An Agent-based Evolutionary Model of Leadership

Alexei Sharpanskykh
Artificial Intelligence Department
VU University Amsterdam
Amsterdam, the Netherlands
sharp@cs.vu.nl

Brian R. Spisak
Department of Social and Organizational Psychology
VU University Amsterdam
Amsterdam, the Netherlands
BR.Spisak@psy.vu.nl

Abstract— **Leadership is a robust human behaviour, which occurs rapidly in groups. It is argued that leadership provides a solution to coordination problems in groups and allows maximizing group benefits while minimizing group costs. In this paper a novel, agent-based model of leadership is presented, which is based on recently emerging literature on the human evolution. The model advances on the traditional research on leadership by identifying fitness-relevant situation dynamics that remained consistent throughout human evolution to select for specific leadership and followership characteristics. Incorporating the mechanics of evolution and the associated environmental pressures accounts for the innate tendencies of human leadership and followership, and consequently yields an increased level of model validity. The application of the model is illustrated by two voting examples and an empirical study, which provide an indication of the model validity.**

Keywords – evolutionary leadership, agent-based simulation, social influence

I. INTRODUCTION

Leadership is a robust human behaviour. It is prevalent cross-culturally [5] and occurs rapidly in groups [17]. This universal and automatic nature of leadership has prompted researchers from evolutionary sciences to investigate if such a trait could have been naturally selected as a means of increasing the efficiency of group dynamics and ultimately fitness [18]. Such inquiry has led to a number of advancements in the understanding of the relationship between leaders and followers in the context of an evolutionary theory of leadership [13].

This theory advances on the existing research on leadership (such as trait-based [20], situation-based [16] and contingency theories [14,7]) by identifying increasingly accurate assumptions for modelling collective action.

Although evolutionary leadership is currently an active area of research in the field of social psychology, no existing formal computational model of evolutionary leadership in human groups is known to the authors. Such a model would be a useful tool to test the theory in a systematic and efficient manner, to explore diverse cases and scenario's by simulation and formal verification. To fill this gap, in this paper we propose a novel, formal, computational, agent-based evolutionary model of leadership. The agent paradigm has proved to be useful to analyse the social dynamics of groups. In contrast to system dynamics approaches [15], properties of a group of agents, such as leadership-followership relations, emerge from local (behavioural or cognitive) properties of individual agents and interaction between them. The bottom-up modelling perspective taken within the agent paradigm is well aligned with the assumptions underlying the evolutionary theory of leadership [13, 17, 18].

According to this theory, leadership-followership relations emerge in interaction between four components: (1) *a fitness-relevant situation*, (2) *context-specific leader traits*, (3) *the leader's projected image*, and (4) *the reinforcing message of the leader*. More specifically, the degree of influence of a (potential) leader on a (potential) follower is determined by how well the leader's traits fit an environmental situation (i.e., by the image of the leader perceived by the follower), by how well the leader's image fits the leader's message, and by how close is the leader's message to the follower's own beliefs. These dependences form the basis for a cognitive agent model proposed in this paper.

The application of the model is illustrated by three data-driven simulation studies. In two studies the model is used to reproduce trends in the voting behaviour of the body of electors in US presidential elections. In the third study the model has been applied in the context of an empirical study. The model predictions obtained by the simulation studies are consistent with the empirical data.

The paper is organised as follows. Theoretical background on evolutionary leadership, which forms the basis of the model, is considered in Section II. In Section III the formal cognitive agent-based model is presented. The application of the model is considered in Section IV. Section V concludes the paper.

II. THEORETICAL BACKGROUND

One of the earliest attempts to define leadership was done in trait-based theories [20], which identified particular 'leader-like' traits such as self-confidence. As a reaction to trait theories, particular situations that required leadership were considered in situation-based theories of leadership [16], suggesting that no one optimal leader existed to fit every type of situation requiring leadership. This was followed by a contingency model of leadership which synthesized these two theories to match particular traits with specific situations [14, 7]. Based on both the situational and contingency theories of leadership computational models were developed [2, 3].

The model proposed in this paper is based on the evolutionary contingency theory of leadership [13, 17], which advances on the existing theories by identifying highly fitness-relevant situation dynamics that remained consistent throughout human evolution to select for specific leadership and followership characteristics. Deconstructing leading and following dynamics to their fundamental components allows for the formation of adaptive assumptions that have been woven into human behaviour over millions of years of hominid evolution.

According to this theory, leadership-followership relations emerge in interaction between four components: (1) *a fitness-relevant situation*, (2) *context-specific leader traits*, (3) *the leader's projected image*, and (4) *the reinforcing message of the leader*. In the following the relations between these components are discussed in detail.

A fitness-relevant situation perceived by an individual in the environment is characterized by *hostility* and *variability* aspects. Environmental hostility is determined by the dynamics of intergroup relations. It is known that "raiding and trading" was (and is) a commonly reoccurring pressure between human groups [11], and indeed intense enough to alter human social behaviour [4]. The degree of environmental hostility determines which leader traits are required to resolve coordination problems efficiently. In particular, the constellation of leadership skills and traits required for exercising dominance over a group (e.g. status-seeking, risk-taking, and aggression) are quite different from those required for more prosocial cooperation (e.g. reciprocity, empathy).

