EMOTION AS AN ENABLER OF CO-OPERATION

Martyn Lloyd-Kelly[1], Katie Atkinson[1] and Trevor Bench-Capon[1]
[1]*Department of Computer Science, The University of Liverpool, Ashton Street, Liverpool, United Kingdom*
{*mlk5060, katie, tbc*}*@liv.ac.uk*

Keywords: Emotion: Multi-Agent Systems: Agent Models and Architectures: Simulation.

Abstract: We investigate the emergence of cooperation through emotions. We use agents playing an iterated Prisoners' Dilemma game, and show how the emotions of gratitude and anger enable cooperation to emerge as a response to the emotional state of the agents without reference to payoffs or history. We investigate the effect of different thresholds for these emotions to change behaviur on individual performance and systems scores.

1 INTRODUCTION

The interplay and differences between rationality and emotion has long been the subject of philosophical and psychological debates. Emotions appear to be particularly significant as determinants of behaviour in co-operative relationships (Fessler and Haley, 2003). We take the view that emotions play a functional role, following (Frijda, 1987).

Our contribution therefore is to model emotions so that they are able to play a functional and beneficial role in allowing agents to determine how to respond to information received from the environment. We use agents playing an iterated Prisoners' Dilemma game (Axelrod, 1984), and show how the emotions of gratitude and anger enable cooperation to emerge as a response to the emotional state of the agents without reference to payoffs or history.

The concept of emotion is hotly contested and no real consensual definition has been found. The idea that an emotion is characterised by a collection of physiological responses is noted as early as (James, 1884) but other psychologists such as (Baumeister et al., 2009) take the view that emotions are functional in that they provide motivations for future behaviour and can act as evaluative tools to explain behaviour that is exhibited in certain situations. We adopt the functional view, and although we recognise that physiological factors are important, we do not consider this aspect here.

A logic of individual emotions for agents has been developed by Steunebrink et al. (e.g (Steunebrink et al., 2007)). The take small subsets of the 22 emotions defined in the Ortony, Clore and Collins model (the "OCC model" (Ortony et al., 1988)). They too adopt a functional view of emotions and prescribe actions that follow after an emotion has been elicited. We adopt the idea of implementing small subsets of emotions from this much larger set as it allows a concentration of effort with respect to the emotions chosen, faithful modelling of these emotions and recognition that different emotions may have different functional roles. The OCC model itself is a framework of emotions which serves as one of the standard psychological frameworks that is well adapted for use in computer science. The applicability of the OCC from a computer-science standpoint and its extensive use by others is the primary reason that we chose to use the model.

Our work furthers the functional use of emotions as behavioural mediators and takes inspiration from Axelrod's *Prisoner's Dilemma* tournament. One of the general rules Axelrod suggested for constructing a *successful* strategy i.e. one that maximises the individual's score and the total score of the system, states that strategies should not be overly complex; in some cases, strategies were so elaborate that they might as well have been acting randomly. It is this rule that allows us to distinguish between our emotional agent and a rational agent. Axelrod's tournament contains rational agents that determine their behaviour on the basis of past, present and future payoffs; in contrast, our emotional agent has no concept of payoffs, they are simple reactive agents inspired by the notions outlined in (Brooks, 1991). Essentially, the emotional agent's behaviour is a product of its emotional *character* and its *current emotional state* with the layer of rationality associated with consideration of past and future payoffs stripped away. This concept of a continuously updated current emotional state is what motivates the design of a novel agent architecture as other architectures suggest actions to perform in the present by consulting emotional responses to the outcomes of actions performed in the past when faced with the same situation.

While rational, self-interested agents can enable co-operation, (Frank, 1988) argues that such behaviour can be self-defeating and emotional individuals are much more likely to establish and maintain co-operation. The importance of gratitude in co-operation is explained by (Berg et al., 1995) who illustrates that alturistic financial loss to an individual can be tolerated if the other party offers *gratitude* for this action. Also, (Fehr and Gächter, 2002) shows that alturistic punishment resulting from *anger* is essential in order for co-operation to flourish. It is important to note here that the rate at which anger/gratitude is elicited may vary and so we introduce the idea of emotional *characters* (described in detail in section 2) in order to take into account these various rates. Consequently, we have chosen to focus our efforts on implementing gratitude and anger and we investigate how these emotions can influence the total score of the system.

Table 1: Emotional agent character (ch.#) descriptions.

