Using Emotional Memories to Form Synthetic Social Relationships

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ABSTRACT

We present a simple, biologically-inspired mechanism by which synthetic entities can be made to form social relationships with each other. We describe an interactive multi-agent system, based on the social behavior of the gray wolf (*Canis lupus*), that features this mechanism of social relationship formation. This installation, shown at SIGGRAPH 2001, allowed several participants to direct semi-autonomous wolf pups in a virtual pack. In our mechanism, an entity has an emotional state that is affected by its interactions. It is able to recognize a social partner as the same individual on successive encounters. It learns an association between interacting with that social partner and its own current emotional state – an "emotional memory" of the partner. When the entity again encounters the social partner, its emotional memory of that partner influences its current emotional state. The emotional state, in turn, affects its expressive range of behavior. Finally, in the wake of each interaction, the entity revises its model of its emotional relationship with the social partner. Our mechanism for social relationship formation could be of use in a variety of domains, for example, creating believable virtual characters, building multi-agent systems, and designing human-computer interfaces.

Keywords

multi-agent systems, emotion, social behavior, virtual characters, human-computer interaction

1. INTRODUCTION

A social relationship is a remembered construct by which an individual keeps track of its interaction history with another individual, and allows that history to affect its current and future interactions with that individual. Context preservation [10] is the essence of social behavior – behaving differently toward individual social partners, rather than interacting with all entities in the same way. The Synthetic Characters Group at the MIT Media Lab, headed by Professor Bruce Blumberg, has created an interactive multi-agent system based on the behavior of packs of gray wolves (*Canis lupus*). Among other abilities, our virtual wolves are able to form social relationships with each other (see Fig. 1). In this paper, we present the mechanism by which our wolves form their relationships.

Fig. 1: Two social computational systems exchange a glance.

The essence of our mechanism of social relationship formation involves emotion, perception, and learning. Each virtual wolf maintains an emotional state that is affected by its interactions with the world. A wolf is able to perceive the identity of its pack mates, recognizing them as distinct individuals. It forms an "emotional memory" of each of its pack mates after its first interaction with that individual. When it again encounters that individual, the emotional memory influences its current emotional state, so that it can "pick up where it left off" with regard to its emotional relationship. Finally, at the end of each interaction, it revises its emotional relationship with that social partner.

An interactive installation featuring our model of social relationship formation was presented in the Emerging Technologies section of SIGGRAPH 2001. In the installation, entitled *AlphaWolf*, three participants help direct the actions of virtual wolf pups in a simulated litter. By howling, growling, whining or barking into a microphone, each participant can tell her pup to howl, dominate, submit or play (see Fig. 2). The actions that the pup takes affect emotional relationships that the pup forms with its littermates and with the adults of the pack. The pups autonomously maintain these relationships and display them by means of the emotional style in which they take the actions

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suggested by the participants. The relationships are also displayed to the participant through dynamic buttons at the top and bottom of each screen, which show each of the social partners of that wolf in a dominant or submissive pose that reflects how the participant's pup views that partner.

Each puppy grows up from pup to adult size over approximately five minutes. By the end of the five-minute interaction, the pups, guided by the users, have worked out their places in the social order of the pack. Participants evidently found the installation "mesmerizing" [20]. We have included with this paper a short video describing the *AlphaWolf* installation (see Appendix A).

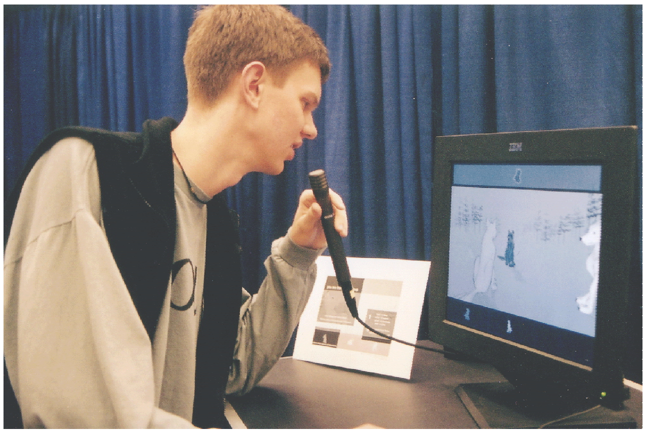

Fig. 2: A participant interacts with the virtual wolf pack.

