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Modeling and Simulation

Modeling the Impact of Education on Rumor Spread

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Abstract

Rumors are an important part of social interaction and their propagation has a significant impact on peoples lives. Rumors spread from an individual who knows of the rumor to an unaware individual in a way comparable to how diseases spreading from an infected person to one susceptible to infection. In this study, a variation of the SIR epidemic model is used to illustrate rumor spread. In this variation, the population is subdivided into educated and uneducated groups, assuming education correlates with technological proficiency. From this model, mean-field equations are derived to describe the dynamics of rumor spreading with consideration of a forgetting mechanism. Numerical solutions for the mathematical model (mean-field equations) were used to analyze the impact of various factors in rumor spreading. These factors include the individuals education, the network's average degree, as well as the rumor forgetting or stifling rate. Our results show that forgetting mechanism and stifling rate exert great influence on rumor spreading and that education has a large impact on rumor spreading trends.

Keywords: SIR epidemic model, Numerical simulation, Forgetting mechanism

1. Introduction

Rumors are a story or piece of information that has not been verified. The person telling the rumor does not know for certain its truth. People who spread rumors often do not bother to determine if the rumors hold any truth. Typically, rumors are spread from person to person and change slightly each time they are told. As a result, they can become exaggerated and otherwise altered over time. In recent years, social networks like Facebook and Twitter have eased the spread of rumors. They have played a crucial role in the recent uprisings of the Arab Spring and the London riots. It is quite remarkable that social networks spread news so fast [1]. Both the structure of social networks and the processes that distribute the news are not designed with this purpose in mind. On the contrary, they are not designed at all but have evolved in a random and decentralized manner.

The spreading of rumors is in many ways similar to the spreading of epidemics by the infectious to the susceptible. After being infected with the rumor, a spreader can become a stifler similarly to how a diseased individual can recover from infection after a some time [1]. Thus, many models for the spread of epidemics have been used to describe the spread of information in the form of rumors. The objective of this research is to simulate the process or rumor spreading using a variation of the SIR (Susceptible-Infected-Recovered) disease spreading model. In the model presented in this research, individuals are either $Ignorant$ to the rumor, $Spreaders$ of the rumor, or $Stiflers$ of the rumor. This research also takes into account the effect that the individuals' educations' have on the spreading of the rumor. It is assumed that educated groups of people both have better access to, and are more proficient in, communications

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technologies. Educated groups are thusly better networked with other individuals through online media such as social networks. The impact of education on rumor spread is modeled through the interactions between and within both educated and uneducated groups. This is done by constructing a mathematical model to analyze the impact of the various factors of rumor spreading.

This paper consists of six main sections. Section 2 describes details on related work. This is followed by a methodology in Section 3 which covers details on Structure of SIR model in rumor spreading process. Section 4 is devoted to numerical simulation. Section 5 provides a discussion of the results of the simulation as well as details on possible future works and Section 6 provides conclusions.

2. Related Work

Various models have been formulated to study rumor propagation. One pair of such models is the Daley-Kendall (DK) and Maki-Thompson (MK) models which are inspired by the S-I-R (Susceptible-Infected-Removed) disease epidemics model [2].

In the DK model, a closed and homogeneously mixed population is subdivided into three groups: those who are ignorant of the rumor, those who have heard it and actively spread it, and those who have heard the rumor but have ceased to spread it. These groups are called $ignorant$, $spreaders$ and $stiflers$ respectively [3]. The rumor is propagated through the population by pair-wise contacts between spreaders and others in the population. The behavior of this rumor spreading model follows the law of mass action. Any spreader involved in a pair-wise meeting attempts to 'infect' the other individual with the rumor.

In the Maki-Thompson (MK) model, the rumor is spread by direct contact between spreaders and others in the population. Furthermore, when a spreader makes contact with another spreader, only the initiating spreader becomes a stifler. The DK and MK models were not suitable for the study of rumor spreading processes in large-scale social networks [4]. These two models are also referred to as'classical models'.

An important shortcoming of the above class of models is that they do not take into account the topology of the underlying social networks along which rumors spread. This shortcoming can be attributed to either the use of highly simplified models of topology, or the use of models which assume a homogeneous mixing population. While such simple models may adequately describe the spreading process in small scale social networks via the word-of-mouth, they become highly inadequate when applied to the spreading of rumours in large social interaction networks[4].

