修士論文要旨

A population dynamics model on the social damage by disinformation spread

偽情報の拡散による社会的損害に関する個体群動態モデル

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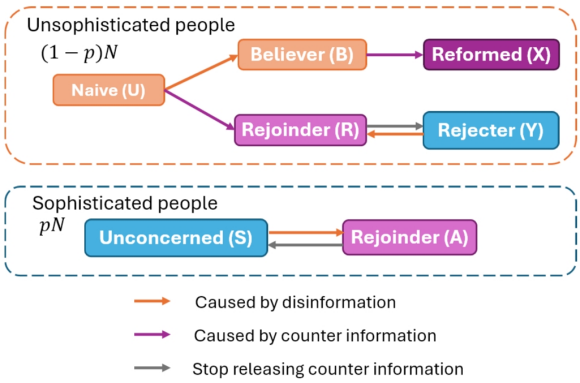
1 Introduction

The development of the Internet has made the exchange of information much easier and more convenient. However, the spread of disinformation also benefits from it. Since anyone on social media can spread information, it is difficult to verify the authenticity and accuracy of each piece of information. Especially during the time of social occasions, such as an election or a pandemic situation, the Internet is filled with various information from unreliable sources [1].

Some works discussed the spread of misinformation and its refutation [2]. In this work, we consider a population dynamics model for the reaction between a piece of spreading disinformation and its counter information in a netizen community. We consider a situation in which some members of the community can distinguish disinformation themselves. We use analytical and numerical results to discuss how the population structure of the netizen community will influence the social damage caused by the disinformation.

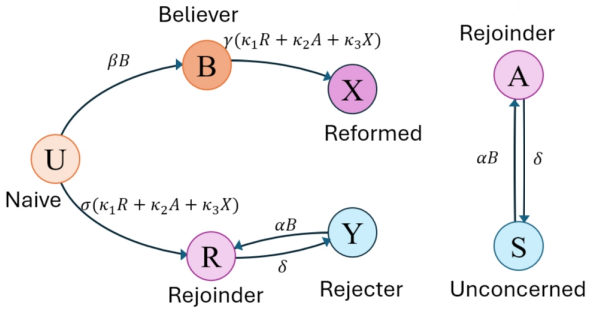
2 Assumptions



- The total population size does not change.
- People are classified into sophisticated and unsophisticated, based on their ability to identify disinformation. The classification does not change.
- Naive people (unsophisticated) may believe the disinformation and become believers.
- Believers spread disinformation. However, they may no longer believe the disinformation after accepting the counter information, becoming reformed people.
- Naive people can also accept counter information.
- Rejoinders release counter information. They may gradually lose interest in the information. Unsophisticated rejoinders become rejecters, sophisticated rejoinders become unconcerned people;
- Reformed people may release counter information;
- After accepting counter information, unsophisticated people will never believe disinformation;
- Sophisticated people will never believe the disinformation.
- After receiving disinformation, unconcerned sophisticated people and rejecters can be "activated" to be rejoinders and release counter information.

3 Mathematical model

N: Total population size;
pN: Population size of sophisticated people;
$(1-p)N$: Population size of unsophisticated people;
U: Population size of naive people;
B: Population size of believer;
R: Population size of unsophisticated rejoinder;
X: Population size of reformed believer;
Y: Population size of rejecter;
A: Population size of sophisticated rejoinder;
S: Population size of unconcerned people.



$$\frac{dU}{dt} = -\beta BU - \sigma(\kappa_1 R + \kappa_2 A + \kappa_3 X)U;$$
$$\frac{dB}{dt} = \beta BU - \gamma(\kappa_1 R + \kappa_2 A + \kappa_3 X)B;$$
$$\frac{dR}{dt} = \sigma(\kappa_1 R + \kappa_2 A + \kappa_3 X)U - \delta R + \alpha BY;$$
$$\frac{dX}{dt} = \gamma(\kappa_1 R + \kappa_2 A + \kappa_3 X)B;$$
$$\frac{dY}{dt} = \delta R - \alpha BY;$$
$$\frac{dS}{dt} = -\alpha BS + \delta A; \quad \frac{dA}{dt} = \alpha BS - \delta A.$$

β: coefficient of naive people believe disinformation;
γ: coefficient of believer stop believing disinformation;
σ: coefficient of naive people accept counter information;
κ_i: coefficient of releasing counter information ($i = 1, 2, 3$);
α: coefficient of rejoinder caused by disinformation;
δ: coefficient of rejoinder stop releasing counter information.

Initial state:

$$(U, B, R, X, Y, S, A) = (U_0, B_0, R_0, 0, 0, pN, 0),$$

where $U_0 > 0, B_0 > 0, R_0 \geq 0$.