At the heart of the *AlphaWolf* installation is our biologically-inspired mechanism for social relationship formation. Social relationships allow animals to benefit in a variety of ways. They reduce the potential for conflict within social groups by negotiating the allocation of scarce resources. [31] They allow individuals to learn more effectively from their social partners. [25] They facilitate cooperation and coalition formation. [23, 51] They enable reciprocal altruism. [36, 48] They promote friendly relations and reduce social distance. [30] They allow certain species (e.g., dogs) to live with humans and thrive as a result of that close contact. [11]

Animals provide an excellent example of autonomous interacting entities. In particular, the social behavior of mammals enables multiple complex individuals to interact repeatedly over relatively long time scales. One focus of our group's research is to explore computational mechanisms, inspired by mammalian social behavior, by which autonomous entities can interact with each other. This paper presents an emotional-memory based mechanism that we have found to be simple and effective at enabling computational entities to form social relationships.

In the remaining sections, we first discuss previous research that is relevant to our project, addressing natural and computational models. We then provide a more detailed description of our mechanism itself. Following that, we present the results of our research. Next, we discuss three possible domains of research and industry to which social-relationship-forming computational entities might be applicable. Finally, we conclude with a summary of the main points of our mechanism and its usefulness.

2. RELATED WORK

There are two main areas of research that we have found to be essential to the creation of the *AlphaWolf* project – the biology of our natural model, the gray wolf, and computational models of social behavior, emotion and emotional learning.

2.1 Natural Model: The Gray Wolf

We have chosen a specific natural example, the social behavior among members of a pack of gray wolves, as the inspiration for our implementation for several reasons. First, they manifest distinct social phenomena that are complex enough to be interesting, yet clear enough to provide direction for our simulation. Second, wolves are closely related to the domestic dog, for which we have a strong conceptual and technical base as a result of previous installations that we have done featuring virtual dogs. [4, 8] Finally, the social behaviors of wolves are similar enough to those of humans that some of the lessons we learn from wolves might be relevant to human social behavior and simulation. Having a concrete model from nature provides a steady direction for our research, and allows us to judge our success at each step of the way. In the next several paragraphs, relying heavily on the work of biologists who study wolves, we describe some elements of wolf social behavior.

In their natural environment, gray wolves form complex social groups called packs. The core of most packs is a family – a breeding pair of adults, their puppies, and sometimes a few adult offspring of the breeding pair. [32, 34] The average pack size is approximately 7-9 individuals, but some packs may contain more than 25 wolves. Large packs may contain more than one breeding pair. Most young wolves disperse from their natal pack in their second or third year to find a mate and begin their own pack. [32]

Wolves communicate with each other in a variety of ways. They have a wide array of vocalizations, including "whimpering, wuffing, snarling, squealing and howling". [54, p. 68] They express their intentions and their motivational and emotional states through body posture as well. For example, a mother wolf assumes different postures with her pups than she does with her mate. [17] The sense of smell is also integral to wolf social behavior (e.g., scent marking). In wolves, as in most social creatures, communication is central to the social relationships that they form.

Wolf social behaviors appear to be derived, over the course of behavioral and physiological development, from other behavioral patterns exhibited by wolves. [41] For example, there are two main types of submission that wolves exhibit – passive submission and active submission. Passive submission involves a wolf lying on his side or back, exposing the ventral side of his chest. The ears are held close to the head, and the tail is tucked between the legs. These behavioral patterns bear a resemblance to infantile behaviors involved in reflex urination[1]. [17] Active submission involves a crouched posture with backward directed ears, and licking or pecking the mouth of the dominant wolf. This behavior is very similar to the food-begging behavior of pups[2].