In this media age, rumors spread faster than before [1]. The classical model flow chart of the rumor spreading process is modified by the SIR (Susceptible, Infected, and Recovered) model and thus makes the rumor spreading process more realistic and apparent. To differentiate from previous models which took the position that ignorants could stay ignorant after hearding rumors via spreaders, SIR model tried to show that ignorants will inevitably change their status to either spreaders or stiflers once they are contacted by spreaders. Moreover, the probabilities that a spreader becomes a stifler by contacting a stifler or another spreader are differentiated into η and γ. It has been found that the former probability is realistically bigger than the latter.

The Susceptible-Infected-Hibernator-Removed (SIHR) model is a new rumor spreading model. This model extends the classical Susceptible-Infected-Removed (SIR) rumor spreading model by adding a direct link from ignorants to stiflers and a new group called hibernators. The hibernator group embodies forgetting and remembering mechanisms of the SIR model [5]. The mean-field equations in the SIHR model consist of one additional equation than SIR model. These equations describe the dynamics of the SIHR model in social networks. The Nekovees rumor spreading model with forgetting mechanisms and the classical SIR rumor spreading model are special cases of the SIHR model [4]. At a steady-state, where the system reaches an equilibrium state, a transcendental equation of the SIHR model is obtained. The transcendental equation is as same as that of the classical SIR rumor spreading model.
In the whole process of rumor spreading, the number of spreaders first increases, then decreases, and finally reach zero when the rumor dies out.

The following equation measures the level of rumor influence:

$$R = final\, R(t) = \lim_{t\to\infty} R(t) = R(\infty) \tag{1}$$

R is a measure of the total population; meaning that when $R = 0.9$, 90 percent of individuals have heard of the rumor in the end of the simulation.

The 2SI2R rumor spreading model models the interaction of parallel rumors within an open homogeneous network [6]. This model starts with an assumption that there are two kinds of rumors spreading in the crowd, called Rumor1 and Rumor2. The whole population is divided into five distinct classes: $Ignorant$ (I), $Spreader1$ (S1), $Spreader2$ (S2), $Stifler1$ (R1), and $Stifler2$ (R2)[6]. The $Ignorant$ group is comprised of individuals who have not heard the rumors and are susceptible to being informed of the rumors. The groups $Spreaders1$ and $Spreaders2$ are those who spread Rumor1 and Rumor2 respectively. Finally, the $Stiflers1$ and $Stiflers2$ groups are composed of individuals who have heard Rumor1 and Rumor2 respectively but correspondingly will not spread them any more. During the time when rumors are being spread in a region, there are some people who come to this area and people who leave. Particularly, when using microblogging to spread rumors, some people register in the microblog to spread information and some people exit microblog in the meantime. So in contrast to classical rumor spreading models, an open population is considered. The vital dynamics include coming and going, and here were suppose the newly coming are all Ignorants. Each individual in the open population is represented as a node and each contact between two individuals can be regarded as an edge connecting the nodes.

The rumor spreading rules are demonstrated as follows: When a $Spreader1$ contacts an $Ignorant$, the Ignorant may become a $Spreader1$. Similarly, when a $Spreader2$ contacts an $Ignorant$, the $Ignorant$ may become a $Spreader2$. As mentioned earlier, classical rumor spreading models define that when a spreader contacts a spreader, the former one can become a stifler. However, in this model, the assumption is that when two spreaders contact each other, the former spreader finds that other people also spread the rumor and the rumor spreading may be considered a fashion. Therefore the former spreader is not as likely to convert to a stifler.

The shortcoming of this model is that the stronger the force of Rumor2 is, the faster Rumor1 dies out. If Rumor1 is considered as negative information and Rumor2 as the contrary information of Rumor1, Rumor1 spreading will be strongly overshadowed by Rumor 2 via the increased force of the spreading of Rumor2. If Rumor1 and Rumor2 are both negative information, it is shown that the bigger the influential force of Rumor2, the earlier the termination of both rumors in the system [6]. Finally the rumors of the 2SI2R model spread faster and terminate earlier in new media than in legacy media. Moreover, Rumor1 is more significant in new media and Rumor2 is more prevalent in legacy media.

There is also a rumor spreading model that considers a time-dependent forgetting rate [7]. The model is used to investigate the process of rumor spreading in small-world networks. From the numerical simulation of [7] it is observed how the forgetting mechanism affects the rumor spreading on LiveJournal when the parameters of the forgetting rate function vary. The main contributions are from the fact that the forgetting rate is not constant but changes over time. It is intuitive that the longer an individual is aware of a rumor, the higher the probability that s/he forgets it. This forgetting tendency over time has important implications for modeling rumor spreading.