		If defecting, #co-ops required to co-op.		
		1	**2**	**3**
If co-op, #defects required to defect.	**1**	Ch.1	Ch.2	Ch.3
	2	Ch.4	Ch.5	Ch.6
	3	Ch.7	Ch.8	Ch.9

2 EXPERIMENTS

The experiments were a set of iterated Prisoners' Dilemma games played as a tournament as in (Axelrod, 1984). This was realised in the *Tileworld* environment (Pollack and Ringuette, 1990). Tileworld was used because further experiments will exploit more features of the environment as we move to consider populations of agents. Agents are initially defectors (liars) or cooperators (truth tellers), Agents were given two emotions; gratitude and anger. If the other player cooperates, gratitude is experienced, and if it defects anger is experienced. Agents have different *characters* corresponding to how intense an emotion must be before it changes behaviour. Agents can thus vary in tolerance (the number of defections required to make anger suffcient move from cooperation to defection) and responsiveness (the number of cooperations required to make gratitude sufficient to give rise to cooperation. Thus there are nine possible characters, as shown in Table 1.

Payoffs were standard: two cooperators each received 3, two defectors 1 each and otherwise the defector received 5 and the cooperator 0, and assigned to agents by a mediation agent. Every round comprised 200 games, although this was not known to the agents, to avoid exploitation of this information.

The strategies used were: an *emotional* agent; a *tit-for-tat* agent (which cooperates on the first round and then repeats the opponents previous move, the most successful strategy in Axelrod's tournament); a *mendacious* agent which always defects; a *veracious* agent which always cooperates, a *random* agent which cooperates or defects with equal probability; a *joss* agent which plays tit for tat, but with a 10% probability of random defection; and a *tester* agent which defects on first round n, if the opponent co-operated on round n then the agent co-operates on rounds n + 1 and n + 2 and defects on round n + 3. If, the opponent defects on round n, the agent plays tit-for-tat for the rest of the game. The emotional agent used each of the nine characters in turn.

We wished to explore which emotional characters would be most conducive to success. Success would be considered both from the perspective of individual agents and from the perspective of the system as a whole.

3 RESULTS AND DISCUSSION

With respect to the question of whether the tit-for-tat strategy can be replicated by emotional response, the results obtained from the *Tileworld Dilemma* are clear-cut. An initially co-operative emotional agent with character 1 replicates the behaviour of the rational tit-for-tat agent exactly. To demonstrate this, we present tables 2 and 3 which contain the average individual scores of the initially co-operative emotional agent with character 1 and the tit-for-tat agent versus the random and joss agents respectively. We have chosen to only present the results from playing these two agents as the behaviour of the random and joss agents is non-deterministic whilst the behaviour of every other agent in the simulation is completely deterministic. Therefore, playing against these two agent types gives the greatest potential for disparateness to exist between the scores of the emotional agent and tit-for-tat agent. Consequently, by presenting these two graphs as evidence we can assert that the behaviour of the tit-for-tat agent is exactly replicated by the emotional agent with the set-up described.

Table 2: Individual scores of intially co-operative emotional agent with character 1/tit-for-tat agent vs. random agent.

	Game Number				
Agent	**1**	**2**	**3**	**4**	**5**
Emotional	462	466	448	445	424
Tit-for-tat	462	466	448	445	424

Table 3: Individual scores of intially co-operative emotional agent with character 1/tit-for-tat agent vs. joss agent.

	Game Number				
Agent	**1**	**2**	**3**	**4**	**5**
Emotional	219	213	213	255	242
Tit-for-tat	219	213	213	255	242

As can be seen in tables 2 and 3, the scores of the emotional agent and tit-for-tat agent exactly overlap showing that their behaviour is undisputedly the same. Explanation of these results is elementary: whereas the tit-for-tat agent responds to its payoffs, the emotional agent responds to information sent to it (as detailed in section **??**). Therefore, both agents react in exactly the same way to inputs that are of different types but which will arise from the same situations. To clarify, if the tit-for-tat agent observes that it has scored 0 in a round when it is currently co-operating or 1 if is it defecting, then it can safely infer that the opponent is defecting therefore its behaviour will switch to defection. Similarly, if the program mediator informs an emotional agent with character 1 that the opponent has defected, then the emotional agent will defect immediately in the next round.

