MODELLING OF ANXIETY SPREAD DURING PANDEMIES

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Introduction

The study aims to develop a hybrid model of pandemic spread of anxiety and panic, calibrated through indirect social anxiety and emotion level indicators.

The developed hybrid model combines agent-based modeling (ABM), dynamic systems modeling with differential equations (SD) and machine learning (ML) methods.

The costs of the COVID-19 on mental health are still being counted, but the preliminary analysis points out the statistically significant increase in the rates of anxiety, stress, poor sleep quality, and unsatisfactory psychological well-being (Escudero-Castillo et al., 2021).

Cognitive anxiety model

Anxiety is one of the primary emotions and a multidimensional reaction to actual or potential dangers.

It combines somatic, cognitive, emotional, and behavioral components representing evolutionary mechanisms to survive or cope with the threatening stimuli, but under certain circumstances, the response might become excessive or maladaptive and manifest in anxiety disorders

The cognitive model of anxiety and anxiety disorders refers to distorted cognitive processes.

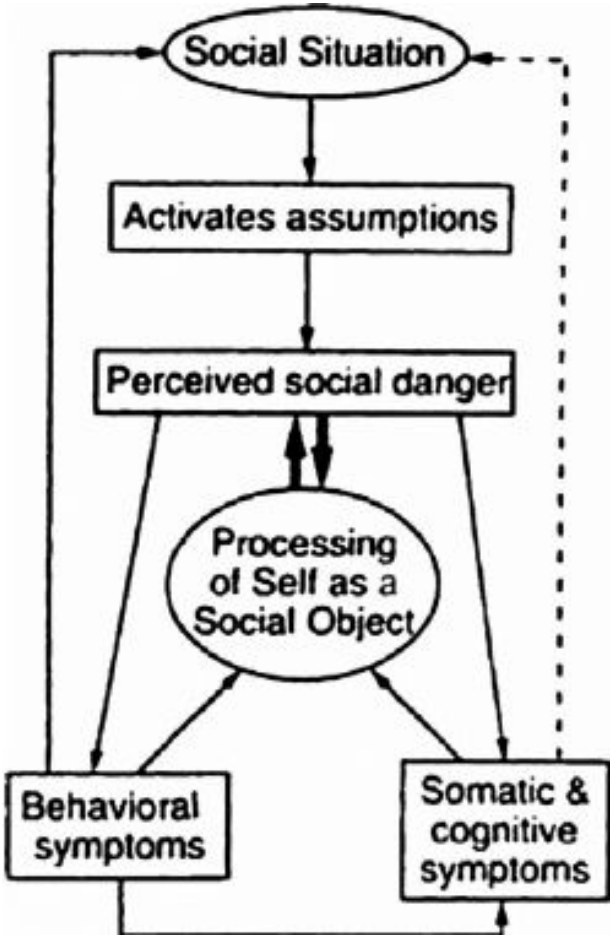
Abnormalities in an appraisal or biased information processing play a central role in triggering anxiety and its disorders (Clark and Beck, 2010).

Furthermore, cognitive specificity of misleading beliefs is considered predisposing or maintaining anxiety. Anxiety sensitivity, intolerance of uncertainty, and pathological worry are among the central concepts related to the cognitive model of anxiety.

Cognitive model of health anxiety (Witthöft & Hiller, 2010) assumes that mild symptoms (e.g., faster breathing) might be interpreted as signs of a serious illness, and this interpretation might lead to an increase in anxiety which in turn will lead to overestimation of symptoms.

Research on earlier pandemics found that overestimation of the threat is associated with increased anxiety

From the point of view of cognitive anxiety theory (*Clark and Beck, 2010*), an important part of the anxiety mechanism is the stimuli that trigger it, which become negative information that spreads in the social space.



Because direct investigation of the prevalence and spread of anxiety and related panic is a complex task, coronavirus morbidity data and indirect anxiety indicator data will be used to calibrate and verify the developed model, which is identified using machine learning algorithms.