[1] Newborn pups only urinate and defecate when their mother licks their belly. By consuming the excrement, she keeps the den clean. [17]

[41] Similarly, dominant behaviors appear to be a form of "ritualized fighting". [21]

2.2 Computational Models

The work of other researchers has provided an invaluable source of inspiration and ideas that have shaped our approach to building synthetic entities who can form social relationships. In this section, we present relevant research in the simulation of social behavior, emotion, and emotional learning.

2.2.1 Social Behavior

Various researchers have studied synthetic social systems from natural models, including flocking in birds [39], schooling in fish [49], virtual gorillas [1], chimpanzees [46] and primate-like artificial agents [24]. Our research differs from these efforts in our focus on learning and emotion as key components of social competence.

Certain areas of artificial intelligence and robotics require several individuals to work together to achieve a common goal. The topic of multi-agent systems has become a significant subset of the research being done in autonomous agents (e.g., International Conference on Multi Agent Systems [28]). Robot soccer competitions are another venue that requires the coordination of multiple entities. [45] Mataric and her research group have done extensive work on multi-robot systems. [22, 29] Many others have also done relevant research into the interactions of multiple autonomous entities (e.g., [14], [35], Bonabeau and others at the Santa Fe Institute [5, 10], etc.).

2.2.2 Emotion

In order to simulate emotional virtual characters, it is necessary to choose a computational representation that captures the necessary range of emotional phenomena. Much research has already been done both in understanding emotions and in simulating them computationally. Darwin's ideas about emotions [13] form the basis for much of modern research into understanding emotions scientifically.

For the *AlphaWolf* project, we considered two main emotional paradigms – a dimensional approach and a categorical approach. The dimensional approach (e.g., [33, 38, 40, 42, 44]) maps a range of emotional phenomena onto explicitly dimensioned space. Various researchers have implemented versions of the dimensional approach; for example, Breazeal [6] used a 3-dimensional space (Arousal, Valence, Stance) to give affective tags to occurrences perceived by her robot, Kismet. These tagged events in turn affected the emotional state of the robot.

The categorical approach separates emotional phenomena into a set of basic emotions – for example, fear, anger, sadness, happiness, disgust and surprise [16]. Ekman's model provided the basis for an implementation by Velasquez [50]; others (e.g., [19]) have also implemented categorical models. Breazeal's Kismet, mentioned above, exhibited a categorical set of emotions that influenced both its behavior system and the motor system. Various other researchers have explored the way in which emotion affects behavior (e.g., [9]). For a far more comprehensive discussion of emotional models in computational systems, the reader is directed to Rosalind Picard's book, *Affective Computing* [37].

2.2.3 Emotional Learning

Our emotional memory mechanism is based on the "Somatic Marker Hypothesis" presented by Damasio [12]. This hypothesis proposes that people (and animals) attach emotional significance to stimuli that they encounter in their environment, and then re-experience that emotion when they encounter those stimuli on future occasions. Various researchers have addressed the significant role that emotions play in animal and human learning e.g., [7, 18, 27]. Other researchers have implemented models of emotional learning or memory in non-social domains, for example "affective tags" [52], "emotional memories" [50], and the work of [26], [19] and [2].

3. MECHANISM

The mechanism by which our virtual wolves form social relationships with each other involves models of emotion, perception, and learning. The relationships in turn are expressed through the behavior of the wolves. This section elaborates on each of these elements.

Fig. 3: The black pup is dominant to the white pup.

3.1 Emotion

The model of emotion in the *AlphaWolf* installation as presented at SIGGRAPH is exceedingly simple – a single floating-point value called *dominance* (see Fig. 3), which varies from 0.0 to 1.0. (Dominance is a subset of a more complex dimensional representation presented by Mehrabian and Russell [33].) Each wolf's dominance value is affected by his interactions (see Fig. 3). For example, being bitten causes a wolf's dominance to drop, and being the target of another wolf's submission causes a wolf's dominance to increase.

