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Docking Agent-based Simulation of Collective Emotion to Equation-based Models and Interactive Agents

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Abstract

The creation and demise of e-communities is greatly influenced by emergent emotional phenomena that warrant study above the level of individuals: collective emotions. Our requirements for an agent-based simulation of these phenomena are constrained both by the data available from online communities as well as by the scenarios of use for the simulation. In this paper, we consider both the relation to mathematical models developed in parallel as well as the use of the simulation as decision support for interactive conversational systems. We show how both of these 'docking' attempts inform the simulation design and contribute to it.

1. INTRODUCTION

Emotional factors play an important role in the interaction of individuals and, while transformed, this is still true for computer-mediated communication in e-communities. The recently started 4-year EU project Cyberemotions[1] has taken on the task of exploring the concept of *collective emotions*, an emotional phenomenon that emerges in e-communities, i.e. among the users of social websites, chats, discussion fora, mailing lists, and similar online media that connect groups of people. Section 2 presents a short characterisation of the concept as well as related notions from theories of emotion that are relevant for the different levels of simulation mentioned later.

An interdisciplinary approach is needed to capture this phenomenon scientifically and a successful account of the dynamics and influence factors of collective emotions has strong implications for detection and intervention possibilities. For this reason, the project connects approaches from psychology, social network analysis, and mathematical modelling with agent-based simulation and application prototyping using interactive agents. The latter are motivated by a long-term vision to allow online analysis and interactive probing of participants in discussions about the current state and, in the distant future, to potentially enable interventions that prolong positive states and shorten negative ones. This paper takes the stance of agent-based simulation as one building block of this project and presents the design implications of the interdisciplinary endeavour to 'dock' simulation to both mathematical equation-based modelling and real-time application in interactive agents exploiting the complementarity of the approaches.

Synergies exist between agent-based and equation-based modelling [22, 23]. Careful design can help to ensure that both approaches benefit. Further, interactive agents can use not only the results of offline simulation as a basis for strategies, but potentially also the results of reduced online simulations as input to its decision processes. Sections 3 and 4 provide details about the specific requirements that this entails. The specifics of agent-based simulation models can also inform the very design of the control architecture of conversational systems, and this is indeed another synergy that the project plans to exploit, however, not topic of this paper.

Finally, section 5 explains the design choices that were prompted by the identified requirements, followed by the conclusions in section 6. The design provides for the different accounts of individual and collective emotions that are used in the project. Varying degrees of affective, cognitive, and reasoning capabilities are foreseen to fulfill the range of requirements selectively, building on previous work in affective agent control architectures [26, 25].

2. COLLECTIVE EMOTIONS

Consider the reaction of thousands of netizens when a celebrity they admired suddenly dies, or the reaction of a group of developers and users of a piece of open source software when a seemingly minor change in functionality triggers a fork[2] (i.e. a split of the development team). Both of these examples, though rather different, can be seen as specimen of *collective emotions*. Psychology, social psychology, and philosophy offer different attempts at a definition of collec-

[1] http://www.cyberemotions.eu/ (all URLs last accessed 2009-11-29)

tive emotions and the related concept of group-based emotions which is, depending on the theory, distinct from the former. This distinction is, e.g., related in [2]; collective emotions are then defined in a general way as those that are shared by a large number of individuals in a society [31] while group-based emotions are felt by individuals as a result of their membership in a certain group or society [30].

Philosophical accounts of collective emotions focus on the (philosophical) intentionality of emotion, i.e., its *mode*, *content*, and *subject* to distinguish individual emotion from different forms of collective emotions [29]. The mode defines the kind of emotion and can be shared, e.g. via emotional contagion [12], or social emotion regulation. A collective emotion of this type would be characterised by a group of people sharing the same type of emotion. The content consists of the *target* at which the feeling is directed, as well as the *concern* that makes it relevant for the subject. Both target and concern can be shared between individuals, an example would be a group of individuals reacting to the same event. For the subject both the individual that has the emotion, as well as the phenomenal subject, the implicit self as which the emotion is felt, are relevant. The latter allows for the idea of a *plural subject*, some group that is committed to doing something as a body, e.g. members of an organisation but potentially also more loosely connected groups such as all users of a specific software.

For the present project the main interest lies in the conditions for the elicitation of collective emotions and particularly their effects on e-communities, their role in forming, strengthening, splitting, or dissolving them. The crucial, and open, theoretical question is the relation of collective emotions to individual emotions in a dynamic social network. The increasing academic interest in the role of (individual) affect for computing resulted in the establishment of the EU-funded Network of Excellence "Human-Machine Interaction Network on Emotion"[3], aiming to contribute to "the development of systems that can register, model and/or influence human emotional and emotion-related states and processes". Since 2004, the network and the subsequently established association have been providing a valuable basis for the study of emotion in human-machine interaction, and its theoretical results [32, 8] as well as our own work as part of the network [26, 27, 28] provide a suitable source for the description of emotions at different levels of granularity.