In order describe the rumor spreading process [7] mean-field equations are established by classifying different spreaders with variable forgetting rates in the network. Hence, the other models which consider the forgetting rate as a constant become a special case of this new model. Numerical simulations are conducted on LiveJournal to further study the properties of the new rumor spreading model. Results show that variation in the parameters of forgetting rate function have important impacts on the final state of rumor spreading [5]. An increase of the initial forgetting rate will lead to a decrease of the rumor presence in the final state of the rumor spreading. The faster the forgetting speed is, the smaller the extent of such influence [8]. In addition to this, the final size of rumor presence on LiveJournal is much higher when the forgetting rate changes over time as compared to the case when the forgetting rate is constant [1].

3. Methodology

In the model introduced here, the population is subdivided into three main groups according to the perception and reaction of an individual to a rumor. These groups are labeled Ignorants, Spreaders, and Stiflers (represented by I, S and R respectively). In addition, there are two types of individuals identified in the model; the educated who use social media to spread rumor, and the uneducated who do not use social media. In order to distinguish the two types of individuals' in the model, the Ignorant and Spreader groups are distinctly partitioned into educated and uneducated subgroups. With respect to this, p_u represents the percentage of uneducated individuals of total population N and p_e represents the percentage of educated individuals of total population N. Rumors spread and fade away through contact between different individuals in these groups. The SSIIR model for the rumor spreading process is shown in Figure 1 for which uneducated and educated groups of individuals are participating. The figure, shown from the uneducated spreaders point of view, illustrates that at time t, a spreader spontaneously loses interest in or forgets about a rumor with probability δ_u. For educated spreader for same consideration, this probability is δ_e.

Stiflers have a negative effect on a spreader when the spreader tries to disseminate a rumor to a stifler. Suppose that stiflers choose not to propagate a rumor because of disbelief or disinterest. In such a case, an uneducated spreader turns into a stifler with probability η_u when individual contacts a stifler in uneducated groups and η_u in educated groups. If a spreader contacts another spreader in the rumor spreading process, they may have different versions of the rumor as a result of individual interpretation and representation of the rumor. In this situation, the initial uneducated spreader may change into a stifler with probability λ_u because individual may doubt the credibility of the rumor. Similarly, the educated spreader may change into a stifler with probability λ_e. With respect to realistic conditions, here both λ_u and λ_e are restricted to be smaller than η_u and η_e respectively, that is, $\lambda_u < \eta_u$ and $\lambda_e < \eta_e$.

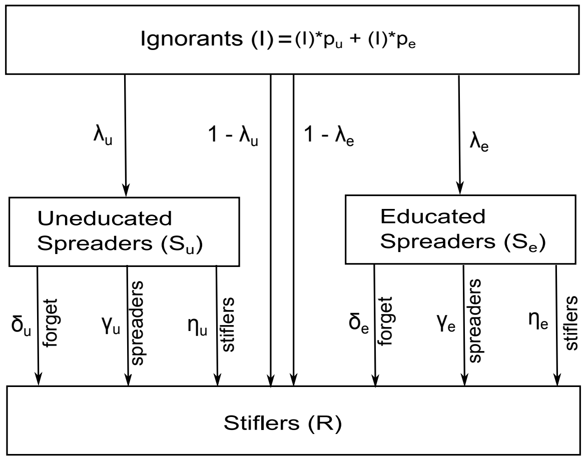


Figure 1: Structure of the SSIIR model for the rumor spreading process

From the ignorants' perspective, an ignorant who is unaware of the rumor will inevitably change status upon hearing a rumor from spreaders. Once individual has heard it at time t, if an uneducated ignorant has had contact with spreaders, then there is a probability of λ_u that individual disseminates the rumor and changes to a spreader and a probability of 1- λ_u that individual becomes a stifler. An educated ignorant in such a case, λ_e is the probability with which educated ignorant become spreader and 1- λ_e is the probability with which educated ignorant becomes a stifler.