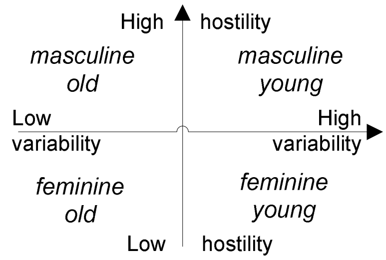
The degree of environmental variability is another prominent aspect of the situation dynamics from an evolutionary perspective. Oscillation of resource availability such as food and water supplies created fluctuations from times of stability to nomadic migrations [13]. Again, as with intergroup coordination problems, potential traits required to maximize stability (e.g. the experience and wisdom of age) differ from the requirements to physically lead group transitions and scout for new resource opportunities (e.g. the physical stamina of youth; [18]).

The aspects of situation dynamics perceived by individuals are characterized by *salience* and *arousal*. Salience is determined by the degree of awareness of an individual about an aspect. Arousal is determined by the strength of an emotional reaction (positive or negative) of an individual to an aspect. Arousal depends significantly on the fitness relevance of the situation for an individual. For example, the 9/11 attacks were arguably both high in salience and arousal for US citizens. This suggests that awareness was extremely focused on hostility in the environment, and the emotional urge to take action to reduce further cost was high.

It is assumed that when the aspects of a situation increase in salience and arousal, so does the activation of a discriminative heuristic decision process favouring the appropriate leadership prototype [19].

The concept of an evolved context-specific leadership prototype proposes that different leadership characteristics have been selected for at a biological level to fit the requirements of specific situation dynamics. For example, research has shown that hormones such as testosterone are linked with dominance tendencies [1] and likewise with masculine facial features and body structures [10]. In essence these outward biological manifestations may serve as a method for increasing the efficiency of followership behaviour by providing diagnostic information about a potential leader's ability to successfully organise favourable outcomes in particular situations. For example, *if* time of conflict, *then* select a masculine looking leader. Similarly, the age of a (potential) leader is an indicator of how efficient he or she will be operating in a dynamically changing environment. The fitting relations between the situational aspects and the leader traits are sketched in Figure 1. By such relations a (potential) follower creates a projected image of a (potential) leader, i.e., the perception of how well a (potential) leader fits the situation.

It is argued that evolved cognitive leadership prototypes presented in Figure 1 are still engaged in our psychology because the evolved group dynamics remain consistent even if the cultural exterior has become more complex [19].



Example of a figure caption.

Figure 1. Fitting relations between the situational aspects (on the axes) and the leader traits (in the quadrants)

Leaders may reinforce their influence on followers by communicating a message. The leader's message is the outward representation of their internal thoughts and motivations. The leader's message is incongruent when it does not fit the leader's perceived image. For example, it occurs when a leader perceived as having a feminine female image espouses a message of aggression and dominance. In this case the degree of influence on (potential) followers decreases. On the contrary, a congruent message reinforces the leader's influence. For example, it occurs when a feminine female leader communicates a message of keeping the peace and encouraging connectivity between groups.

To summarize, the degree of influence of a (potential) leader on a (potential) follower is determined by how well the leader's traits fit the environmental situation (i.e., the perceived image of the leader), by how well the leader's image fits the leader's message, and by how close is the leader's message to the follower's own beliefs. It is proposed that the closer the follower's beliefs to the leader's message, the more open the follower to the leader's message and influence.

In the following section the identified concepts and relations are formalised by a model.

III. FORMAL MODEL

The theory of evolutionary leadership described in section II was formalised by an agent-based model comprising three essential parts considered in this section: perception of a situation by an agent (section III.A); prototypical influence (section III.B), determined by the leader's image; and overall influence, taking into account the leader's message (section III.C).

A. Perception of a situation by an agent

Situation s perceived by agent a is characterized by two aspects: a *degree of hostility* $h_{s,a}(t)\in[0,1]$ and a *degree of variability* $v_{s,a}(t)\in[0,1]$. Each aspect is associated with a *degree of salience*: $sal_{h,s,a}(t)\in[0,1]$ and $sal_{v,s,a}(t)\in[0,1]$ and a *degree of arousal*: $val_{h,s,a}(t)\in[0,1]$ and $val_{v,s,a}(t)\in[0,1]$.

The perception of agent a of the salience of aspect x of situation s changes over time depending on the expressiveness of the environmental cues of the aspect ($salenv_{x,s,a}(t)$), the agent's arousal ($val_{x,s,a}(t)$), and the intensity of discussion on the aspect in the agent's group G:

$$sal_{x,s,a}(t+\Delta t) = sal_{x,s,a}(t) + \alpha 1(salenv_{x,s,a}(t)^{g_{x,s,G(t)}} - sal_{x,s,a}(t))\Delta t, \quad (1)$$

where $\alpha 1$ determines the sensitivity of the agent to the environmental changes.

