wakker, & Sarin 1997; Damasio 1994; Clore, Gasper, & Conway 2001)). Finally, and most importantly, emotions are crucially involved in *social control* (Frijda 2000; Cosmides & Tooby 2000) ranging from signaling emotional states (e.g., pain) through facial expressions and gestures (Ekman 1993) to perceptions of emotional states that cause approval or disapproval of one's own or another agents' actions (relative to given norms), which can then trigger corrective responses (e.g., guilt). Yet, there is not even agreement among emotion researchers about how to construe *basic emotions* or whether the concept is coherent (Ortony & Turner 1990; Griffiths 1997).

The difficulties with emotion concepts are also reflected in AI, where different forms of emotions have been been investigated to varying degrees ever since its beginnings (e.g., (Toda 1962; Simon 1967; Pfeifer & Nicholas 1982; Dyer 1987; Pfeifer 1988)). Over the recent years, various "believable synthetic characters and life-like animated agents" (e.g., (Bates 1994; Hayes-Roth 1995; Maes 1995; Lester & Stone 1997; Rizzo *et al.* 1997)), "emotional pedagogic agents" (e.g., (Gratch 2000; Shaw, Johnson, & Ganeshan 1999; Lester *et al.* 1997; Okonkwo & J.Vassileva 2001; Conati 2002)), "emotional virtual agents and robots" (e.g., (Bates, Loyall, & Reilly 1991; Velásquez 1999; Michaud & Audet 2001; Breazeal 2002; Arkin *et al.* 2003)), and "computational models of human emotion" (e.g., (Eliott 1992; Cãnamero 1997; Wright 1997; Allen 2001; Marsella & Gratch 2002)) have been proposed.[1] Yet, there are divergent views among all these researchers about what it means to implement emotion in agents (e.g., (Ventura & Pinto-Ferreira 1999; Wehrle 1998; Picard 2001; Scheutz 2002a)).

Most of this work in AI has focused on what could be called *effect models* of emotion. Effect models implement only overt, observable effects of emotional behavior. They are intended to get the "input-output mapping" of a given behavioral description right. In the extreme case, such a mapping could be as simple as that employed in an animated shopping agent which displays a surprised face if the user attempts to delete an item from the shopping basket. Many architectures of so-called "believable agents" (e.g., (Hayes-Roth 1995; Scheutz & Römmer 2001; Rizzo *et al.* 1997; Loyall & Bates 1997) for simulated agents and (Shibata & Irie 1997; Breazeal 1998; Velásquez 1999; Michaud & Audet 2001; Murphy *et al.* forthcoming) for robots) are part of this group, where the primary goal is to induce the belief in the human observer that the agent is in a particular emotional state.

The main problem with effect models is that they are silent about the role of emotion in agent architectures. They may or may not actually implement emotional processes to achieve the desired overt behaviors. And if they do, the implemented states are often labeled with familiar terms, without specifying how the implemented states differ from those usually denoted with these terms (McDermott 1981; Scheutz 2002a). A state labeled "surprise", for example, may have very little in common with the complex processes underlying notions of "surprise" in humans and various animals (i.e., the violation of a predicted outcome (Ortony, Clore, & Collins 1988; Macedo & Cardoso 2001)), if it is functionally defined to be triggered by loud noises (Velásquez 1997a; 1997b) (for such a state, "startle" would be the more appropriate label). Effect models are, therefore, inadequate for determining the utility of emotions in agent architectures.

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[1] This list is only a brief excerpt of the recent literature and by far not complete, see also (Trappl, Petta, & Payr 2001; Hatano, Okada, & Tanabe 2000; Pfeifer 1988).

*Process models* of emotion, on the other hand, are applicable as they are intended to model and simulate aspects of emotional processes (typically in humans) as they unfold (Peschl & Scheutz 2001), following predictions of psychological or neurological theories of emotion (Scherer 1993; Panksepp 1998; Ortony, Clore, & Collins 1988)). Process models are much more complex than effect models, given that they focus on the internal processes of an agent's control system, and are typically only implemented in simulated agents (e.g., (Wright 1997; Marsella & Gratch 2002; Cãnamero 1997; Allen 2001; McCauley & Franklin 1998)).

The problem with current process models is threefold: for one, they do not provide or use a conceptual framework to characterize the implemented emotional states (i.e., what kind of state it is they implemented and what it takes in general to implement such a state), nor do they investigate variations of such states sytematically. And most importantly, they typically do not evaluate emotional states with respect to their utility (neither by varying architectural parameters nor by comparing them to other implementations of the same task). Hence, the potential of the states, other than to be present in a particular model, remains unclear.