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[2] When the pack has young pups, the adult wolves travel away from the den to hunt, and carry back meat in their stomachs to feed the pups. Upon their return, the pups perform stereotypical food-begging behavior, in which they crouch in front of an adult and lick or peck at the adult's muzzle. This pup behavior incites the adult to regurgitate the meat, which the pups excitedly consume. [41]

The wolf's emotional state affects the style in which the wolf takes its actions. For example, a wolf with a current dominance value near 0.0 might walk with his tail between his legs and his ears back, while a wolf with a higher dominance value will hold his tail and ears erect. Our system blends between example animations to give an expressive range to the behavior of the wolves. [15]

In addition, when a wolf is behaving autonomously, its emotional state affects what actions it chooses to take towards its social partners. For example, a submissive wolf might choose to roll over on its back, while a dominant wolf might growl.

3.2 Perception

The second major section of our system is the way in which the wolves perceive each other. The wolves are able to tell their pack mates apart in order to form different relationships with each of them. They also know when they are in an interaction with each other. (For example, being bitten is a much different experience than seeing someone else get bitten.)

The wolves disambiguate among their social partners by means of a unique identification tag. While it may seem simplistic for entities to "know" each other by means of a unique ID, real wolves appear to be able to distinguish each other by scent. [3]

From the point of view of an individual wolf **A**, an interaction with a partner **B** begins when **A** has **B** as its Object of Attention, and perceives that **B** is reciprocally attending to him. For **A**, the interaction ends when it changes its Object of Attention so that it is no longer attending to **B**, regardless of whether **B** is still attending to **A**. In fact, **A** would have no way of telling whether **B** was still attending to it, since that information should be unavailable to it unless **B** is its Object of Attention.

To summarize, a character is able to identify individuals, to have an Object of Attention, and to assess when it is the Object of Attention of another individual.

3.3 Learning

The first time individual **A** ends an interaction with individual **B**, it forms an "emotional memory" of **B**. Our model of an emotional memory contains three pieces of information – the unique ID of **B**, an emotional value, and a confidence value.[3] When the emotional memory is first formed, the emotional value stores the emotion that **A** was feeling at the time its interaction with **B** ended. Since the interactions that **A** has had with **B** may have altered its emotional state over the course of their interaction, forming the emotional memory at the end of the interaction rather than at the beginning will reflect the emotional content of the relationship more accurately.

The next time **A** switches to have **B** as its Object of Attention, its emotional memory of **B** will influence its current emotional state in proportion to its confidence in that model. The formula by which the emotional memory is applied to the current emotional state is:

$$\mathbf{E' = (C \times E_m) + ((1 - C) \times E)}$$

where E' is the wolf's new emotional value, C is the confidence value of the emotional memory being applied, E is the wolf's emotional value prior to the application of the emotional memory, and E_m is the emotional value that is stored in the emotional memory.

At the end of each successive interaction, **A** revises its emotional memory of **B**. Upon revision, two of the three elements of an emotional memory are changed – confidence and emotional value. We revise confidence before we revise the emotional value so that the change in the emotional value will reflect the change in confidence, thereby preserving the effect of deviations from the expected emotional interaction.

The formula by which confidence is revised is:

$$\mathbf{C' = C + ((Min(C, 1\text{-}C)) \times (T_c - |E_m - E|) \times L)}$$

where C' is the new confidence value for the emotional memory, C is the previous confidence, T_c is some confidence threshold between 0 and 1, E_m is the emotional value that is stored in the emotional memory, E is the wolf's current emotional state, and L is a learning rate. (Multiplying the learned component by the Min of C and 1-C effectively clamps the confidence value to between 0 and 1, and helps to polarize relationships.)

