Overview, design concepts, details

Using the *Cyberemotions* framework, this agent-based model abstracts the dynamics of collective emotions and the spread of emotional information online. Collective emotions are understood as emotional states shared and spread by a group of individuals, As such, they may be studied as an emergent phenomenon using a complex systems approach. Following the principle of Brownian agents, the agents of the Cyberemotions framework are described by a set of state variables that may change due to deterministic and stochastic influences. In the model, agents (representing human individuals) communicate their emotional states with each other using a communication field (representing aggregates of social media posts, such as threads in discussion forums). This field, in turn, provides feedback that affects the individual emotional states of the agents. On a group level, this leads to the spread of emotions from one agent to another and the emergence of *collective* emotions.

1. Purpose

This implementation of the *Cyberemotions* modeling framework was designed to investigate the dynamics of collective emotions in online discussion forums, where users may directly respond to the posts of others in the same thread. The model and its results are intended to be used as a hypotheses generator and its predictions may be tested against real-world data.

2. Entities and state variables

The two types of entities of the model are (1.) the agents representing forum users, and (2.) the communication field that represents one specific thread in a forum. Both are treated as objects and defined as Python classes, with each instance of the respective class containing its own state variables. The state variables representing the emotional state of agents, valence and arousal, are numerical values that can be either positive or negative, with negative numbers indicating a negative emotional charge and positive numbers a positive emotional charge. As the number gets higher, the emotions it represents become more positive, and as it gets smaller, the more negative they become. A charge of 0, in that sense, is emotionally neutral and considered an equilibrium state.

Valence and *arousal* are the two variables that represent the emotional state of each agent. While Valence represents a quantification of the degree of pleasure associated with an emotion, arousal represents its degree of activity. The *field variable* represents the emotional charge of the communication field.

3. Process overview and scheduling

For each simulation, the model initializes a set number of agents and the communication field. Once the initialization phase is over, it goes through the same following processes (abstracted as class methods) for every agent in the model and for every step in time. Over time, agents will enter a satiated state and drop out of the simulation. Once there are no more agents present, the simulation ends. Additionally, the model is initialized with a maximum number of time steps it may go through. Once this limit was reached, the simulation ends regardless of the number of agents left. The model processes that occur for each time step are scheduled as follows:

1. Every agent

    I. *perceives* the field and adjusts its state variables.

    II. may *express* its emotions.

    III. may enter a *satiated* state and drop out.

IV. *relaxes* and adjusts its state variables.

2. The field enables *communication* by adjusting its state variable to the agent expressions.

4. Design concepts

The design of the model follows the social interactionist paradigm that highlights communicative interactions between individuals. These interactions may lead to unexpected patterns of behavior on the group level, and emergent phenomena. In this case, agents communicate their emotions (internal state variables) with each other by storing emotionally charged information (expression variables) in a field that is perceived by all agents. This expression of emotions, in turn, is triggered by the emotional charge of the field (field variable) itself.

In principle, every agents has individual factors that determine what effect the emotional charge of the field has on its own emotional state (representing personal traits such as empathy or responsiveness), based on the general idea that agents already in a specific state may be more affected by particular emotions of others. For the purpose of this model, it is assumed that the impact of the emotional information that agents perceive depends on their emotional state in a non-linear manner. For example, the positive emotional state of an agent may become more positive when perceiving positive emotional information from other agents.

While the individual behavior of the agents follows a set of simple rules, new patterns of group behavior may emerge when emotional information spreads and emotional states are shared by multiple individuals. Both, all agents and the field, are treated as individual objects and instances of their respective class.

5. Initialization

The simulation is treated as a function that initializes the model taking basic settings (number of agents and maximum number of time steps) as input arguments. This allows to easily run multiple instances of the model at various settings. At the beginning of each model run, the set number of agents and the field are initialized by creating instances of their respective class. The initial agent state variable baselines of valence and arousal, and their fixed arousal thresholds, are set using a standard normal distribution, while the initial charge of the field is 0.

6. Input data

The only input data are the input arguments for the function starting the simulation, determining the basic simulation settings.

7. Submodels

There are five major submodels that are all described as methods of their respective Python classes. (I.) *Perception*, (II.) *expression*, (III.) *satiation*, and (IV.) *relaxation* are methods of the agent class, while (V.) *communication* is a method of the field class. More detailed descriptions of all four submodels, and an explanation of the equations they are based on, are part of the *Cyberemotions* framework.

I. Perception

This submodel describes the rate of change of the agent internal state variables *valence* and *arousal* through the effects of the *field variable*. It is based on an equation that takes deterministic influences (the communication field and emotional feedback of other agents) and stochastic factors (unexpected events represented by a random numbers taken at a given point in time from a distribution of stochastic shocks with a mean of 0) into account.

The perception function F describes how perceiving the emotional charge of the field, represented by the the field state variable h, changes valence v and arousal a of an agent i at time point t. The random number ξ represents stochastic components affecting v and a and the strength of its influence on an individual is determined by constant amplitudes A.