We now address the question of whether any other emotional character set-up is more successful with respect to maximising the total system score when playing against periodically defecting strategies than the set-up previously discussed. To determine this, we measure success in terms of total system payoff or, more specifically, the aggregated average total system score (the sum of each average total system score achieved by an agent). As demonstrated in table 4, we find that an initially co-operative agent with character 7 - the most tolerant and most responsive - offers the greatest aggregated total average system score so a more successful strategy does indeed exist. To explain this outcome we have identified three criteria which must be considered and discussed in turn: fairness, readiness to co-operate and tolerance.

We define *fairness* as the extent to which all members of a system are equal; in the context of the *Tileworld Dilemma*, the fairest system possible is one where each agent has an equal score at the end of each game. Systems that are maximally fair are achieved by agents who employ strategies that are quick to punish and defect (as noted by Axelrod). If such a strategy is used by both players and a cycle of defection is locked into on the first round, then each player's score at the end of a game will be 200. Whilst this is individually fair, the final system score is relatively low. For a player who wishes to achieve system fairness and maximise the score of each player then the best possible score that can be achieved is 600, which is achieved by players immediately locking into a co-operation cycle on the first round and maintaining this for a full game. We observe that the only agent pairs to do this are those that co-operate initially, those that are quick to punish/defect and those that always co-operate, no matter what i.e.:

- Initially co-operative emotional agent with any character and tit-for-tat agent.
- Initially co-operative emotional agent with any character/tit-for-tat agent and veracious agent.

Table 4: Intially co-operative emotional agent aggregated average total system scores.

Character	**Aggregated Average Total System Score**
1	5230.80
2	5069.80
3	4979.80
4	5774.80
5	5241.80
6	5140.80
7	5895.60
8	5328.80
9	5235.80

However, as mentioned above, such behaviour does not maximise the system's score when agents that seek an advantage, such as the random, tester and joss agents, are also present (see table 4); from the system's view, achievement of a good system score requires two goals to be achieved:

- Co-operation must be established between the members of the system.
- Co-operation must be maintained between the members of the system.

The score of a system is increased if agents lock into cycles of co-operation quickly and break them slowly. Therefore, readiness to co-operate and tolerance of defection are *both* important factors. If we compare the average total scores for an initially co-operative emotional agent of character 7 to an initially lying emotional agent of character 7 (see table 5) then the effect of being quick to co-operate becomes clear.

If an agent initially defects, co-operation cycle establishment is delayed, resulting in lower total system scores as it becomes more likely that the players will establish cycles of defection. Conversely, the quicker an agent is to co-operate and forgive its opponent, the quicker a co-operation cycle is established. Therefore, by co-operating initially an agent is more likely to find concurrent co-operation in a round and establish a co-operation cycle early in the game (important as the number of rounds in a game is finite); table 6 clearly illustrates this point. The same pattern also holds true for initially defective/co-operative emotional agents with characters 1-3/4-6.

It is not enough to simply establish a cycle of co-operation; in order to maximise the score of the system then the established co-operation cycle must be maintained, even when the other player temporarily defects (as self interested agents will tend to do). If we consider the scores of emotional agents with characters 1, 4 and 7 displayed in table 4, we observe that as an agent becomes more tolerant to defections, the greater the aggregated average total system score becomes. If we then consider the individual scores which are aggregated together for the initially co-operative emotional agent of character 7 (see table 7) we can see that character 7 sacrifices system fairness by taking a reduced score in order to maximise the total system score. This phenomenon of *tolerance* is the crucial difference between character 7 and characters 1 and 4. Therefore, we can see that increased levels of tolerance are integral to maximising the total system score, if playing against agents that periodically defect.

By being tolerant an agent enables the maintenance of a co-operation cycle. Whilst the fairest system possible entails the deployment of a strategy that is quick to reward and quick to punish, such behaviour breaks co-operation cycles quickly causing lower total system scores to be achieved. By one agent continuing to co-operate in the face of defection the system scores five rather than two, so that when the defector decides to co-operate again and it is met with co-operation, a total system score of six is achieved. A drawback to becoming more tolerant however is suffering a reduction in the tolerant agent's individual score; table 8 illustrates the extent to which this occurs.

Table 8 offers some interesting results, especially if we consider those scores that pertain to the emotional agent playing against the random agent. We observe that the average individual score of each agent decreases as tolerance to defection increases yet, as tolerance is increased the rate at which the average individual score decreases slows; this can also be observed in figure 1 and table 9. The salient point here is: when the opponent is not a veracious or tit-for-tat agent, there is a trade-off between fairness and total system score. From table 8 we can calculate this trade-off exactly: for every point earned by the system, the emotional agent must lose two points from its individual score. This raises the question: how much of a reduction in fairness is acceptable to achieve these system gains?