## Evaluating the Utility of Emotional Architectures

We proposed a methodology that allows for an objective evaluation of the utility of emotions, which consists of a four step process: (1) emotion concepts are analyzed and defined in terms of architectural capacities of agent architectures (Sloman 2002). (2) Agent architectures with particular emotional states (as defined in (1)) are constructed for a given task, for which also a performance measure is defined. (3) "Experiments with agent architectures" (Pollack *et al.* 1994; Hanks, Pollack, & Cohen 1993)) are carried out with the so-defined emotional agents (either in simulations or on actual robots) and their performance is determined for a predetermined set of architectural and environmental variations. The outcome then is a *performance space* that corresponds to the varied parameters. The last two steps are repeated with agents implementing non-emotional (or, in general, other) architectures. (4) All resulting performance spaces are then compared, in particular, with respect to the agents' *performance-cost tradeoffs*, i.e., their performance taken relative to the (computational) cost necessary to maintain and run the instantiated architecture. The last point is crucial as it may well be that emotional agents do not perform better than non-emotional ones on a given task in absolute terms, but that they do much better in relative terms, i.e., with fewer resources (which is usually believed to be the case by emotion researchers).

We have applied this methodology in various settings and tasks and found, for example, that *emotional action selection* can be very effective in the competition for resources in hostile multiagent environments (Scheutz 2000; Scheutz, Sloman, & Logan 2000; Scheutz under review). Emotional control mechanisms performed much better in a variety of foraging, survival, and object collection tasks in environments with little to no structure than agents with much more sophisticated deliberative control systems (including $A^*_\epsilon$ planning (Pearl 1982), plan executing methods with error feedback, and goal management mechanisms) if the "cost of deliberation" is taken into account (Scheutz & Logan 2001; Scheutz & Schermerhorn 2002; 2003). Furthermore, we found that emotional states like "fear" and "aggression" (Scheutz 2001)) are likely to evolve in a variety of competitive multiagent environments. Finally, in studies of the potential of *emotion expression and recognition for social control* we found that emotions can have a beneficial regulatory effect in social groups (Scheutz 2002b) and lead to superior conflict resolution strategies (Scheutz & Schermerhorn forthcoming).

In the following, we will briefly demonstrate this methodology.

## Architectural Requirements and Mechanisms for Emotional Control

We start with a brief characterization of emotional states and show the difference between simple and complex versions in terms of architectural requirements and mechanisms.

Simple *emotions* are caused by some disparity between an agent's desire state and the state of the environment, and are themselves causes for actions that are intended to change the state of the environment so as to make it agree with the agents' desires (Sloman, Chrisley, & Scheutz forthcoming).[2] A simple "anger state", for example, is caused by the perception of a potentially threatening environmental condition (e.g., the approach of another agent) and causes the agent to change its behavioral dispositions so as to deal with the threat (e.g., to fight). It can be implemented by a controller integrating the frequency of perceptions of the threat over a given time interval (Scheutz 2001; under review), e.g., using the differential equation $\partial Output/\partial t = Output \cdot (G_{sensor} \cdot S_e - G_{discount})$, where $Output$ is the output of the controller, $G_{sensor}$ is the gain for the sensor input and $G_{discount}$ is the discount value for the past output.

More complex emotional states (such as "worrying about whether a grant proposal can be completed in time") can be caused by a combination of perceptions and processes internal to the agent (e.g., results of complex deliberations about the utility of trying to achieve a particular goal compared to alternatives).

Such emotions may include any of the following components and possibly more (based on the analysis in (Beaudoin & Sloman 1993; Ortony, Clore, & Collins 1988; Wehrle & Scherer 2001) and others):

1. an elicitor (e.g., *the grant proposal*)
2. an eliciting condition (e.g., *the possibility of (1) not being completed by the deadline*)
3. criteria for the evaluation of (2) based on various factors such as beliefs, goals, norms, standards, tastes, attitudes, etc. (e.g., *completing (1) by the deadline is crucial to research career*)
4. an evaluation of (2) in terms of (3) (e.g., *(2) is undesirable*)

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[2] Often, emotions are themselves the states that the agent does or does not desire.

5. possible causes for (2) (e.g., *deadline approaching rapidly, work progressing too slowly, etc.*)
6. a hedonic attitude towards (2) (e.g., *displeasure*)
7. a measure of the urgency to act on (1) given (2) (e.g., *urgent*)
8. a set of strategy to cope with (2) (e.g., *cancel meetings, focus attention on (1), etc.*)
9. a set of motivations to be instantiated based on (8) (e.g., *being able to continue one's research, being able to fund students, etc.*)
10. a set of emotions to be instantiated based on (4) through (8) (e.g., *distress*)
11. the selected motivation (if any) based on (4) through (8) (e.g., *being able to continue research*)

Consequently, complex representational and processing mechanisms (e.g., frames (Minsky 1975) or scripts (Schank & Abelson 1977) combined with pattern matching and rule instantiation mechanisms) are required for architectures to be able to support complex emotions.

## The Utility of Anger in Biological Settings

This section illustrates how a simple form of "anger" can be implemented in a biologically plausible way in a schema-based agent architecture and used to influence the agent's *action selection*. Furthermore, it demonstrates the systematic exploration of the performance space defined by this architectures by systematically varying architectural parameters. Comparing the performance space of "angry agents", for simplicity sake, with those of "non-angry" agents in a survival task, the (relative) benefits of emotional control can be determined. The left part of Figure 1 shows a schema-based architecture (Arkin 1989; Arbib 1992) for a foraging agent that needs to find food and water in a hostile multi-agent environment in order to survive. The small crossed circles indicate gains of schemas that are taken as architectural parameters: the degree to which an agent is attracted to food ($gf$), to water ($gw$), and to other agents ($ga$).