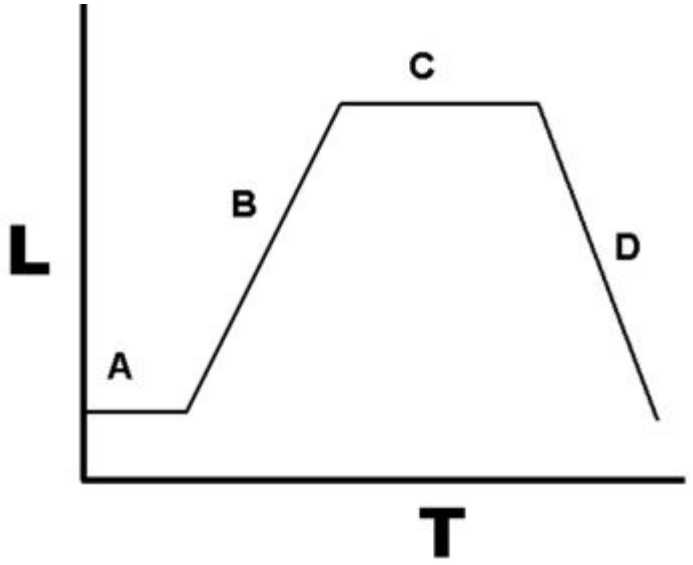
Dynamic SEIR model

The SEIR model has been implemented for modelling of COVID-19 infection spread taking into account the non-symptomatic case of desease as exposed (latent infection):

Susceptible-Exposed-Infected-Recovered

$$S \rightarrow E \rightarrow I \rightarrow R$$

Taking into account the dynamic change of respiratory pathogen activity (RPA) the characteristic function of PA is implemented, identified with respect to statistical infection data (*Wijngaard et al, 2008*).



Finally, the model with demographic factors is presented by system of differential equations (Brauer & Castillo-Chávez (2001) :

$$\frac{dS}{dt} = b \cdot S - \alpha \cdot S \cdot I - d \cdot S$$

$$\frac{dE}{dt} = \alpha \cdot S \cdot E - \beta \cdot I \cdot E - d \cdot E$$

$$\frac{dI}{dt} = \beta \cdot E \cdot I - \gamma \cdot I - dt \cdot I$$

$$\frac{dR}{dt} = \gamma \cdot I - d \cdot R$$

Note, parameters of the system are estimated according to applied PA characteristic function.

Anxiety Spread Modelling

The spread of anxiety and panic associated with fear of contracting a viral disease is a characteristic feature of pandemics (Blakey & Abramovitz, 2017).

Anxiety is described and measured using the methods of management psychology, or psychometrics.

For instance, according to the Spilberger method (*State-Trait Anxiety Inventory, Tilton, 2008*), 4 levels of anxiety can be distinguished, starting from the lowest to the highest.

Note, certain individual enxiety levels may be associated with panic behavior.

Thus, 4-level anxiety spread dynamic model is developed:

$$P1 \leftrightarrow P2 \leftrightarrow P3 \leftrightarrow P4$$

$$\frac{dP1}{dt} - a(I) \cdot P1 \cdot P2 + b(I) \cdot P2$$

$$\frac{dP2}{dt} = a(I) \cdot P2 \cdot (P1 - P3) + b(I) \cdot (P3 - P2)$$

$$\frac{dP3}{dt} = a(I) \cdot P3 \cdot (P2 - P4) + b(I) \cdot (P4 - P3)$$

$$\frac{dP4}{dt} = a(I) \cdot P3 \cdot P4 - b(I) \cdot P4$$

$$P_1(t) + P_2(t) + P_3(t) + P_4(t) = 1$$

Note, the model implemented considering for simplicity the ratio of transition to adjacent level to be constant.

Of course, the coefficients of transition *a* and *b* may differ in different equations, as well as the transition from one level to other may depend on the proportion of the population accumulated at levels of higher anxiety, and so on.

The application of different modeling paradigms allows to examine this complex socio-psychological phenomenon at different levels of abstraction: from aggregated population-wide dynamics (SD) to the interaction of individuals and their groups with each other and their environment (ABM).

In constructing the model of anxiety due to the spread of infection, it can be assumed that the anxiety spreading factor ***a*** depends on the extent of the infection and is equal to $a(I)$, where I is the volume of infected ones.

The number of infected I might be taken from statistical data or calculated according to SEIR model of the infection spread, developed above.