The spectrum starts from the characterisation of emotions as areas in a multi-dimensional space such as pleasure, arousal, and dominance [21] and a rough correlation of the dimensions to physiological parameters like skin conductance rate and specific muscle activation, see e.g. [15]. At the other end, one can find complex process models of the elicitation and behavioural consequences of emotions that relate the notion of concern, i.e. "a motive or need, a major goal or value, a more or less enduring disposition to prefer particular states of the world" [10] p.7, through evaluation criteria to processes of appraisal and regulation [9, 6].

A successful use of modelling and simulation for the purpose of decision support and understanding [34, 7] depends on the availability of reference data. For the realm of individual emotions this consists of self-report as well as behavioural and physiological measurements [20], including laboratory measurement of physiological correlates of emotional responses occurring during interaction in experimental settings [15]. This type of data relates mostly to dimensional accounts of emotional states. Data about online communication consists mainly of the raw message exchanges collected (and anonymised) from online channels such as MySpace, news fora, blogs, or Internet Relay Chat (IRC). Compared to human face-to-face interaction these communication channels are severely impoverished. Only rarely, messages are annotated with affective valences, e.g. mood icons for posts in discussion fora, leaving automatic classification as the most practical option [4]. Part of the project are efforts to incrementally improve automatic methods for annotating text messages in online communication with valences using different classification methods [24] as well as to adapt these methods to further kinds of online channels acknowledging the different communication styles used. As a bare minimum, the annotation of individual messages with separate values of positivity and negativity is assumed.

An important requirement for agent-based simulation of the effect of collective emotions is therefore to balance the connection to available data with the levels of cognitive capabilities that are indicated by different accounts of individual emotions. For simulations that incorporate more complex notions of individual emotion processes, their value for the purpose of understanding lies also in the operationalisation of theories, even before there are corresponding methods of more direct evaluation based on data.

3. EQUATION-BASED MODELLING

One starting point for the study of the influence of collective emotions is opinion dynamics [14, 13, 17, 33, 18]. In continuous opinion dynamics models, agents hold a fixed set of opinions modelled as continuous values; interactions between agents gradually adjust the opinions of the participants. Overall these models are characterised by the assumption of mostly homogenous agents, potentially distinguishing between different bounds of confidence, the analysis of results focuses on consensus, polarisation, or fragmentation in the simulated population, typically illustrated with bifurcation diagrams. Such a modelling approach lends itself to a math-

[2] See http://developer.pidgin.im/ticket/4986 for an example of a discussion that preceded a fork.

[3] HUMAINE http://emotion-research.net/

ematical formulation and an analysis in terms of master and rate equations [16] since the resulting simulations obey the Markov property, i.e. the future is determined only by the present and not by the past. The models are, further, examples of sociophysics, i.e. the application of methods that are successful in physics to large scale social phenomena: social processes are characterised in analogy to physical quantities and the analysis often aims to identify general laws such as the applicability of fluctuation scaling [5] or power-law behaviour in empirical data [3].

While equation-based models certainly offer the prospect of strong clarity of understanding, an agent-based simulation is complementary and allows for model-to-model analysis [11] by *docking* the different simulation models [1, 23]. The prerequisites are studying the same phenomenon which is ensured by the relation to data collected during the project and comparable parameters and outcomes of the simulations. For the general mathematical models of collective emotions, a dimensional account of emotion is, at least initially, suitable. The emotional state of individuals, the emotional content of messages, and the emotional state of aggregate entities such as complete networks or sub-graphs (e.g. discussion threads) are quantified as points in a three-dimensional space of valence, arousal, and dominance. The states of aggregate entities are also part of outcomes of interest, in addition to stable partitions of the graph of interacting agents.

While this choice of representation might change during the evolution of the mathematical model, our agent-based simulation should ensure to relate to this notion of emotionality in its most basic variant. Further versions that increase the complexity of emotion modelling in individual agents would ideally track the evolution of the equation-based model or map to the three-dimensional characterisation.

The main differences between the approach presented in this section and an agent-based simulation is the focus on the individual agent. The discretisation of individuals in an agent-based model is necessary for a more detailed modelling of emotional processes; it also allows for different requirements posed by interactive applications that are presented in the next section. The commitment to track the evolution of the mathematical model that is developed in parallel ideally ensures the comparability between the two, one aiming for generality the other focusing on increasing levels of detail.