The equation

$\dot{v}_i = F_{v_i}[h, v_i(t)] + A_{v_i}\xi_v(t)$

describes the change of valence $\dot{v}$ of an agent i given the emotional charge of the communication field h, while

$\dot{a}_i = F_{a_i}[h, a_i(t)] + A_{a_i}\xi_a(t)$

describes the change in arousal $\dot{a}_i$ of the same agent. The perception functions F_v and F_a define the changes in v_i and a_i that are caused by different values of h and the sign of $|h|$. Furthermore, the unique stochastic components A and ξ are added that account for unpredictable factors in emotional changes of individuals (e.g. multiplicative noise).

The functions

$F_v[h, v_i(t)] = h * [b_0 + b_1 v_i(t) + b_2 v_i(t)^2 + b_3 v_i(t)^3]$

and

$F_a[h, a_i(t)] = |h| * [d_0 + d_1 a_i(t) + d_2 a_i(t)^2 + d_3 a_i(t)^3]$

define how the state variable v_i is affected by the the field variable h, while a_i is affected by the absolute value of the field variable $|h|$. Their change is determined by the constant coefficients b and d.

- v valence
- a arousal
- i agent instance
- F perception function
- h field variable
- t point in time
- A amplitude
- ξ stochasticity
- b valence change coefficients
- d arousal change coefficients

II. Expression

Submodel expression describes how agents express the valence of their emotions by creating an *expression variable* that is a function of the sign of its valence and activated when their arousal surpasses an individual *arousal threshold*. It is based on an equation that includes the assumption that agents do not communicate all details about their emotions, but only whether it is a positive or negative emotion. The expression of emotions also causes an immediate down-regulation of valence and arousal by a constant factor.

Expression variable s of agent i is a function of the sign of its valence v, but only stores a positive or negative value (1 or -1) if its arousal a is larger than the arousal threshold τ.

The equation

$s_i(t) = sgn[v_i(t)]\Theta[a_i(t) - \tau_i]$

describes the relationship between s_i and the sign of v_i as a Heaviside step function Θ. If a_i is larger that τ_i, then s_i stores a positive value when v_i is likewise positive, or a negative value when v_i is negative. Else, no expression is triggered when a_i does not pass threshold τ.

In case an emotion was triggered, the values a_i and v_i are instantly down-regulated using the formulas

$v_i(t) \leftarrow [v_i(t) - b_i] * k + b_i$

and

$a_i(t) \leftarrow [a_i(t) - d_i] * k + d_i$

that adjust the distance of v_i and a_i to their respective baselines b_i and d_i by a proportional value relying on the constant factor k.

s_i expression variable

Θ Heaviside step function

τ arousal threshold

b_i valence baseline

d_i arousal baseline

k down-regulation factor

III. Satiation

Satiation describes the process of determining if an agent drops out of the simulation due to reaching a satiated emotional state by creating a *satiation variable*. It is based on a quadratic *satiation function* of agent arousal and accounts for random influences on the emotional state of an agent. The agent may become satiated given a certain probability that is derived from its arousal.

The satiation variable n of agent i is assigned a value when the output of the quadratic function S is larger than stochastic component ξ (a random number between 0 and 1). The satiation function S describes the probability of the agent dropping out, which is determined by the absolute value of arousal a.

Satiation variable n_i only stores a value if function S is larger than ξ is formalized by

$n_i(t) \leftrightarrow S[a_i(t)] > \xi$

whereas $0 \leq \xi \leq 1$. Satiation function

$S[a_i(t)] = |a_i(t)|^2$

squares the absolute value of a_i and returns a value representing the probability of an agent reaching a satiated state at time step t.

n satiation variable

S satiation function

IV. Relaxation

The relaxation submodel describes the individual relaxation of the valence and arousal of agents towards their *baseline* values using specific *decay parameters* that are unique to every agent and to its respective state. It is based on an equation that assumes an exponential decay of valence and arousal in agents over time.

The state variables valence v and arousal a of agent i at time t are reduced by a combination of their initial values minus their baseline times the decay parameters γ (which vary for each agent and are different for valence and arousal) that define the time-scale of this decay. This decay represents the relaxation of emotional states towards the baseline values.

The functions

$R[v_i(t)] = -\gamma_{v_i}(v_i(t) - b_i)$

and

$R[a_i(t)] = -\gamma_{a_i}(a_i(t) - d_i)$

specify the relaxation of valence v_i and arousal a_i towards their respective values b and d given the decay parameters γ.

R relaxation function

γ decay parameter

V. Communication

This submodel describes how the emotional charge of the field changes when agents express their emotions. It is based on a function that calculates aggregates of all positive and negative *agent expressions*.

While N is the total number of agents with an either positive or negative expression variable, s is a fixed amount by which the field variable increases or decreases for every agents that expresses its emotions. In addition to agent expressions, the decay parameter γ represents a decrease in impact of emotional information on agents over time.

Equations

$\dot{h}_+ = s_h N_+(t) - \gamma_+ h_+(t)$

and

$\dot{h}_- = s_h N_-(t) - \gamma_- h_-(t)$

calculate the emotional charge of the respective positive or negative field variables h_+ or h_- using the total number of agents that contribute to the field N in combination with a fixed impact variable s. Additionally, the decay parameter γ_+ and γ_- account for a loss of emotional impact over time. While

$h = h_+(t) - h_-(t)$

creates a total of the emotional charge of the field that is either positive or negative, using the field variables h_+ and h_-.

h_+ (positive) field variable

h_- (negative) field variable

s_h impact variable