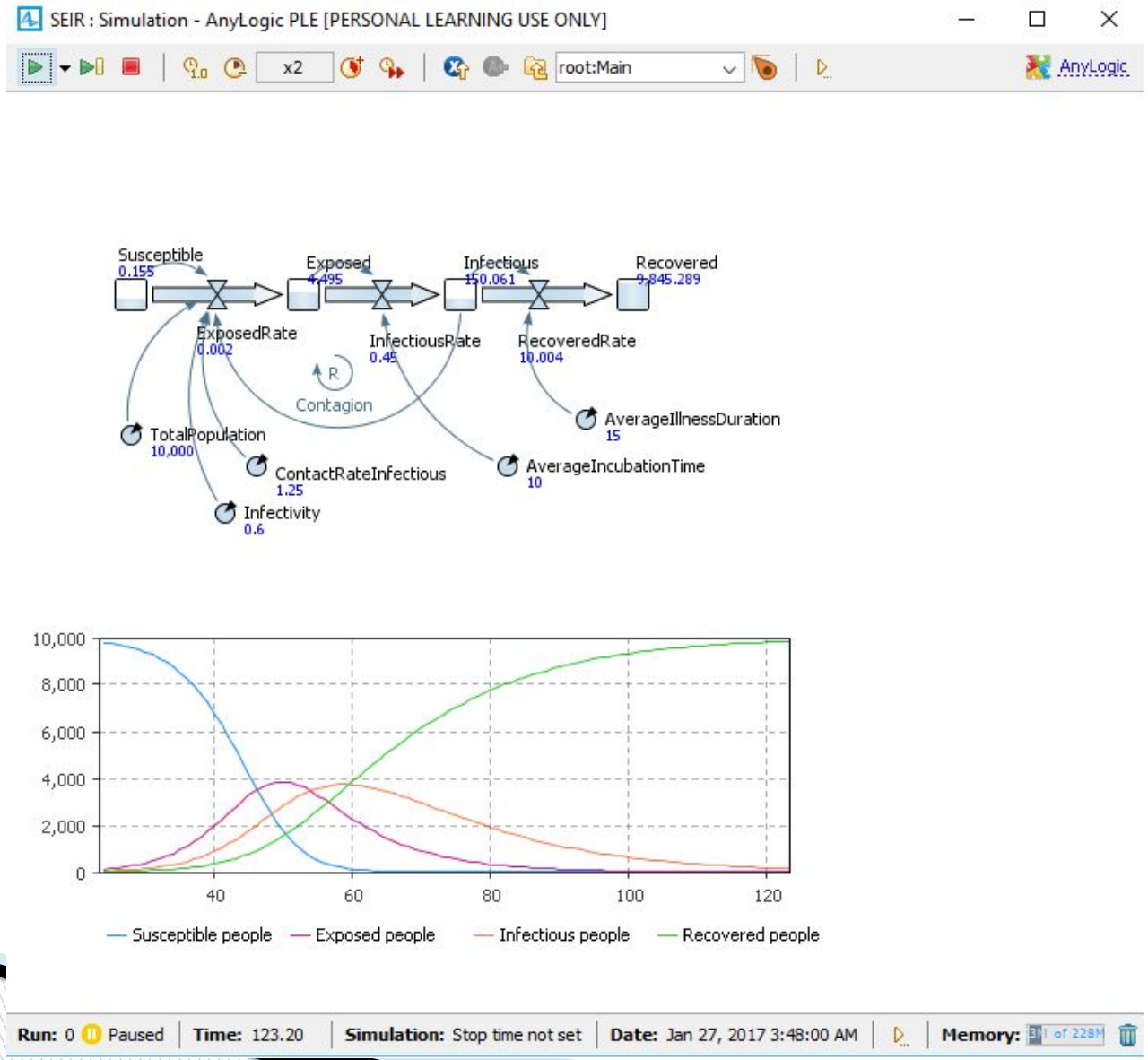
Of course, this dependence is stochastic, however intensity of relation shows either anxiety spread is related with infection or this spread is caused by self-generation within information media.

Model Implementation and Computer Simulation

The proposed hybrid model is implemented using the *AnyLogic* modeling system because it supports 3 main simulation modeling paradigms (SD, DE, ABM) and helps the development of hybrid models.