The salience grows when the environmental cues of a situational aspect attract (positive arousal) or repel (negative arousal) the agent. In both cases the agent becomes more aware of the aspect. Group discussion also increases the agent's awareness. Both these tendencies are reflected in $g_{x,s,G}(t)$ from (1):

$$g_{x,s,G}(t) = \omega(1-|val_{x,s,a}(t)|) + (1-\omega)(1- \textstyle\sum_{b\in G,\, a\neq b} sal_{x,s,b}(t))/(|G|-1)) \quad (2)$$

The perception of agent a of arousal of characteristic x of situation s changes over time depending on the degree of fitness relevance of situation s for a, the degree of salience of the aspect, and the emotional influence from the agent's group G:

$$val_{x,s,a}(t+\Delta t) = val_{x,s,a}(t) + \omega 2(f_{x,s,a}(\beta 1,f1_{x,s,a}(t), f2_{x,s,a}(t)) - val_{x,s,a}(t))\Delta t, \quad (3)$$

where $\omega 2$ determines the emotional sensitivity of the agent for the situational aspect, $f_{x,s,a}$ is a combination function of form

$$f_{x,s,a}(\beta 1,x,y) = \beta 1(1- (1- x)(1- y)) + (1-\beta 1)xy,$$

used to combine in (3) the influence of the situational fitness relevance $f1_{x,s,a}(t)$ and the emotional influence of the group $f2_{x,s,a}(t)$, defined in the following.

The influence of the situational fitness relevance $f1_{x,s,a}(t)$ is defined by the fitness relevance $fr_{s,a}(t)$ intensified by the salience of aspect x of s:

$$f1_{x,s,a}(t)=sign(fr_{s,a}(t))|fr_{s,a}(t)|^{1-|fr_{s,a}(t)|sal_{x,s,a}(t)}, \quad (4)$$

Spread of emotions in a group is modelled as a social diffusion process [12]. To describe this process two parameters are introduced for each agent a: expressivity ε_{ab} with which a outputs emotions to an agent b and openness δ_{ab} for emotions from agent b. The aggregated emotional impact of group G on agent a is determined by:

$$f2_{x,s,a}(t)= \textstyle\sum_{b\in G,a\neq b} \varepsilon_{ba}\, \delta_{ab}\, infl(b,a,s,m,t)\, val_{x,s,b}(t)/ \textstyle\sum_{b\in G,a\neq b} \varepsilon_{ba}\, \delta_{ab}\, infl(b,a,s,m,t), \quad (5)$$

here $infl(b,a,s,m,t)$ is the overall influence of agent b on agent a described in Section III.C.

The higher the salience and arousal of the situational aspects, the better an agent realizes the need for an appropriate prototypical leader. To quantify the fit between a situation and the traits of a leader the notion of *prototypical influence* is introduced.

B. Prototypical influence

A potential leader is characterized by $age\in[0, 1]$ (the higher the older) and the degree of masculinity $mas\in[0, 1]$ (the higher the more masculine). As argued in section II, perception of the salience and arousal of the situational aspects creates a niche for a leader of particular type. A potential leader, whose traits fit the situational aspects (i.e., hostility and variability) the best, has the highest prototypical influence on the followers. The measure of such fit for a potential leader l and its potential follower a is expressed by:

$$infl_{proto}(l, a, s, t) = \omega 1\, sal_{h,s,a}(t)\, val_{h,s,a}(t)\, e^{\,g1(mas_l,\, h_{s,a}(t),\, \omega_2,\, \omega_3)} + (1-\omega 1)\, sal_{v,s,a}(t)\, val_{v,s,a}(t)\, e^{g2(age_l,\, v_{s,a}(t),\, \omega_2,\, \omega_3)} \quad (6)$$

here $\omega 1$ determines the relative contribution of each of the leader's traits to the prototypical influence.

Function $g1$ in (6) determines the fit between the leader's masculinity and the situational hostility:

$$g1(mas_l,\, h_{s,a}(t),\, \omega 2,\, \omega 3) = -(|mas_l - h_{s,a}(t)|/\omega 2)^{\omega 3}, \quad (7)$$

where $\omega 2$ and $\omega 3$ are parameters that determine the degree of steepness and the threshold.

Function $g2$ in (6) determines the fit between the leader's age and the situational variability:

$$g2(age_l,\, v_{s,a}(t),\, \omega 2,\, \omega 3) = -(|age_l - v_{s,a}(t)|/\omega 2)^{\omega 3} \quad (8)$$

C. Overall influence

The prototypical influence determines the agent's predisposition to accept the leader's message. The actual acceptance of the message by the agent depends also on the degree of similarity of the message and the agent's own beliefs about the situation (the principle of bounded confidence [6]). The higher the agent's predisposition to accept the message, the higher the agent's tolerance *tol* to the difference between the message and own beliefs:

$$tol(a,l,s,m,t) = |mes(l,m,t) - bel(a,m,t)|^{infl_{proto}(l,a,s,t)}, \quad (9)$$

where $mes(l,m,t) \in [0,1]$ and $bel(a,m,t) \in [0,1]$ are the confidences of the leader's message *m* and the agent's belief about *m*. If a leader communicates $n>1$ messages, then the tolerance for the aggregated message *m* is determined as

$$tol(a,l,s,m,t) = \sum_{mi} |mes(l,m_i,t) - bel(a,m_i,t)|^{infl_{proto}(l,a,s,t)}/n$$