We then revise the emotional value stored in the emotional memory:

$$\mathbf{E_m' = (C \times E_m) + ((1 - C) \times E)}$$

where E_m' is the new emotional value stored in the wolf's emotional memory, C is confidence, E_m is the emotional value in the memory prior to the revision, and E is the wolf's current emotional state.

These equations represent a simple (but for our purposes perfectly serviceable) implementation of the mechanism described. For more elaborate social behavior, any or all of these equations might be made more complex.

The emotional memories described here function as remembered constructs by which an individual keeps track of its interaction history with another individual. They allow that history to affect its current and future interactions with that individual. These two elements satisfy the definition of a social relationship that we offered at the beginning of this document.

3.4 Expression

Each wolf's emotional state affects what it does and how it does it. The most sublimely complex representation of a social relationship isn't of much use without an equally expressive range of behavior. Our system uses the work of Marc Downie [15] to let our characters have dynamic expressive ranges. Downie's expressive motor system allows a wolf's current emotional state to affect the style in which the wolf behaves (e.g., run dominantly or submissively). Since emotional memories affect the wolf's current emotional state, they also affect the style of the wolf's behavior. While the motor system is not the focus of this paper, it is an important element of the social relationship system in the wolves.

[3] Although the social relationship mechanism that we describe treats *individuals* as emotional significant stimuli, a stimulus does not have to be an individual – only a *causative entity* [12]. Forming emotional memories of other kinds of stimuli (e.g., the presence of two wolves at the same time) could result in other kinds of relationships (e.g., alliance formation).

4. RESULTS

In order to demonstrate that our mechanism creates functional and believable social relationships among computational entities, we have evaluated it in two ways. The first evaluation involves a synthetic experiment that compares packs of virtual wolves featuring our mechanism to packs without it. The second evaluation results from the response of people who interacted with the *AlphaWolf* installation at SIGGRAPH 2001.

4.1 Polarization of Relationships

In order to evaluate our mechanism of social relationship formation we have conducted a synthetic experiment that measures the polarization of relationships among packs of wolves with varying degrees of our emotional memory mechanism. More polarized relationships (i.e., those with a greater disparity in the dominance of the individuals involved) are less likely to result in long, mutually-dangerous fighting [17] "Fighting within the wolf pack is reduced through social hierarchy." [17, p. 147] In our experiment, we sought to determine if polarization increased, since polarization leads to a reduction in conflict.

Our methodology for this experiment involved creating virtual packs with different strength emotional memories and comparing the polarization of their relationships. Fig. 4 presents data from a simulation we performed on packs of non-graphically-embodied wolves. Each pack began with 10 virtual wolves on a 7x7 grid world. At each time step, wolves randomly moved to an adjacent space, or remained in their current space. If a wolf moved onto a space occupied by another wolf, the two wolves had a probabilistic dominance interaction that favored wolves according to their dominance. Prolonged interactions reduced the dominance of both wolves. The loser of the interaction moved away, and the winner's dominance increased. In addition, each pack had a few members added and removed at random during the run.

Fig. 4 shows the results of this experiment. The vertical axis measures the average dominance disparity among all the dyadic relationships in the pack. For example, if **A** feels 0.9 dominant to **B**, and **B** feels 0.1 dominant to **A**, then the disparity in this dyadic relationship is $|0.9 - 0.1| = 0.8$. The horizontal axis represents time.

The bottom three runs (drawn in dark gray) were our control case, showing packs who could not form emotional memories of each other. Their dominance value was only affected by their interactions and their previous dominance value. The average dominance disparity is unsteady and averages approximately 0.3.

The middle three runs (drawn in light gray) featured wolves with a half-strength version of the emotional memory mechanism. When these emotional memories were applied, they only had 50% of the full impact on the wolf's emotional state. These runs achieved equilibria between 0.5 and 0.6, and were more stable than the control case.

The top three runs (drawn in black) show packs who featured a full emotional memory mechanism. These packs have average dominance disparities between 0.8 and 1.0, and tend to increase over time.