By the way, the implementation of the SEIR model in the AnyLogic system using the above system of differential equations and describing it with the system dynamics diagrams looks like this (so far, without demographic factors).

Example of system dynamics diagram and simulation in *AnyLogic*



Opinion mining for stimuli modeling

One of the possible reflections of public anxiety is the content of social media (*Bjorkdahl & Carlsen, 2017, Kumar et al., 2020*).

Due to this opportunity the **sentiment analysis** is performed to identify and extract subjective information about anxiety and emotional level from the web media content.

In this way, the application of machine learning methods helps us to identify additional variables and their properties in the development of a hybrid model.

Sentiment analysis, in context of this research, is a process of retrieving information about a public's perception of information published in news and social media.

News has direct impact to public anxiety through news publications. With help of sentiment analysis in news the influence of media to people anxiety levels is modeled and explored.

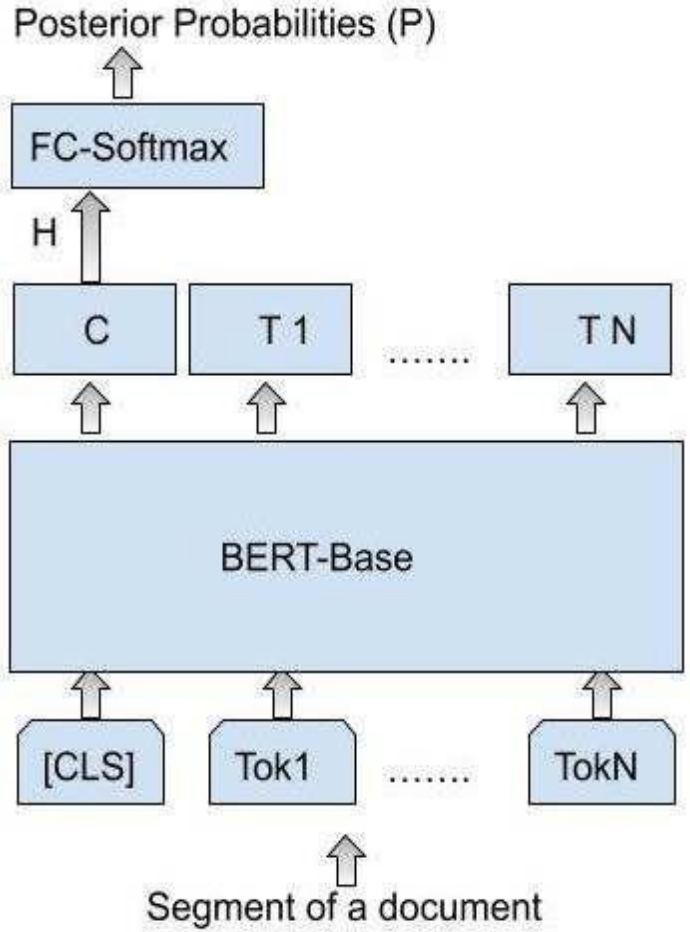
A Bidirectional Encoder Representations from Transformers (BERT) is used for sentiment analysis in the hybrid model.

Applying the bidirectional training of Transformer, a popular attention model, to masked language modelling can have a deeper sense of language context and flow than single-direction language models.

News media classification to anxiety level is performed with a method created by Raghavendra Pappagari, et al.

(*Raghavendra Pappagari et al. 2019. Hierarchical Transformers for Long Document Classification. arXiv:1910.1078*)

The model takes BERT as a base and is trained to classify defined anxiety classes.



Discussion and conclusions

- The hybrid model of pandemic anxiety and panic dynamics is developed, which consists of two sub-models: a modified infection spread SEIR model and a 4-level anxiety spread dynamic model.
- Taking into account the seasonal, etc., changes in respiratory pathogens activity, the characteristic function of RPA change is implemented in the model.
- The model is calibrated through indirect social anxiety and emotion level indicators, taken from statistical data and/or web content.

- The developed model combines agent-based modeling, dynamic systems modeling with differential equations and machine learning methods.
- The model presents a tool for the analysis, forecasting and management of anxiety and related panic scenarios during various quarantine scenarios.