Modeling public fear under the information environment of emergencies as COVID-19 and wars

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Abstract. Under the recent pandemic of corona-virus disease COVID-19, people have repeatedly reacted to the information concerning the spread of the epidemic, which has flooded in our society throughout the whole time. By using the statistical data obtained in Japan, a mathematical model treating the relation between the information environment and the public reaction caused by fear is proposed. The input quantities for this model are the time-varying environment of information on the COVID-19 together with the amount of public communication or the amount of information search on the COVID-19 via the SNS. Between those two quantities, we introduce three variables such as the amount of information released by the news media every day, the novelty of information, and the extent of people's surprise to the information. Regarding the amount of information, we use the real quantity observed in Japan, whereas the novelty of information is related to the so-called oblivion function by which the extent people forget the information in the past is given. Two types of oblivion function, the power-law type and the exponential type, are introduced. On the other hand, the extent of people's surprise by the information on COVID-19, which is determined so as to make sure the consistency of the model as a whole, has revealed to have sharp peaks at the earliest time of the pandemic, and the beginning of every emergent-state declarations over eight times. Such a reaction around the people's surprise is due to the emotional contagion in the fearful field of information environment. To compare the time-dependent trend of those variables to the other cases of social events, we have introduced the case of Ukraine-Russia conflict reported in Japan since 1 January 2022. The people's surprise in this case has revealed that people astonished only at the first time of the conflict, without any surprise after that even the novelty of information has been high. Discussion was made on the sources about the difference regarding the people's surprise between the cases COVID-19 and Ukraine-Russia conflict.

1. Introduction

The author has proposed a mathematical model, which relates the amount of news released in the society to the public reaction such as the search for more reliable information under the circumstance of emergency of COVID-19, by using the preliminarily data up to September 2021 in Japan [1]. The public behavior of information seeking during the period from February to April 2020, when a sort of panic had prevailed among Japanese, clearly showed the abrupt increase of the amount of communication among people via the SNS. The time-varying feature of the communication has revealed to be composed of three stages as 1) the sudden occurrence of communication among people caused by the insufficient information and mysterious fear, 2) the transient phase of communication and 3) the roughly-equilibrating phase of communication with the news reporting the emergency in the society. Here the public behavior as such was assumed to originate from the unknown and weird character of the disease and the fearfulness and disgust to the virus. The strength of such emotion was

also assumed to be proportional to the amount of communication via the SNS and the information retrieval via the Internet, which are considered as information-seeking behaviors. Such behaviors are originated from the compensation of anxiety and uneasiness about the lack of reliable information. In such a case the society can be treated as a single reactor immersed in a homogeneous environment where the emotion is oriented to a given direction. The collective behavior of the public as a whole was, therefore, also considered as caused by the emotional contagion of fear and disgust from the information environment regarding COVID-19. We should note that situations as such are realized also in music halls and theaters, or some type of deeply impressed lectures which cause some moving emotion in the audience common to all [2,3].

Our mathematical model for deriving emotional quantities under the condition of emergent climate is outlined in Section 2. In Section 3 applying the statistical data up to 31 March 2023, together with the data of time-varying public fear to COVID-19 derived by using the public opinion survey, we investigate the appropriateness of the form of so-called oblivion function and the extent of time–varying surprise of the Japanese during the whole period of COVID-19 event. To compare the variables for COVID-19 to the other emergent event, we study the case of Ukraine-Russia conflict during 1 January to 31 March in 2023 in Section 4, and concluding remarks are made in Section 5. From what type of news media we acquire the primary information regarding those social events depends on the circumstance of the society different from every country. It also depends on the difference of society and public sensitivity on the matter how the every-day information diffuses into the society, and what reactions of people are resulted from the information. A model for the Japanese society is, therefore, proposed here by using real data in Japan, but it is well applicable for any society by adjusting values of several variables and constants.

2. Mathematical model

Figure 1 shows the schematic figure of our model. The emotion induced strongly in all people by the contagion from the information environment is almost unpleasant and energetic [4]. We suppose it as a negative and fearful emotion so that, in what follows, we exemplify the public fear of a corona virus disease and the fright of a war. The strength of the fear people feel at time t from the information environment, $\xi(t)$, is assumed to be given by

$$\frac{d\xi}{dt} = -c_1 \frac{\xi}{\tau} + c_2 \cdot \varepsilon(t) \cdot I_{evn}(t) \cdot \Delta(t) \tag{1}$$

where c_1 and c_2 are constants, τ is the time scale for the variable ξ, I_{env} is the strength of information environment, ε is the novelty of the information and Δ is an extent of emotional contagion which is a factor connecting the fear ξ and the information environment.