Thus, the agent's tolerance is determined by interaction between the agent's perception of the leader's image (i.e., prototypical influence) and the leader's message. The leader's image is determined by interaction between the situational aspects and the leader's traits. The notion which combines interaction between all model components is *the overall influence of a (potential) leader on a (potential) follower:*

$$infl(l,a,s,m,t+\Delta t) = infl(l,a,s,m,t) + \alpha 3\, \varepsilon_{la} \delta_{al}(m,t) b(a,m,t)(1/(1+e^{g(l,a,s,m,t,\omega 4,\omega 5)}) - infl(l,a,s,m,t) - \omega 6 \sum_{k \in PLEADER,\, k \neq l} infl(k,a,s,m,t))\Delta t, \quad (10)$$

where

$$g(l,a,s,m,t,\omega 4,\omega 5) = -\omega 4\ (1 - tol(a,l,s,m,t)) + \omega 5,$$

$\omega 4$ and $\omega 5$ are steepness and threshold parameters; $\alpha 3$ is the parameter indicating how quickly leader *l* gains (looses) his or her influence on *a* provided positive (negative) experience of *a* with *l; PLEADER* is the set of all potential leader names, ε_{la} is expressivity of *l* towards *a*, and δ_{al} is openness of *a* for the message from *l*. Note that the closer the follower's belief approaches the leader's message, the more open is the follower to the leader's message and influence:

$$\delta_{al}(m,t) = 1 - |mes(l,m,t) - bel(a,m,t)|^{\gamma}, \quad (11)$$

where γ is the parameter indicating the degree of the follower's trustfulness.

To capture reciprocal inhibiting relations between several competing leaders, the term

$$-\omega 6 \sum_{k \in PLEADER,\, k \neq l} infl(k,a,s,m,t)$$

is introduced in (10). It makes the notion of the overall influence of a leader on an agent relative w.r.t. other competing leaders; the degree of relativity of the leader's influence is determined by parameter $\omega 6$.

The lower the agent's confidence of the belief about the situation, the less the agent is inclined to change its acceptance of the leader's influence. This is reflected by the factor *bel(a,m,t)* in the second term in (10).

The overall degree of influence of a leader on an agent determines to which extent the leader's message is incorporated in the agent's belief set. For a situation with several competing potential leaders:

$$bel(a,m,t+\Delta t) = bel(a,m,t) + \sum_{k \in PLEADER} \varepsilon_{ka} \delta_{ak} infl(k,a,s,m,t)(mes(k,m,t) - bel(a,m,t)) / \sum_{k \in PLEADER} \varepsilon_{ka}\, \delta_{ak}\, infl(k,a,s,m,t) \quad (12)$$

This formula expresses that the higher the potential leader's influence on an agent, the more the agent adjusts its beliefs about the situation in the direction of the leader's message.

IV. Applications

The application of the model is demonstrated by three simulation studies considered in this section.

A. US Elections 2004

In the first study the model was used to reproduce trends in the voting behaviour of the body of electors in the US presidential elections in 2004. The model was initialised using the election statistics from [8]. In the simulation the electorate was represented by 1000 agents, forming three groups: supporters of G.W. Bush (group SB, initially 44%), supporters of J. Kerry (group SK, initially 50%), and undecided voters (group U, initially 6%). The simulation time was 1000 time points.

The perception of the environmental aspects by the members of each group was specified as shown in Table I. The characteristics of the potential leaders – G.W. Bush (agent *B*) and J. Kerry (agent *K*), defined based on [14], are provided in Table II. The agent *B*'s message *m1* was social conservative with the special focus on the *B*'s ability to win the war on terror. The agent *K*'s message *m2* was domestically liberal with the special focus on anti-Iraq war measures. Furthermore, according to the empirical data, the *K*'s message was fluctuating in time. The attitudes (beliefs) of the potential followers to the potential leaders' messages were initialized based on statistics from [8].

TABLE I. THE RANGES OF THE UNIFORMLY DISTRIBUTED CHARACTERISTICS OF THE POTENTIAL FOLLOWERS OF AGENTS *K* AND *B*.

Variable	SB	SK	U
$h_{a,s}$	[0.8, 0.9]		
$v_{a,s}$	[0.2,0.3]	[0.7,0.8]	[0.25, 0.75]
$salenv_{h,s,a}(0)$	[0.7, 0.9]		
$salenv_{v,s,a}(0)$	[0.1, 0.3]	[0.6, 0.8]	[0.2, 0.7]
$fr_{s,a}$	[0.8, 0.9]		
ε_{ab}	[0.5, 0.8]		
Parameters	ω=0.5, $\omega 1$=0.5, $\omega 2$=0.5, $\omega 3$=4, $\omega 4$=10, $\omega 5$=5, $\omega 6$=0.02; $\alpha 1$=0.8, $\alpha 2$=0.4, $\alpha 3$=0.8, $\beta 1$=0.6		
bel(a, m1, 0)	[0.8, 1]	[0.5, 0.7]	[0.6, 0.9]
bel(a, m2, 0)	[0.5, 0.7]	[0.8, 1]	[0.6, 0.9]

Since the simulation model contains stochastic elements (i.e., the uniformly distributed characteristics of the agents), 50 simulation trials were performed. The votes of the agents were determined in the end of each simulation trial as follows: when *infl(B,a,s,m,1000)>infl(K,a,s,m,1000)*, then agent *a* chooses agent *B*, otherwise *a* chooses *K*. Here *m* is the aggregated message comprising *m1* and *m2*.