4 Analytical results

CONVERGENCE OF STSTE:

$(U, B, R, X, Y, S, A) \to (0, 0, 0, X^*, Y^*, pN, 0)$ as $t \to \infty$.

SPECIAL CASE WITH $\delta = 0$, $R_0 > 0$, $A \equiv 0$:

With $\gamma = 0$:

$$(U, B, R) \to (0, B^*, R^*) \quad \text{as } t \to \infty,$$

where $B^* = (1-p)N - R^*$ and

$$R^* + B_0\Big(\frac{R^*}{R_0}\Big)^{\frac{\beta}{\sigma\kappa_1}} = (1-p)N.$$

With $\gamma > 0$:

$$(U, B, R, X) \to (0, 0, R^*, X^*) \quad \text{as } t \to \infty,$$

where $X^* = (1-p)N - R^*$.

With $\kappa_3 = 0$ and $\gamma = \sigma$:

$$(1-p)N = R_0 + \sum_{n=0}^{\infty} \frac{1}{\frac{n\beta}{\sigma\kappa_1} + 1}\Big(\frac{B_0}{U_0 + B_0}\Big)^n \Big\{R^*\Big(\frac{R^*}{R_0}\Big)^{\frac{n\beta}{\sigma\kappa_1}} - R_0\Big\}.$$

With $\kappa_3 = \kappa_1$, $\gamma = \sigma$ and $\beta = \sigma\kappa_1$:

$$(1-p)N = R^* + \sum_{n=1}^{\infty}(-1)^{n+1}\frac{1}{n!}\Big(\frac{B_0}{U_0}\Big)^n \times \Big\{(1-p)N\Big(\frac{R^*}{R_0}\Big)^n - \frac{1}{n+1}R^*\Big(\frac{R^*}{R_0}\Big)^n - \frac{n}{n+1}R_0\Big\}.$$

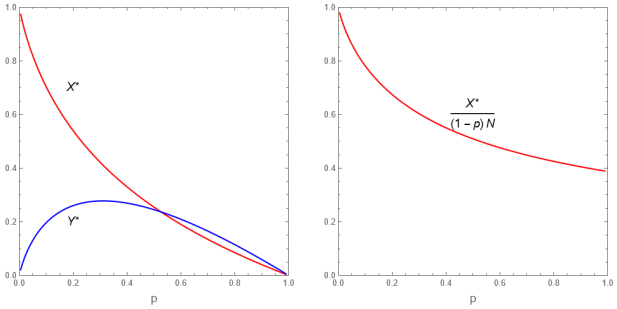
SPECIAL CASE WITH $\sigma = 0$:

$$(U, B, X, S, A) \to (U^*, 0, X^*, pN, 0) \quad \text{as } t \to \infty,$$

where

$$\begin{cases} U^* = 0, & \text{if } \kappa_3 = 0; \\ U^* > 0, & \text{if } \kappa_3 > 0. \end{cases}$$

5 Numerical investigation



$N = 1.0$, $\beta = 1.0$, $\kappa_1 = \kappa_2 = \kappa_3 = \kappa$, $\gamma\kappa = 0.8$, $\sigma\kappa = 1.5$, $\alpha = 5.0$, $\delta = 6.0$, $B_0 = 1.0 \times 10^{-7}$, $R_0 = 0.0$.

The social damage X^* monotonically decreases in terms of p. The risk of unsophisticated people being cheated also monotonically decreases in terms of p, but has an infimum that is positive.

6 Concluding remarks

From the numerical calculation, we found that a netizen community with a larger proportion of sophisticated people can suppress the social damage by disinformation to be smaller. The risk of unsophisticated people is also smaller in a community with a larger proportion of sophisticated people. However, this risk cannot be reduced to 0, which means that even though most people in the community are sophisticated, those unsophisticated people are still not totally safe.

We also explored other cases, with different properties of the netizen community. In those communities with no voluntary sophisticated people, it is necessary to have some external sources of counter information. Without them, the community can not clear out the disinformation itself. In these communities, more sophisticated people can decrease the social damage, but may not reduce the risk of unsophisticated people. Besides the voluntary behavior of sophisticated people, it is also important to have the counter information acceptable to unsophisticated people. Otherwise, the community would suffer a relatively large social damage.

References

[1] Cuan-Baltazar, J.Y., Muñoz-Perez, M.J., Robledo-Vega, C., et al. Misinformation of COVID-19 on the Internet: Infodemiology Study. *JMIR Public Health Surveill*, 6(2): e18444, 2020. https://doi.org/10.2196/18444

[2] Zhang, Y., Xu ,J., Nekovee, M., and Li, Z. The impact of official rumor-refutation information on the dynamics of rumor spread. *Physica A*, 607: 128096, 2022. https://doi.org/10.1016/j.physa.2022.128096