We assume the extent of the fear proportional to the strength of the information environment which, in turn, is proportional to the strength of information seeking by people. Differentiating equation (1) and substituting the ξ by the number of people's access to the SNS or the Internet per unit time, which indicate the strength of information seeking by people, $x(t)$ [1], we obtain the quantity Δ as

$$\Delta(t) = MAX\left[\frac{1}{c_3 \cdot \varepsilon(t) \cdot I_{env}(t)} \left\{ x(t+1) - x(t-1) + \frac{2}{\tau} x(t) \right\}, 0 \right] \tag{2}$$

where c_3 is a constant and MAX[a, b] is the maximum of either a or b. The quantity $\Delta(t)$ depends on the difference of the strengths of public's information seeking before and after the time t. Such dependence on the difference x(*after event*)-x(*before event*) indicates the extent of unexpectedness of the event which occurs at t, so that it resembles the dependence of a surprise function [5]. We therefore call the quantity $\Delta(t)$ as the surprise factor which represents the extent of surprise caused by the emotional contagion. The second term on the right-hand side of equation (1) is a source term for the variation of the ξ., which indicates the public emotion such as fear, being derived by the product of the

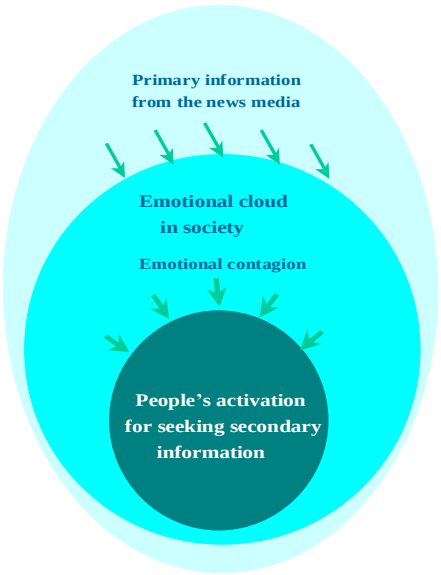

Figure 1. Schematic figure for the diffusion of negative information in the society

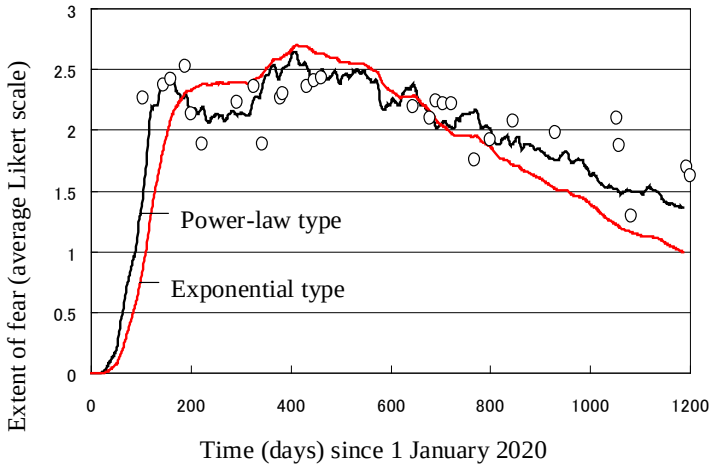

Figure 2. Time variation of the extent of public fear against COVID-19 in Japan. Circles are average Likert number derived by using public opinion surveys, and black and red solid lines are the time dependent memories of negative information people possessed, which were calculated by using the oblivion functions of the power-law type and of the exponential type, respectively

strength of the novelty of information (which is given by the product of the extent of the novelty and the amount of information) and the extent of surprise by the information.