TABLE II. THE RANGES OF THE UNIFORMLY DISTRIBUTED CHARACTERISTICS OF THE POTENTIAL FOLLOWERS OF AGENTS *K* AND *B*.

Variable	**B**	**K**
age	*0.6*	*0.6*
mas	*0.8*	*0.4*
ε_{ab}	*1*	*0.9*
infl(l,a,s,m,0)	*0.3*	*0.6*
mes(l, m1, t)	*1*	*Changed every 30th iteration from 0.5 to 0.9 and vice-versa*
mes(l, m2, t)	*0.6*	*Changed every 30th iteration from 0.6 to 1 and vice-versa*

The following voting results were obtained: for agent *B* voted in average 51% of the agents (variance 0.78%), and for agent *K* voted 49%. All initially undecided voters chose for agent *B*, and around 1% of the agent *K*'s supporters changed their mind and voted for *B*. These simulation results are close to the real outcomes of the elections (51% voted for Bush, 48% voted for Kerry, 1% for the third candidate, not considered in the simulation study). The dynamics of the behaviour of the agents, which resulted in this outcome, is considered in the following.

The prototypical influence of agent *B* on his supporters and the undecided voters was higher than of agent *K* (Figure 2). Note that in this and in the following figures only 200 time points are shown to zoom into the dynamic patterns, which do not change over time.

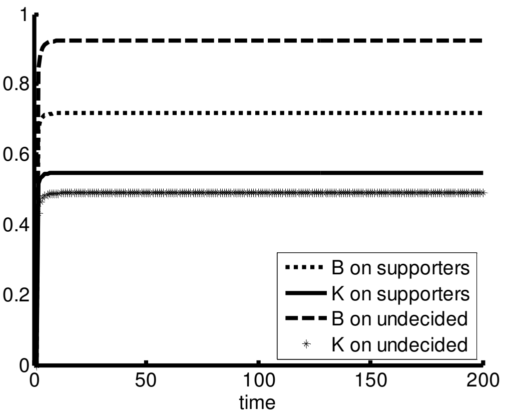


Figure 2. Average prototypical influence of B and K agents on the potential followers from SB, SK and U groups.

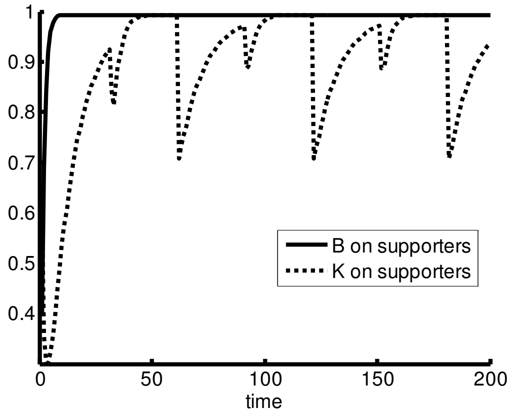


Figure 3. Average overall influence of B and K agents on their supporter agents.

The overall influence of agent *B* on his supporters was high and relatively stable over time, which is also reflected in the real voting statistics (Figure 3). The overall influence of agent *K* on his supporters was varying following the change of his message (also reflected in the real statistics) (Figure 3).

The overall influence of agent *K* on the undecided agents was lower and varied more significantly than the overall influence of agent *B* (Figure 4).

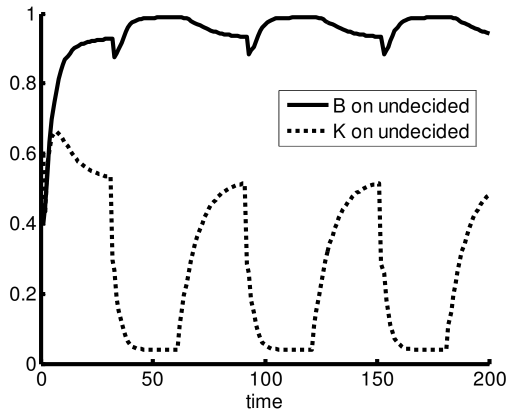


Figure 4. Average overall influence of B and K agents on the undecided agents.

The methods described in Section III were implemented in Matlab. Simulation time was 1030 with the initial stabilization interval [0, 30]. For each simulation setting 50 iterations were executed. The number of agents was varied across simulation runs: 50, 100, 200, and 500. The initial states of each agent for the strengths of support for the two decision options *s1* and *s2* were uniformly distributed in the interval [0,1].

In addition to the agents external sources were used, which number was 10 times less than the number of agents. The average time between two subsequent messages provided by each external source to a randomly chosen agent was varied across simulation runs: 1, 2, 5, and 10.

Each average time value can also be interpreted as a ratio of the time scale of the group's internal dynamics to the time scale of the external dynamics. The impact of these ratios on approximation errors was investigated. The parameters γ and η of each agent were taken from the uniform distribution in the interval]0,1]. Moreover, Δt = 1.25 and ν = 0.8.

B. US Elections 2008

In the second study another case of voting behaviour of the United States electorate in the presidential elections in 2008 was investigated. The model was initialised using the election statistics from [21]. As in the first case the electorate was represented by 1000 agents, but in contrast to the first study no groups of voters were distinguished. This is because empirical information used for this study was based on random samples of potential voters throughout the US. The simulation time was 1000 time points.