4. USE IN INTERACTIVE SYSTEMS

As part of the Cyberemotions project, the development of conversational systems that interact with users of network communication channels is undertaken. These systems communicate with members of various groups of Internet users to probe for affective states and background knowledge related to those states. We call these kinds of systems *Affect Listeners*, a family of systems with various components, sharing the following characteristics: These systems communicate with users, rely on integrated affective sentiment analysis for detecting textual expressions of the users' affective states, and use the acquired information to aid generation and selection of responses. Affect Listeners monitor events and processes that draw attention of Internet users, by analysing content of a number of websites (e.g., automatic and semi-automatic news aggregators as well as folksonomy-driven sites[4]).

These systems interact with users via a range of communication channels and interfaces, both predominantly synchronous ones (e.g., Internet Relay Chat, Jabber/XMPP, online chat sites) and asynchronous ones such as online fora. The aim are systems that are capable to adapt to the users' affective states, and to suitably respond to users' utterances both on the content- and the affect-related level. The planned evaluation scenarios of the systems include also their application in a laboratory for measuring physiological correlates of emotional responses occurring during interaction in experimental settings, as described above.

The system-user communication is text-based, real-time and oriented at the detection and acquisition of users' affective states. The initial realisation is an open-domain system, i.e., communication is not limited to a specific domain, topic, or ICT-mediated community. These conversational systems form both an additional data source for the study of collective emotions as well as an application area for modelling. The functionality of the conversational systems consists of direct conversation with an online user, listening to a multi-party conversation, and, in later iterations, targeted interventions in an online conversation. Of course, conversational systems like these, are strongly limited in the sense that they cannot match the conversational abilities of a human. However, this is neither the goal of the Affect Listener systems nor required for them to fulfill their purpose. While the interaction is, as mentioned above, unrestricted, the domain is constrained in so far as the system concerns itself merely with the emotional states of individual participants as well as the dynamics of collective emotions and employs suitable strategies to keep the conversation going.

The role of agent-based simulation in this kind of interactive system is to serve as decision support. This entails several requirements that concern both the results of simulation runs as well as runtime characteristics and the adaptability of the simulation based on data collected during previous interactions. Relevant questions that a conversational system would benefit from getting answers to are:

- Which individual in a group will be most likely to provide an accurate response to probing about the group's emotional state, and which one will be most reliable?
- What influence can individuals have on the evolution of

[4] An example is http://www.reddit.com/

the collective emotions in an e-community, and which of the specific participants is likely to have the biggest influence?

- Can potential escalations, both in the negative and in the positive direction, be detected early on?
- What influence will a specific intervention of the conversational system have at the current moment, and which style of intervention is most effective?

While offline simulation, as well as the results of equation-based models, can be very helpful for the control architecture of these conversational systems, the potential for interactive use, i.e., running a simulation on demand to query about the above questions, is most promising. This not only adds the requirement of timely, or ideally anytime, responses but also the need to parameterise the simulation to quickly adapt to the current state of an e-community, ideally using the recorded history as input.

5. AGENT-BASED IMPLEMENTATION APPROACH

As a starting point for the implementation of our agent-based simulation of collective emotions in e-communities, we designed a simulation that exhibits the same statistical properties as one of the first datasets collected in the project. The website of the BBC offers topical message boards, i.e. discussion fora, to its visitors. These fora often host heated debates, and a subset of these were selected for initial data collection activities as part of the Cyberemotions project. Any user of a message board can open a new discussion thread, many of these, however, never get any answer from another user and only some of them will grow to a considerable length. The dataset therefore contains a set of messages that are linked to a specific discussion thread, and originate from a specific user. The messages in a thread are ordered temporally and they have a certain length. Figures 1 and 2 show the histograms of the number of messages that are posted in a thread as well as the number of users that participate in a thread. Initially, we ignore any affective annotation of the data or reply-relations that show a more detailed communication structure.

Starting with a model of non-affective communication provides a basis for the selective introduction of emotional model elements to enrich the simulation incrementally and allows for the comparison to previous iterations. Since the minimal affective annotation to be expected in datasets encodes affective content as attributes of the messages rather than as affective states of the agents, we chose a simple attribute of messages, their length, as next target for simulations. Figure 3 shows a histogram of the average lengths of all the messages sent by a user. Further iterations could replace this element of the model with affective annotations as they become available. While the structure of different communication channels that are of interest in the project is different, especially concerning synchronicity and other temporal characteristics as well as typical message length (cf. Internet Relay Chat and instant messaging versus discussion fora), the basic structure of this dataset is suitable for a prototype since the basic elements are there: agents, messages, as well as groupings of these, e.g. threads.