The extent of novelty of information $\varepsilon(t)$ is assumed to be given by a learning curve which is a function of the extent of public memory $Z(t)$ regarding the event considering. Approximating an exponential form, the $\varepsilon(t)$ is given by

$$\varepsilon(t) = \exp\left(-\gamma Z(t)\right) \tag{3}$$

where γ is a constant. On the other hand, the $Z(t)$ is given by

$$Z(t) = c_4 \int_0^t I_{env}(t) \cdot \omega(t', t) dt' \tag{4}$$

where c_4 is a constant and $\omega(t', t)$ is the fraction of the information released at t', which remains to be memorized by people until t. The $\omega(t', t)$ is called the oblivion function for which the following two forms of a power-law type and an exponential type are introduced [6] for the comparison of its appropriateness.

$$(I) \quad \omega(t', t) \propto g \cdot \left(\frac{t_0}{t_0 + t - t'} \right)^k + (1 - g) \tag{5}$$

$$(II) \quad \omega(t', t) \propto g \cdot \exp\left(-\frac{(t - t')}{t_0} \right) + (1 - g) \tag{6}$$

where t_0 and k are constants so as to be determined as they reproduce some observational data, and g is

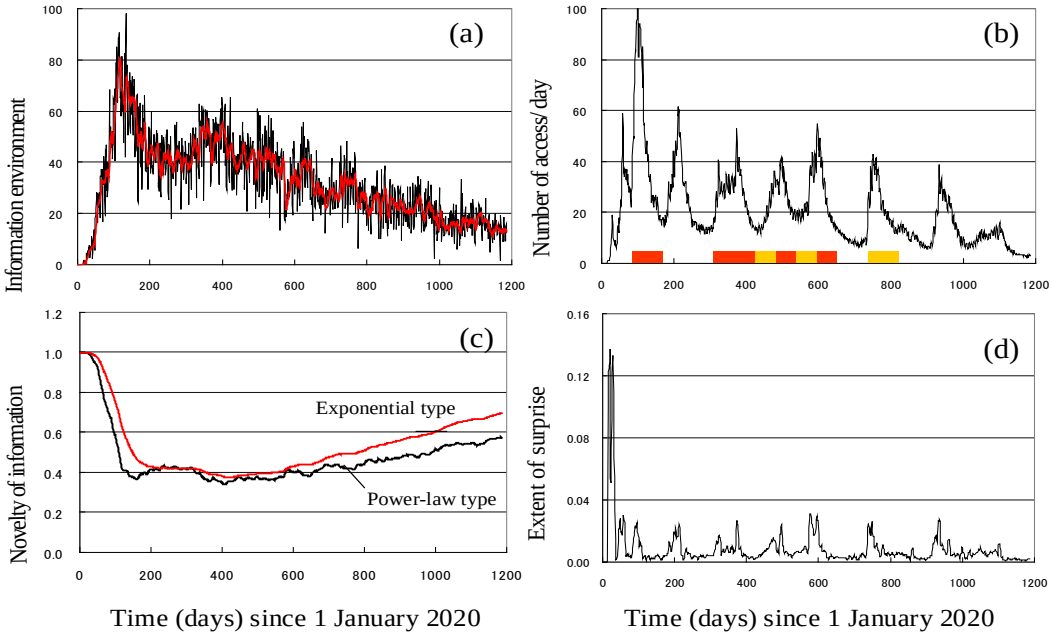

Figure 3. (a) Time variation of the strength of information on COVID-19 released by the new media in Japan where a red line is the seven days moving average; (b) The number of access to Google search. Red and yellow bands indicate the periods of the declaration of the state of emergency and the semi-state of emergency in Tokyo, respectively; (c) The time behavior of the novelty of information newly released on COVID-19; and (d) The extent of public surprise by the information. This is the seven days moving average of the surprise

the fraction by which people finally forget information.

More precise description of the model is given in a previous paper [1].

3. Public emotion relating to COVID-19

Here we use [day] as a unit of time and see the time-varying feature of variables on and after 1 January 2020 when we set t=1. The secular variation of the observed fear people felt to COVID-19 is shown in figure 2 by circles. The ordinate shows an indicator of people's fearfulness P which was derived by using Likert number r_i and the data of public opinion surveys executed during the period of COVID-19 regarding the fearfulness and the risky feeling of people against the infection of the disease [7-9] as $P = \sum_i r_i \cdot p_i$, where p_i is the rate people select the i'th choice in the choices of question. Quantity P=0 corresponds to the state people never feel fearfulness, whereas P=3 to the sate people feel maximum fearfulness. According to figure 2 people's fear seemed rapidly increased up to t=100~200, became minimum and maximum at around t=200~300 and 400~500 respectively, gradually decreased after that with several bumps of small maxima and minima.