The perception of the environmental aspects by the agents representing potential followers was specified as shown in Table III. The characteristics of the potential leaders – J. McCain (agent *M*) and B. Obama (agent *O*) are provided in Table IV. The agent *M*'s message *m1* focused on his experience and military record. Furthermore, over time *M*'s message became less pronounced and focused. The agent *O*'s message *m2* focused on change and anti-war measures.

TABLE III. THE RANGES OF THE UNIFORMLY DISTRIBUTED CHARACTERISTICS OF THE POTENTIAL FOLLOWERS OF AGENTS M AND O.

Variable	Value
$v_{a,s}$	*[0.7, 1]*
$salenv_{v,s,a}(0)$	*[0.7, 1]*
ε_{ab}	*[0.5, 0.8]*
Parameters	ω=0.5, $\omega 1$=0.5, $\omega 2$=0.5, $\omega 3$=4, $\omega 4$=10, $\omega 5$=5, $\omega 6$=0.1; $\alpha 1$=0.8, $\alpha 2$=0.4, $\alpha 3$=0.8, $\beta 1$=0.6
bel(a, m1, 0)	*[0.4, 0.7]*
bel(a, m2, 0)	*[0.7, 1]*

The dynamic variables $h_{a,s}$, $salenv_{h,s,a}(0)$, $fr_{s,a}$ are defined based on qualitative trends in the empirical data. In particular, $h_{a,s}$, $salenv_{h,s,a}(0)$ capture the remembrance of 9/11 events (time point 67), when the perception of the hostility of the environment was particularly high, after that it decreased gradually:

$$h_{a,s}(t) = \begin{cases} e^{-(\frac{t-67}{50})^{20}}, & t \geq 67 \text{ and } h_{a,s}(t-1) \geq h_{a,s}(0) \\ val \in [0.4, 0.6], & otherwise \end{cases}$$

$$salenv_{h,s,a}(t) = \begin{cases} e^{-(\frac{t-67}{50})^{40}}, t \geq 67, \; salenv_{h,s,a}(t-1) \geq salenv_{h,s,a}(0) \\ val \in [0.3, 0.5], \quad otherwise \end{cases}$$

The degree of fitness relevance went over time from medium-high transitioning from G. W. Bush's policies to very high as the economy started to worsen and directly affect more US citizens:

$$fr_{s,a}(t) = x + \frac{(1-x)}{1+e^{-0.05t+5}}, \text{ where } x \in [0.5, 0.7]$$

TABLE IV. CHARACTERISTICS OF THE POTENTIAL LEADERS M AND O.

Variable	M	O
age	*0.7*	*0.4*
mas	*0.8*	*0.4*
ε_{ab}	*0.8*	*1*
infl(l,a,s,0)	*0.5*	*0.6*
mes(l, m1, t)	*1 for t≤100, fluctuated between 0.6 and 0.9 for t > 100*	*n/a*
mes(l, m2, t)	*n/a*	*1*

By simulation the overall influence ratio $\sum_{a\in PSUPPORTERS}$ *infl(O,a,s,m2,1000)/infl(M,a,s,m1,1000)* was obtained equal to 1.23, which reflects roughly the actual voting statistics (52.9% voted for Obama and 45.7% voted for McCain).

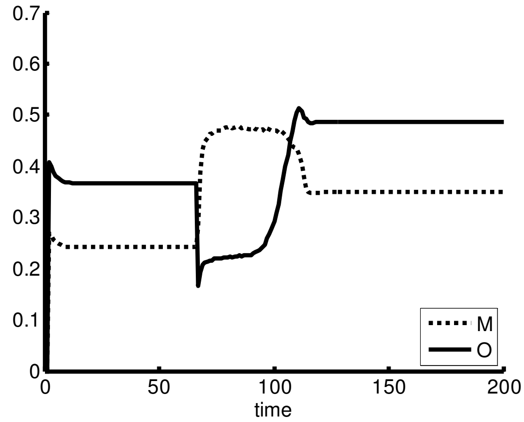


Figure 5. Average prototypical influence of M and O agents on the agents.

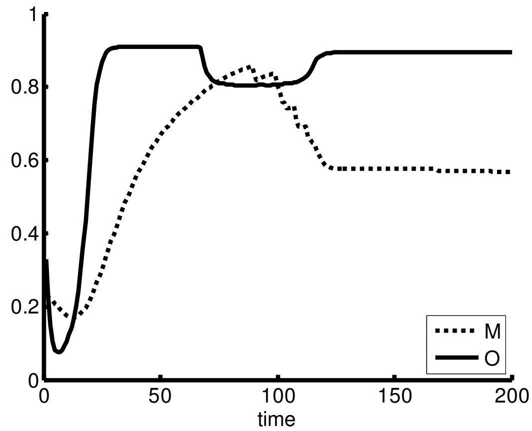


Figure 6. Average overall influence of M and O agents on the potential followers.

The prototypical influence of agent *O* was on average higher than of agent *M*, with the exception of a short time period following the remembrance of the 9/11 events (Figure 5). These dynamics is also visible in the actual voting statistics.

The effect of an increase and then a gradual decrease of the perception of the environmental hostility is also reflected in the overall influence of agents *M* and *O* (Figure 6). The average overall influence of agent *M* decreases slowly after this disturbance, influenced by the instability of the *M*'s message. This result is also consistent with the actual voting statistics.