Table 8: Average individual score of initially co-operative emotional agents with character 1, 4 and 7 when played against random, tester and joss agents.

	Opponent		
Character	**Random**	**Tester**	**Joss**
1	449	533	228.4
4	398.2	465	417.2
7	372.4	443	449.4

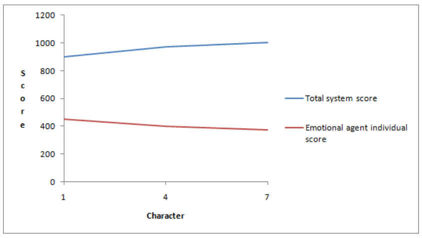

Figure 1: Total system score achieved when initially co-operative emotional agents of characters 1, 4 and 7 plays against a random agent plotted against the individual score of the initially co-operative emotional agents.

Table 9: Percentage of total system score owned by the initially co-operative emotional agents of characters 1, 4 and 7 when playing aginst the random agent.

	%Total Score Owned	
Character	**Emotional**	**Random**
1	49.9	50.1
4	40.9	59.1
7	37.1	62.9

It is worth mentioning that the situation is different when the initially co-operative emotional agents

Table 5: Comparison of the average total scores of an initially co-operative emotional agent of character 7 and an initially defective emotional agent of character 7.

	Opponent					
Ini Dis.	**Mendacious**	**Veracious**	**Random**	**Tit-for-tat**	**Tester**	**Joss**
Co-op	409	1200	1002.8	1200	1111	972.8
Defect	400	1199	1001.8	1198	400	968.6

Table 6: Comparison of the average total scores for intially co-operative emotional agents with characters 7, 8 and 9.

	Opponent					
Character	**Mendacious**	**Veracious**	**Random**	**Tit-for-tat**	**Tester**	**Joss**
7	409	1200	1002.8	1200	1111	972.8
8	409	1200	942	1200	1089	488.8
9	409	1200	902	1200	1036	488.8

Table 7: Average Individual scores of initially co-operative emotional agents with characters 1 and 7.

	Opponent$_j$					
Character$_i$	**Mendacious**	**Veracious**	**Random**	**Tit-for-tat**	**Tester**	**Joss**
1	199_i, 204_j	600_i, 600_j	449_i, 451_j	600_i, 600_j	533_i, 533_j	228.4_i, 233.4_j
7	197_i, 212_j	600_i, 600_j	372.4_i, 630.4_j	600_i, 600_j	443_i, 668_j	449.4_i, 523.4_j

with characters 1, 4 and 7 play against a joss agent. As the emotional agents become more tolerant, the emotional agent's average individual score increases (see figure 2 and table 8). This is due to the joss agent's behaviour, which enables the maintenance of co-operation cycles in the face of rare, one-off, periodic defections.

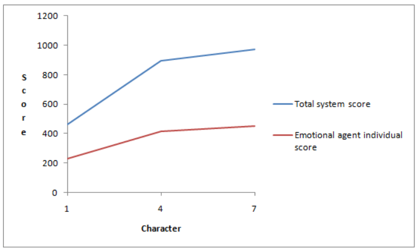

Figure 2: Total system score achieved when initially co-operative emotional agents of characters 1, 4 and 7 plays against a joss agent plotted against the individual score of the initially co-operative emotional agents.

In order to determine when the trade-off between an individual's score and the system's score becomes unacceptable we need to make note of a number of thresholds. To do this we consider a number of various maximal and minimal scores that can be achieved/tolerated for/by each entity in the *Tileworld Dilemma*; table 10 below illustrates these values:

Table 10: The differing threshold values present in the *Tileworld Dilemma* along with how they are derived and their maximum/minimum values.

Threshold Value	**How Derived**	**Max.**	**Min.**
Average Agent 1 Score (A1)	A1 Individual Score	1000	0
Average Agent 2 Score (A2)	A2 Individual Score	1000	0
Average System Score	A1 + A2	1200	400
Average Fairness Score	A1/A2	1	0

The best possible score that an individual agent can achieve is 1000 whilst the worst is 0, achieved when a mendacious strategy is played against a veracious strategy. An individual score of 0 is the worst scenario possible; yet, the lowest acceptable score that can be achieved by a single agent is 200, caused by two players locking into a defection cycle for a whole game. The best possible score from the system's perspective is 1200, achieved when two agents co-operate initially and lock into a co-operation cycle for a whole game and the worst score is achieved by two agents locking into a defection cycle for a whole game, leading to a total system score of 400. The rating of fairness ranges from 0, to 1, the closer to 1 the more equal the two player's scores are.