The additions and removals of wolves from the packs are only visible in those packs with fully-enabled emotional memories, where the average dominance disparity drops occasionally but rapidly recovers. In the control packs, this variability is lost in the noise of their graphs. The continued stability of the pack structure in the wake of these changes in pack make-up demonstrate that our relationship formation mechanism is robust and adaptable.

These data show that the average dominance disparity is increased and stabilized by emotional memories. Greater dominance

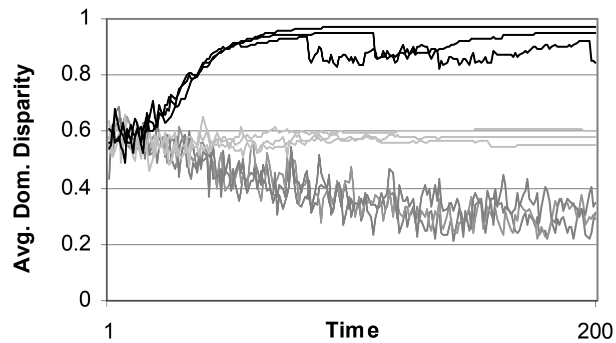

Fig. 4: Three packs without emotional memories of each other (dark gray, bottom), three packs with partial emotional memories (light gray, middle), and three packs with full emotional memories (black, top). Emotional memories appear to polarize and stabilize relationships, thereby reducing the potential for conflict.

disparity is the definition of more polarized dominance relationships. By enabling more polarized relationships, our emotional memory mechanism reduces the potential for conflict in groups of computational entities.

4.2 User Interactions

The second way in which we evaluated our mechanism was by observing the people who interacted with the *AlphaWolf* installation at SIGGRAPH. While we were unable to collect statistical information, the great majority of the 500-1000 people who interacted with the installation appeared to become immersed in their interactions with their pups. We show a few representative interactions in the short video that accompanies this paper.

In the *AlphaWolf* installation, many people were a little uneasy about the prospect of howling into a microphone in front of a crowd. In order to introduce people to their pups and to the microphone, we caused the puppies to start off asleep (see Fig. 5); any noise into the microphone would wake up a puppy. By the time most people had awakened their pup and engaged in their first interaction with another wolf, they appeared to be immersed in the interaction and unconcerned about making any manner of wolf noise in front of a crowd. This transformation from anxious observer to enthusiastic participant causes us to believe that the *AlphaWolf* installation provided participants with a compelling interaction, in large part because of the social relationships being formed among the pups.

People appeared to find the wolves' behavior, emotions, and social relationships to be explicable. The wolves "made sense", given what people know about dogs and wolves. The fact that our virtual wolves seemed plausible to participants suggests that the wolves were meeting people's expectations about how wolves should behave in response to social and emotional situations.

People often empathized with their pups, getting excited when the pups met new pack mates or "feeling bad" when somebody else dominated them. People mirroring the affect of their pups is a case of *social referencing*. [43] The gusto with which many interactors engaged their virtual wolves gives us hope that our mechanism for virtual social relationships resonates with human social competence.

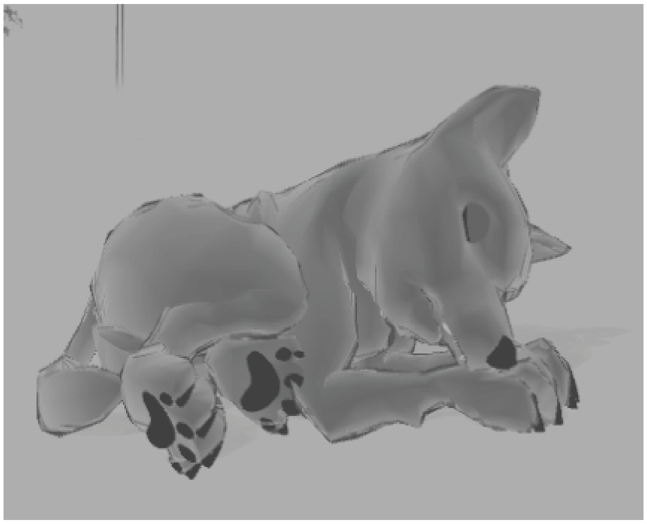

Fig. 5: A pup rests between social interactions.