C. Empirical study

To further investigate the validity of the proposed model, data from an experiment described in [19] were used. In the following the experimental setup is summarized. Fifty undergraduate students participated in the experiment designed to investigate potential gender-biases in the emergence of leadership in groups. Teams of participants played a public-goods game under conditions of either intragroup competition, intergroup competition, combined intra- and intergroup competition, or no competition. In all conditions participated played a step-level version of the investment task in which they made decisions on how much money to invest in a private versus a group fund. The teams that elicited enough group investment to reach the step-level were rewarded with a group bonus whereas those teams that failed to reach the step-level lost their individual investment to the group. For all conditions participants were provided with fictitious information about a male and female teammate. The participants were required to choose either the male or female as a leader to raise group investments, and asked to rate both candidates expected effectiveness at maintaining positive intragroup relationships and winning intergroup competitions. More details on the experiment can be found in [19].

The empirical data from the experiment were used to initialize the model as shown in Tables V and VI. The situational aspects were indicated clearly in the description of the experiment provided to the participants, so no misinterpretation of the conditions is assumed. In the simulation agent *S* (Sarah) is a potential female leader and agent *P* (Peter) is a potential male leader. Messages of the potential leaders were not considered in this experiment. The combined intragroup condition was not simulated in this study, as the data gathered during the experiment were not sufficient to initialize the model for this condition.

TABLE V. THE RANGES OF THE UNIFORMLY DISTRIBUTED CHARACTERISTICS OF THE POTENTIAL FOLLOWERS OF AGENTS S AND P.

Condition / Variable	Intra	Inter	Control
$h_{a,s}$	*[0.1, 0.4]*	*[0.7, 1]*	*[0.4, 0.6]*
$v_{a,s}$	*[0.1, 0.2]*		
$salenv_{h,s,a}(0)$	*[0.7, 1]*		
$salenv_{v,s,a}(0)$	*[0.1, 0.2]*		
$fr_{s,a}$	*[0.5, 0.8]*		
Parameters	$\omega=1$, $\omega1=0.8$, $\omega2=0.5$, $\omega3=4$, $\omega4=10$, $\omega5=5$, $\omega6=0.1$; $\alpha1=0.8$, $\alpha2=0.3$, $\alpha3=0.8$, $\beta1=0.6$		

The simulation results indicate a strong preference for female intragroup leadership and male intergroup leadership (Figures 7 and 8).

TABLE VI. CHARACTERISTICS OF THE POTENTIAL LEADERS S AND P.

Variable	S	P
age	*0.2*	*0.2*
mas	*0.1*	*0.9*
$infl_{proto}(l,a,s,0)$	*0*	*0*

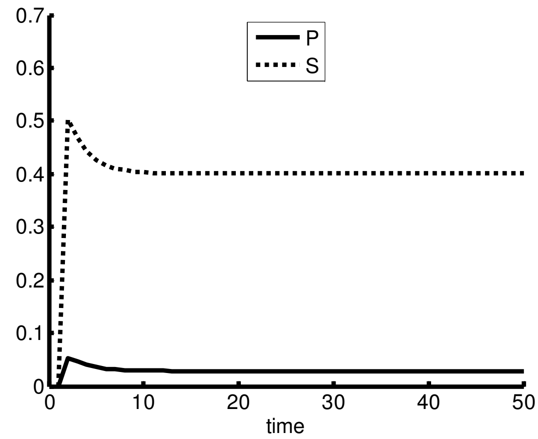


Figure 7. Average prototypical influence of P and S agents on the follower agents in the intragroup condition.

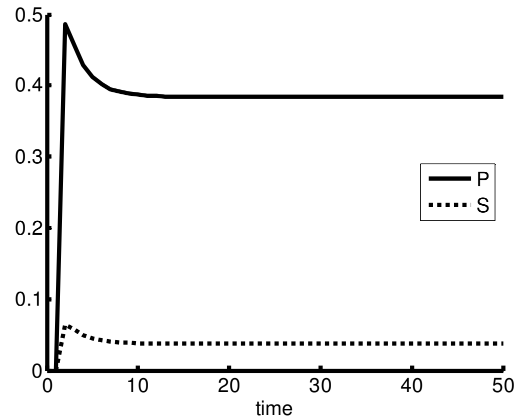


Figure 8. Average prototypical influence of P and S agents on the follower agents in the intergroup condition.

The simulation results are consistent with the experimental results reported in [19], in which the degree of overall influence was related to the percentage of votes for the potential leaders.

In the control condition no significant difference in the prototypical influence of agents *P* and *S* was established (Figure 9), which is also confirmed by the experimental results.

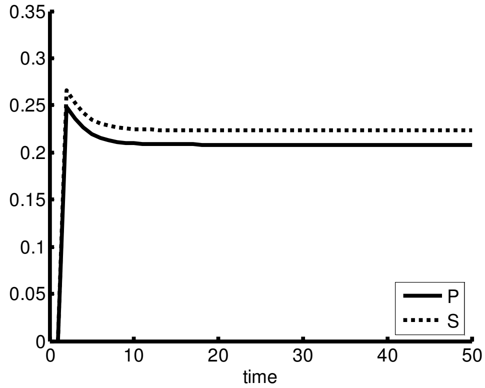


Figure 9. Average prototypical influence of P and S agents on the follower agents in the control condition.