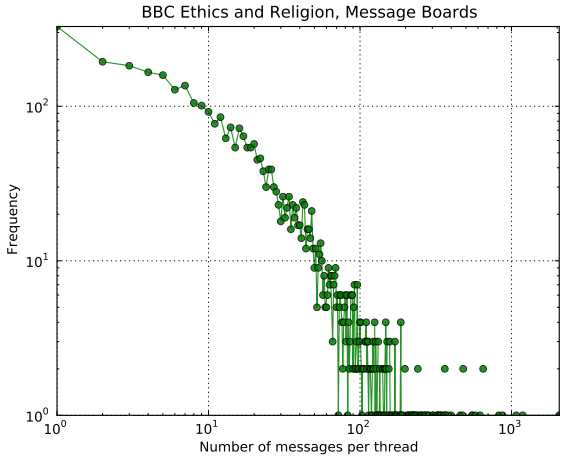

Figure 1: The distribution of the number of messages in a discussion thread.

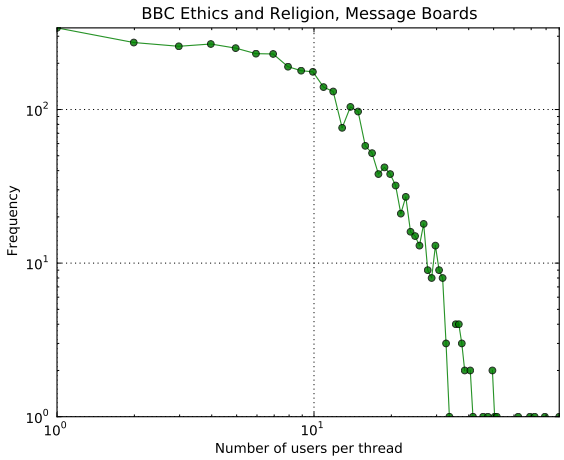

Figure 2: The distribution of the number of participants in a discussion thread.

5.1. Implementation Tools

As an implementation platform for the first simulation, we selected the framework MASON [19] in combination with the social networks package JUNG. The latter provides the graph

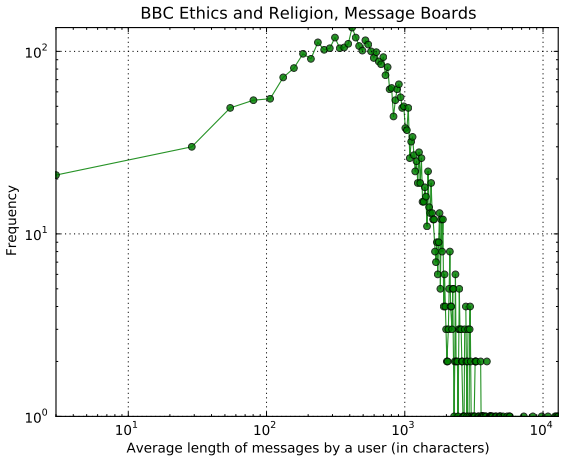

Figure 3: The distribution of the average length of messages by a user.

representations needed in later evolutions of the model as well measures that are of interest for graph structures, such as centrality.

The baseline simulation of message exchanges relies on probability settings for the agent population, divided into a number of groups. The probabilities influence the likelihood of an individual agent to start a new discussion, to read recently posted messages, and to respond to read messages. Further iterations also adjust the latter two probabilities based on message lengths while the length of messages generated by agents is randomly determined from a predefined range. Using such a parameterisation is not suitable for a theoretical account of the statistical features found in available datasets. It does, however, provide a starting point not only for further development of the simulation but also for the comparison with equation-based models that are developed with these features in mind. The comparability as well as the possibilities for extending the model are of interest for the present paper.

5.2. Simulated Collective Emotions

A simulation of collective emotions should account for the different types of collective emotions that are possible, as described in section 2. *Sharing subjecthood* is the one prerequisite for sharing emotions that can be accounted for in a simulation most directly. By tracking different groups of agents, distinguished by a specific feature, e.g. simply by participating in a single discussion thread, these groups can be modelled as a plural subject with the possibility of sharing an emotion. For *sharing the mode* of an emotion, or its content, i.e. *target* and *concern*, the design of the baseline model needs to be adapted.