Figure 3(a) shows the secular variation of the intensity of information environment in Japan up to 31 March 2023 (t=1186), the derivative method of which is given in the previous paper [1]. The interest in COVID-19 by the news media seems to have decreased in t>400 although a wavy feature has appeared several times in t>400 in the released amount of information. Figure 3(b) shows the frequency of information search on Google with a key word *corona*, which we consider as an indicator for people to compensate their anxiety due to the shortage of information.

When people are immersed in an environment of negative information, the quantity $Z(t)$ is

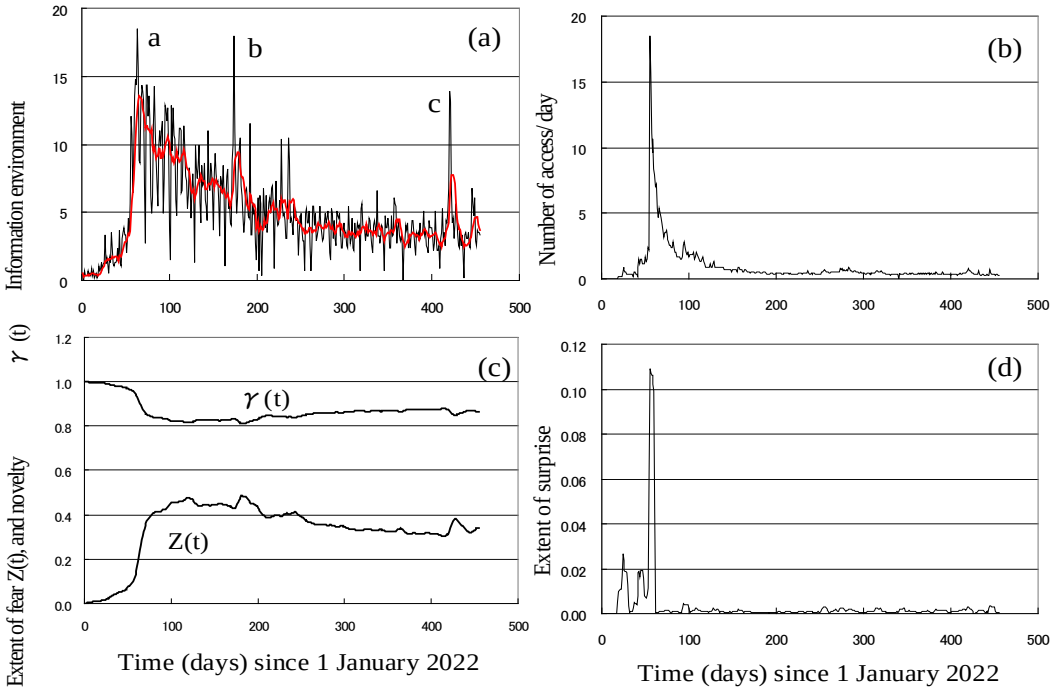

Figure 4. (a) Time variation of the strength of information on Ukraine-Russia conflict released from 1 January 2022 by the new media in Japan where a red line is the seven days moving average. See the text about the peaks a, b and c; (b) The number of access to Google search with a key word *Ukraine*; (c) The time behavior of the novelty of information newly released and the extent of public memory on Ukraine-Russia conflict; and (d) The extent of public surprise by the information. This is the seven days moving average of the surprise

considered to be proportional to the extent of negative emotion held in people [1,6,10]. Hence the time dependent behavior of Z(t) for the case of COVID-19, for instance, might be resemble to the secular variation of people's fear shown in figure 2. We show two curves for the Z(t) corresponding to the above respective functions (I) and (II) for oblivion in figure 2, for which constants were determined so as the index defined by $\Xi = \left\{ \sum_{i=1}^{n} \left[Z(t_i) - P(t_i) \right]^2 / n \right\}^{1/2}$ becomes minimum. The values of the Ξ thus determined are respectively Ξ(I)=0.275 with t_0=1.45 and k=0.947 for the type (I), and Ξ(II)=0.440 with t_0=16.84 for the type (II) both for g=1.0, which infers a favorable form of the power-law function (I) as compared to the exponential one (II) for the oblivion function. We therefore adopt the type (I) form in what follows.