V. CONCLUSIONS

In this paper a novel, agent-based computational evolutionary model of leadership is proposed. The formal model builds on the basis of recent findings in the theory of evolutionary leadership [13, 17-19]. The application of the model is demonstrated by three data-driven simulation studies. The consistency between the model predictions generated in these studies and the trends observed in the reality provides an indication of the validity of the model. In the future a more extensive empirical study will be performed, in which all essential elements of the model and their dynamics will be examined in detail.

A preliminary sensitivity analysis of the proposed model was performed, by which the most influential model parameters were identified. Among them are the situational aspects: hostility and variability, and the beliefs of agents about the situation. Thus, to increase the overall influence effectively, a potential leader may manipulate these parameters, e.g., by influencing the perception of the situational aspects of followers through media. On the other hand, these parameters may be also manipulated to decrease the overall influence of opponents effectively. In the future the model parameters identified by sensitivity analysis will be compared with manipulation strategies used by leaders in reality.

Another possible application of the developed model is prediction of emergence of a leader of a particular type in a particular situation. In an ambient-assisted context intelligent devices may employ the proposed model to identify an individual with the highest overall influence. For example, in an emergency situation with prominent coordination needs such an individual may be provided information from an intelligent device (e.g., a path to an evacuation exit) that could be used for efficient coordination of collective action.

Thus, the proposed model has a potential to become a useful tool for explaining, predicting and influencing the dynamics of collective action in groups.

ACKNOWLEDGMENT

This research has partly been conducted as part of the FP7 ICT Future Enabling Technologies program of the European Commission under grant agreement No 231288 (SOCIONICAL). This research was also supported by funding from the United States Office of Naval Research Global (ONRG) under grant agreement No N62909- N62909-11-1-7010.

REFERENCES

[1] Archer, J. (2006). Testosterone and human aggression: an evaluation of the challenge hypothesis. Neuroscience and Biobehavioral Reviews, 30, 319-345.
[2] Bosse, T., Duell, R., Memon, Z.A., Treur, J., and Wal, C.N. van der. (2009). An Ambient Agent Model for Group Development Support. In Proceedings of IAT'09. IEEE Computer Society Press, pp. 505-510.
[3] Black, J.A., Oliver, R.L., Howell, J.P., and King J.P. (2006). A dynamic system simulation of leader and group effects on context for learning. The Leadership Quarterly, ISSN 10489843, 17(1): 39.
[4] Bowles, S. (2009). Did warfare among ancestral hunter-gatherers affect the evolution of human social behavior? Science, 324, 1293-1298.
[5] Brown, D.E. (1991). Human universals. New York, NY: McGraw-Hill.
[6] Deffuant, G., Amblard, F., Weisbuch, G. (2004) Modelling group opinion shift to extreme: the smooth bounded confidence model. In Proceedings of the European Social Simulation Association Conference.
[7] Fiedler, F. (1964). A contingency model of leadership effectiveness. In Advances in Experimental Social Psychology (149-190). New York: Academic Press.
[8] Jones, J.M. and Joseph, C. (2005). Changing Minds in the 2004 Election? A Report on Gallup's Post-Election Panel Survey. http://www.gallup.com/poll/16576/Changing-Minds-2004-Election.aspx
[9] Little, A. C., Burriss, R. P., Jones, B. C., and Roberts, S. C. (2007). Facial appearance affects voting decisions. Evolution and Human Behavior, 28, 18-27.
[10] Pound, N., Penton-Voak, I. S., and Surridge, A. K. (2009). Testosterone responses to competition in men are related to facial masculinity. In Proceedings of the Royal Society B: Biological Sciences, 276, 153-159.
[11] Ridley, M. (1997). The origins of virtue: Human instincts and the evolution of cooperation. London: Penguin Books.
[12] Rogers, E.M. (2003). Diffusion of innovations. New York, NY: Free Press.
[13] Spisak, B. R., Nicholson, N., and Van Vugt, M. (forthcoming). Leadership in organizations: An evolutionary perspective. In G. Saad (Ed.), Evolutionary Psychology in Business Sciences. New York: Springer.
[14] Spisak, B.R., Homan, A. C., Grabo, A., and Van Vugt, M. (2011). Facing the situation: Testing a biosocial contingency model of leadership in intergroup relations using masculine and feminine faces. The Leadership Quarterly, doi:10.1016/j.leaqua.2011.08.006
[15] Sterman, J.D. (2000). Business Dynamics: Systems thinking and modeling for a complex world. McGrawHill.
[16] Thompson, G., and Vecchio, R. P. (2009). Situational leadership theory: A test of three versions. Leadership Quarterly, 20, 5, 837-848.
[17] Van Vugt, M. (2006). The evolutionary origins of leadership and followership. Personality and Social Psychology Review, 10, 354-372.
[18] Van Vugt, M., and Ahuja, A. (2010) Selected: Why some people lead, others follow and why itmatters. London: Profile.
[19] Van Vugt, M., and Spisak, B.R. (2008). Sex differences in leadership emergence during competitions within and between groups. Psychological Science, 19, 854-858.
[20] Zaccaro, S. J. (2007). Trait-based leadership. American Psychologist, 62, pp. 6–16.
[21] Official tracking polls available at http://www.gallup.com.