The mode requires first of all a representation of emotion in the system. As explained above, dimensional characterisations of emotion, while less than ideal for in-depth modelling of processes related to emotions, provide a baseline in this respect. For sharing the mode of an emotion between participants, one of the following is needed:

- The emotional content of a set of posts is aggregated by, e.g., requiring them to be close to each other in the dimensional space used and/or to be related through the structure of the communication system (i.e. threads or agents) or even by an external object.
- The emotional state of agents is modelled based on the initial settings and a model of the influence of participation in discussions. Similarly to messages, the emotional states of a set of agents can then be aggregated.

Shared content can be analysed separately for a shared target of an emotion and sharing the concern that is responsible for the relevance of the emotion. For modelling shared content, the emotional annotation needs to include the target of the emotion for which two possible approaches are identified:

- As a first step, only the messages themselves and the communicating agents serve as potential targets of emotions.
- A full model needs to include external objects as potential targets of emotion, and also as referents of messages.

A prerequisite for shared concerns, is the modelling of concerns as distinct elements of the participating agents. The next subsection will provide more details on the planned design. Similarly to aggregating the emotional mode, an aggregate of a set of agents can be used to model such a shared concern.

Apart from these design choices regarding the complexity of the cognitive capabilities of agents, the possibilities for representing exchanged messages range from an annotation with values for positivity and negativity that directly relate to basic methods of text classification to the introduction of referent objects and tagged values that code for the *action tendency* reflected in a message. The latter is necessary for more detailed influences on participants.

5.3. Varying Degrees of Affective Capabilities

As explained above, the baseline for the simulation of communicating agents uses stochastic modelling. One of the goals of this project is to iteratively enhance this using elements of the operationalisation of appraisal processes as described in theories of emotion. The minimum requirements for the modelling of appraisal processes in an affective agent architecture are representations of an agent's concerns or desires, including standards about praise- or blameworthy behaviour, as well as preferences for certain types of objects

or situations. Further, a method for evaluating changes in an agent's environment based on these conditions is needed. For the purpose of e-communities, the changes to be evaluated encompass the posted messages and their content as far as it is modelled, but also the perceived entrance or exit of a participant in a discussion thread.

The modelling of a complete affective architecture is not the goal for our simulations. However, we expect that the introduction of specific *surface concerns* and a suitable approximation of an agent's evaluation processes could be used to account for observed behaviour in e-communities. It is important to keep in mind that this level of affective capabilities cannot be related directly to existing datasets, but the results could be an indication for beneficial extensions of future data collection efforts and are of theoretical interest by themselves. A simple example is the demonstrable effect of daytime on the behaviour of participants in an online channel. Modelling not only the location of participants, i.e. their time-zone, but also their concerns regarding engagement with the communication channel depending on daytime would account for these effects.

5.4. Comparability of Results

To ensure the comparability of results between different levels of simulation and different modelling methods, the available data serves as a (dynamic, i.e., continually extended) reference frame. The tracking of groups of agents and membership in groups is crucial for the relation to other methods. These groupings form the basis for accounts of both plural subjects and sharing the mode of emotions, as well as for the evaluation of simulation results concerning creation, partitioning and dissolving of (sub-)communities. The status of these aggregate entities, as well as standard network measures provide the lowest common denominator for the comparison of simulation results.

The unlimited potential to refine groupings is one source of the complementarity of agent-based simulation to equation-based modelling, since it allows more flexibility in accounting for the individual differences of agents. Increased complexity necessarily limits the size of the simulation, but it also offers an increasing potential for iterative development and introduction of further emotional model features.

Exploiting simulation results for use in conversational systems benefits from the possibility of parameterisation of the simulations based on data collected by these systems. The current state of an individual agent, of a group of agents, or of a part of the communication channel as detected by the conversational system should influence a simulation run to reflect the probabilities of future developments of the actual environment that the system is interacting with at the moment. Groups of participants described by population size, time-zone distribution, as well as groupings according to communication style and emotional configuration will be explored during development.

6. CONCLUSIONS

In this paper, we presented the design choices for an agent-based simulation of collective emotions in e-communities. The relation to mathematical models developed in parallel influences the choice of a baseline simulation as well as the requirements for the simulation outcomes to be considered. The use of the simulation as decision support for interactive conversational systems adds different requirements including real-time and online use. Both of these connections contribute to the design of the simulation and will be references during its evolution over the course of the project.

Future work, apart from implementing those elements of the design that were presented here, will focus on modelling the potential role of individuals in the genesis of collective emotions; as mentioned, this is an important aspect for the use in interactive agents. Similarly, the effect of specific intervention types on the evolution of a specific e-community will be studied in close collaboration with the development of the conversational systems.

7. ACKNOWLEDGMENTS

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