During and after their interaction with *AlphaWolf*, many people told stories about their pups to their companions (or to anyone who would listen, sometimes!) These stories usually focused on the relationships that their pup had developed with the other wolves. The emotions and relationships that people attributed to the wolves in the stories were quite similar to what the virtual wolves were actually "feeling" (computationally). People's ability and desire to tell these stories suggests that our wolves' relationships were both clear enough for people to interpret and interesting enough for them to care.

Many people appeared to form new social relationships with other people at the *AlphaWolf* installation. For example, two people whose pups were in the same litter would often talk to each other during the interaction or afterwards. The fact that people formed social relationships more readily in the presence of the virtual wolf pack suggests that the installation created a social atmosphere. This could be considered an instance of the psychological phenomenon of *social facilitation,* [53] and suggests that people viewed the wolves as social entities.

5. APPLICATIONS

There are several main areas of application for our mechanism of synthetic social relationships. Virtual characters, multi-agent systems and human-computer interfaces could all benefit from the ability to form social relationships.

5.1 Virtual Characters

Being able to form social relationships could make virtual characters more convincing to human audiences and interactors. In order for people to relate to a character, that character needs to share some of the characteristics of people. Stories abound with social and emotional characters. Virtual characters with social abilities would seem more familiar to people. Those characters could make stories (e.g., animated movies) and other interactions (e.g., computer games) more enjoyable and immersive experiences.

5.2 Multi-Agent Systems

As we described above, social relationships are beneficial to many species of animals. Multi-agent systems could derive many of the same benefits from social relationship formation that animals do. Social relationships could help systems negotiate the allocation of scarce resources. They could enable individuals to learn from each other in dynamic ways. They could facilitate the coordination and control of large-scale multi-robot systems. Finally, they could allow multi-agent systems to integrate with pre-existing human social relationship structures (e.g., a family) in much the same way that animals do (e.g., pets).

5.3 Human-Computer Interface

Both of the above applications point toward a more general reason for computational entities to be able to form social relationships. Ultimately, humans are inherently social creatures; allowing our computational systems to understand and work with our sociality (in at least some cases) will make those systems more functional and our interactions with them more rewarding.

6. CONCLUSION

We have presented an emotional-memory-based mechanism by which computational entities may form social relationships with each other. This mechanism incorporates models of emotion, perception, and learning. Our mechanism has been implemented in the *AlphaWolf* installation, which was exhibited in the Emerging Technologies section of SIGGRAPH 2001.

The mechanism is quite simple, and is derived from biological studies of animal behavior (e.g., [32]) and emotion (e.g., [12]). Since it is simple, it should be applicable to a wide array of potential applications, including those that require real-time performance. Since the model is derived from biological research, it should integrate with other biologically-inspired models. As our results show, our mechanism can be used to allow the dynamic introduction of new entities to a pre-existing social structure.

The broader issue of computational entities with the ability to form social relationships is important for several main disciplines – for example, virtual characters, multi-agent systems, and human-computer interfaces. From smarter "good guys" and "bad guys" in video games, to more convincing virtual actors for movies and television, to toys that form relationships with the kids who play with them, to educational aids, to more robust multi-agent systems, social behavior can contribute to robust functionality and to the "illusion of life" [47]. Social relationships may help create more functional multi-agent systems, as well as systems that are more intuitive and immersing for people who interact with them.

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APPENDIX A: VIDEO

We have included with this submission a video showing the installation as it was presented at SIGGRAPH 2001. We hope that this video demonstrates that our characters formed social relationships, and that people found the relationships compelling. The video is also available on the web at:

http://www.media.mit.edu/~badger/alphaWolf/resources.html

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