Therefore, if we take the above discussions into consideration we can say that an initially co-operative emotional agent with character 7 is more successful than an initially co-operative emotional agent with character 1 due to its ability to quickly establish and maintain co-operation. Granted, the total system scores produced are not fairly distributed: against a random agent the system/fairness value for an initially co-operative emotional agent of character 7 is 0.59, whereas for an initially co-operative emotional agent of character 1 the system/fairness value is 0.99 (see table 10 for details on how fairness is calculated. Despite this, the system total achieved by an initially co-operative emotional agent of character 7 is much higher than that achieved by its less tolerant peers. It is conceivable that more tolerant agents will produce greater total system scores at the expense of fairness, but only until a certain point i.e. when their individual score passes below the threshold of 200; after this the trade-off becomes definitely unacceptable since consistent defection produces a better result and there are no individual gains from co-operating.

4 CONCLUSION

Our experiments have demonstrated that the rational behaviour exhibited by the tit-for-tat strategy present in (Axelrod, 1984) can be replicated by an initially co-operative emotional agent with character 1 i.e. an agent with a low anger threshold resulting in immediate punishment in response to defection and a low gratitude threshold resulting in immediate reward in response to co-operation. Furthermore, we have also shown that when playing against strategies that intersperse co-operation with periodic defection a readiness to co-operate and degree of tolerance are key characteristics that are required in order to maximise the total score of the system. However, by becoming increasingly tolerant and remaining just as ready to co-operate, one must expect to suffer a loss with respect to one's individual score. Consequently, such altruism is only demonstrated if it is worthwhile to do so.

Following on from this work, we have implemented and begun testing an extension to the *Tileworld Dilemma* entitled *Emotional Population*. This test-bed consists of a population of agents (338 in total) that are entirely emotional and capable of being initialised with individual characters in exactly the same way as described in this paper. The *Emotional Population* however incorporates into the existing emotion set consisting of anger and gratitude the additional emotion of admiration. Admiration has the potential to be elicited when an agent's neighbour obtains the highest individual score after n number of rounds, but, as with anger and gratitude, agents have varying degrees of sensitivity with respect to admiration. If admiration is elicited then the evaluating agent will change its initial disposition and emotional character to become more like the successful agent. Through this new scenario we aim to analyse which emotional characters become prevalent in a population and how, as well as investigating the conditions and number of initial co-operators/defectors must be present in a population before co-operation/defection becomes the dominant strategy used.

REFERENCES

Axelrod, R. (1984). *The Evolution Of Cooperation*. Basic Books, Inc.

Baumeister, R. F., DeWall, C. N., Vohs, K. D., and Alquist, J. L. (2009). *Does Emotion Cause Behavior (Apart from Making People Do Stupid, Destructive Things)?*, chapter 7, pages 119–136. Oxford University Press.

Berg, J., Dickhaut, J., and McCabe, K. (1995). Trust, reciprocity and social history. *Games and Economic Behaviour*, 10:122–142.

Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence*, 47:139–159.

Fehr, E. and Gächter, S. (2002). Altruistic punishment in humans. *Nature*, 415:137–140.

Fessler, D. M. and Haley, K. J. (2003). *Genetic and Cultural Evolution of Cooperation*. Cambridge, MA: MIT Press.

Frank, R. H. (1988). *Passions Within Reason: The Strategic Role of the Emotions*. W.W. Norton & Company.

Frijda, N. H. (1987). *The Emotions*. Cambridge University Press.

James, W. (1884). What is an emotion? *Mind*, 9:188–205.

Ortony, A., Clore, G. L., and Collins, A. (1988). *The Cognitive Structure of Emotions*. Cambridge University Press.

Pollack, M. and Ringuette, M. (1990). Introducing the tileworld: Experimentally evaluating agent architectures. In *In Proceedings of the Eighth National Conference on Artificial Intelligence*, pages 183–189.

Steunebrink, B. R., Dastani, M., and Meyer, J.-J. C. (2007). A logic of emotions for intelligent agents. In *22nd Conference on Artificial Intelligence*, pages 142–147.