By using the quantity Z(t) with such a behavior we show in figure 3(c) the time-varying novelty of information by using equation (3). The novelty people felt decreased rapidly around t≃100, after that it was almost constant or gradually increased with time. On the other hand figure 3(d) shows the seven days moving average of the quantity Δ(t), which as noted before gives an indicator for people to be surprised by the information of COVID-19, that is the extent of the emotional contagion people received from the information environment from time to time. The Δ(t) became maxima at the very first time of the epidemic and every beginning of the spreading wave of the disease with much weaker values than that of the beginning at t ≃100.

4. The case of Ukraine-Russia conflict

Figure 4(a) shows the variation of the amount of primary information released by the news media in Japan during 1 January 2022 (when it was set as t=1 with a unit of [day]) to 31 March 2023 (t=455), which was derived by the same statistical method as the COVID-19 case. The unit of the ordinate of this figure is the same as that in figure 3(a) so that the intensity of the information environment was weaker to about 20% than the case of COVID-19. Three tremendous peaks have appeared in the information, *a*, *b* and *c*; the peak *a* at 4 March 2022 (t=63) corresponds to just one weak after the invasion of Russia, where the overseas evacuation of Ukrainian and various difficulties caused by this conflict were largely reported. The peak *b* is at 23 June (t=174) corresponds just to the Okinawa memorial day in Japan and four months after the beginning of this conflict so that many reports appeared regarding the antiwar ideas and movements. On the other hand the peak *c* is at 24 February 2023 (t=420), when it is just one year after the outbreak of the conflict, corresponds to the news reporting the state of agglutination of the war.

Figure 4(b) is the distribution of the number of information search on Google with the key word "*Ukraine*". The maximum scale of this ordinate is assumed as (maximum amount of media release per day for Ukraine-Russia case)/(maximum amount of media release per day for COVID-19 case)$\times$100. The primary information shown in figure 4(a) has a maximum at 4 March (t=63), whereas the number of information search in (b) only had one sharp peak at 24 February (t=55) when the first report on the outbreak of this conflict was released from the news media with an amount of relatively small scale. Although people sensitively reacted to this emergent news to result in seeking more precise and reliable information, which caused the early peak at t=55 in figure 4(b), they seemed rapidly to lose interest after that without requiring any information about it.

Figure 4(c) shows the extent of information of this issue memorized by people $Z(t)$ with the use of the oblivion function of the type (I) where we have used constants as the same value as COVID-19, together with the novelty of information $\varepsilon(t)$. Whereas in figure 4(d) shown is the emotional contagion factor Δ(t), that is an indicator by what extent people were surprised by the war. The unit of the ordinate of figure 4(d) is also the same as figure 3(d) so that this figure indicates the relatively weaker strength of the surprise caused by the war occurring in Europe far from Japan, even at its initial time around t=55, than the case of COVID-19 in Japan.

4. Concluding remarks

Since January 2020 negative climate regarding an infectious disease of COVID-19 has been formed via the information released primarily by the traditional news media and Internet news sites. Emotions as anxiety and fear against corona virus have been brought in people who have searched more precise and reliable information via the SNS and the Internet search. In this paper a mathematical model has been proposed which describes the relation between the public reaction of information seeking as such and the strength of information environment. With this model we have made clear that the oblivion function of the form of power-law type is much better than an exponential type to reproduce the extent by what fraction people forget the information obtained in the past. By using such an oblivion function, we have derived the extent of surprise people feels from the information on COVID-19 released every day. People's surprise thus derived has revealed to make a sharp maximum just at the beginning of the spread of disease and small local maxima at every occurrence of the waves of spread.

Such a model has extended to adopt another case of emergency, the Ukraine-Russia conflict which has been loudly reported since January 2022 in Japan, to compare the case of COVID-19. In the case of this conflict people were surprised by the information environment only just at the beginning of this conflict without any surprise after that even the novelty of information has been high. Such a behavior of people is quite different from the case of COVID-19, indicating that people's surprise is dependent on the extent of possible and direct risk of their life, which is imagined from the information environment. For the possible matter which may cause some risk on the lives of their own, people sensitively react to it to result in the surprise, leading the action of information seeking. But on the other hand when the event occurs in far from themselves, they only make a surprise just at the beginning. People's surprise rapidly disappears and does not continue after that without holding their

interest even the information is continuously released every day.

Although the COVID-19 was an unhappy event, it may become a happy event if the study newly finds relations between the public behavior and feeling and the negative information environment in emergency period by analyzing their relevant data.

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