The bold-face circle labeled "Anger" represents a schema that is only present in the "angry agents" (non-angry agents do not have it nor the associated links). It is connected to an "alarm schema" (Acol), which is triggered if an agent touches another agents and implements a simple emotional control circuit as described above by virtue of influencing the gain of a motor schema that changes the agent's propensity to fight other agents: the higher the output of the controller, the more likely the agent will fight (for details see (Scheutz under review)).

The right part of Figure 1 shows the performance space for both agent kinds using "average number of survivors after 10000 cycles" (averaged over 40 simulation runs) as the performance measure. As can be seen from the graph, angry agents reach a global maximum at $ga = 10$ and $gw = 30$ (which is statistically marginally significant: t-test, $p < 0.09$ for $alpha = 0.05$). Consequently, in the kinds of environments studied, being (capable of being) "angry" does prove useful for survival.

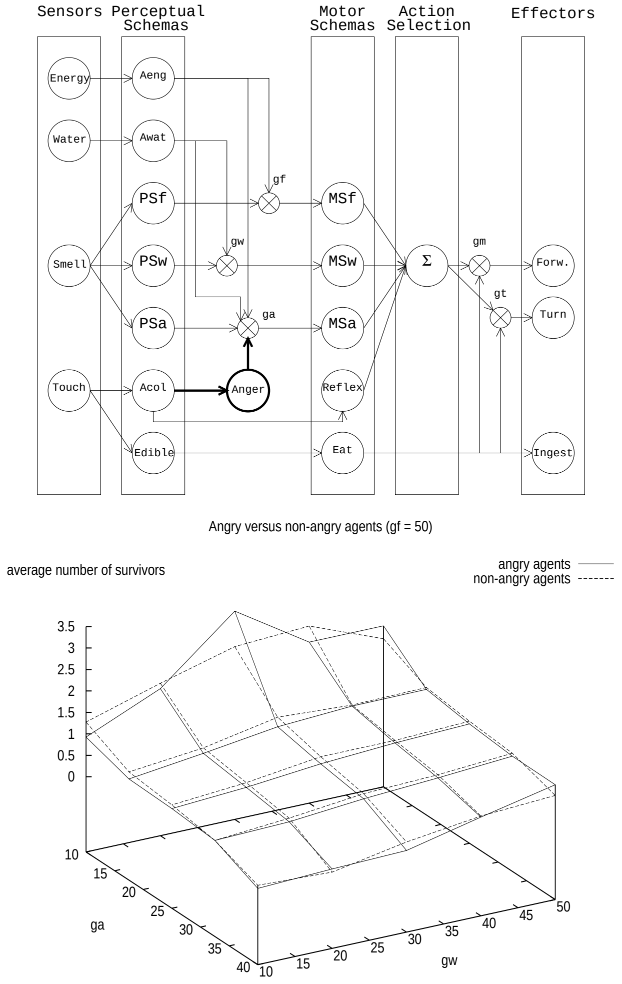

Figure 1: Left: a schema-based emotional architecture for simulated agents. Right: a performance comparison of emotional and non-emotional agents along two architectural dimensions.

The experimentation and evaluation method demonstrated here with a simple example can be straightforwardly applied to more complex agents, tasks and environments (as we have done in the past (Scheutz & Schermerhorn 2002; 2003)). It is also worth mentioning that the emotional subsystem of the proposed architecture was based on what emotion researchers presume to be the functional organization of the emotional "fear/anger system" in many animals, given that animals are typically taken to exhibit either a "fight" or a "flee" behavior (e.g., (Berkowitz 2003)). Since fight and flee behaviors are very directly linked with their emotional makeup (fear will lead to flee, anger to fight behavior), these two emotions are typically taken to be incompatible, i.e., they cannot be present at the same time, e.g., (Anderson, Deuser, & DeNeve 1995)). While the above architectures are even more restrictive in that an agent cannot have fear and anger at different times, only a few simple modifications need to be applied to the architecture to allow an agent to be capable of having both kinds of emotions (either an addition of a simple switch system that flips the sign on the gain in certain circumstances would allow the agent to have fear sometimes and anger other times, or another emotional controller could be added as mentioned above allowing for fear and anger to be present at the same time, an architecture that would find support from recent results, e.g., (Berkowitz 2003)).

## Conclusion

The methodology proposed in the paper will allow researchers to study the utility of emotions in a very general way that applies to biological organisms and aritifical agents alike. It is built on a systematic way of defining emotional states in terms of capacities of agent architectures and exploring their utility for the control of agents in experiments with agent architectures by systematically varying architectural (and environmental) parameters for the given task. By comparing the resulting performance spaces of emotional and non-emotional agents (in particular, using performance-cost tradeoffs), we believe that it will be possible to answer important open questions about the utility of emotions for both biological and artificial agents in a great variety of tasks.

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