The mean-field equations are described as follows:

$$\frac{dI(t)}{dt} = -\bar{k}_u p_u I_u(t) S_u(t) - \bar{k}_e p_e I_e(t) S_e(t) \tag{2}$$

$$\frac{dS_u(t)}{dt} = \lambda_u \bar{k}_u p_u I_u(t) S_u(t) - \bar{k}_u S_u(t)[\gamma_u S_u(t) + \eta_u R_u(t)] - \delta_u S_u(t) \tag{3}$$

$$\frac{dS_e(t)}{dt} = \lambda_e \bar{k}_e p_e I_e(t) S_e(t) - \bar{k}_e S_e(t)[\gamma_e S_e(t) + \eta_e R_e(t)] - \delta_e S_e(t) \tag{4}$$

$$\begin{aligned}\frac{dR(t)}{dt} = &(1-\lambda_u)\bar{k}_u p_u I_u(t) S_u(t) + \bar{k}_u S_u(t)[\gamma_u S_u(t) + \eta_u R_u(t)] + \delta_u S_u(t) \\ &+ (1-\lambda_e)\bar{k}_e p_e I_e(t) S_e(t) + \bar{k}_e S_e(t)[\gamma_e S_e(t) + \eta_e R_e(t)] + \delta_e S_e(t)\end{aligned} \tag{5}$$

4. Experimentation

The implementation of the SIR model was constructed in MATLAB using a system of differential equations representing the mean-field equations. Each of the three equations in the system is a Cauchy initial value problem. The method of solution used within MATLAB was the ode45 ordinary differential equation solver. This solver uses the Dormand-Prince method, a method within the Runge-Kutta family of numerical methods, to solve these equations.

The system is considered as a three-dimensional vector of differential equations of the first order where the initial condition of the vector of equations is also a three-dimensional vector.

4.1. SSIIR Model

Figure 2 shows the trends of the various groups of people in the population. There is minimal change in the model until the fourth day, during which exponential growth is observed. This is mainly due to only one person knowing the rumor at the beginning of the model. By the end of the tenth day, the model reaches a steady state with just under 96.8% of the total population being rumor stiflers. The following figures examine each of the groups in greater detail to examine trends within the groups and their causes.

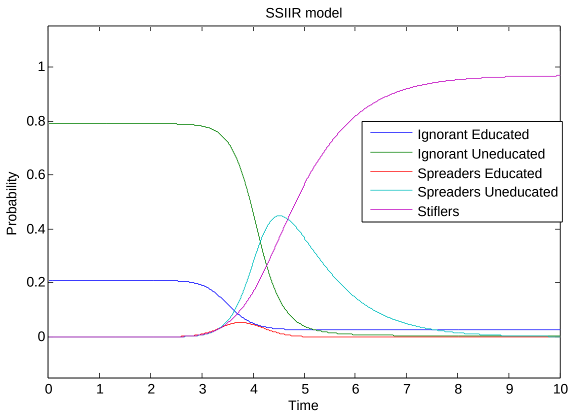


Figure 2: Structure of the SIR model for the rumor spreading process

4.2. Ignorant

Figure 3 shows the trending of both the uneducated and educated ignorant groups. There is minimal growth seen in the first three days in either group. Since the rate at which ignorant individuals become spreaders and stiflers is dependant on encounters between either of these groups, shrinkage of ignorant individuals can only be observed on a small scale until the populations of spreaders and stiflers become sufficiently large.

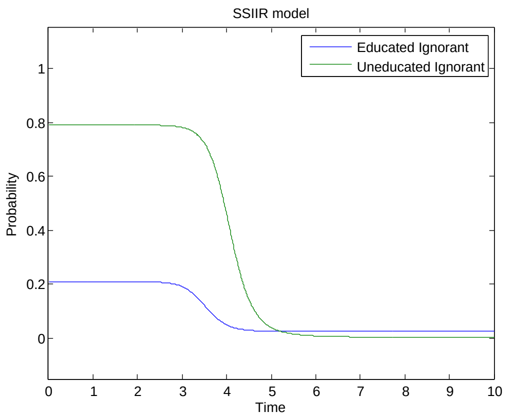
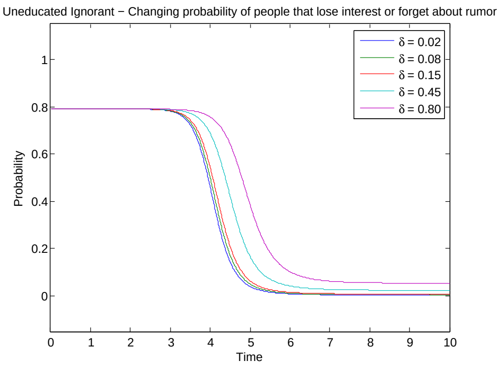
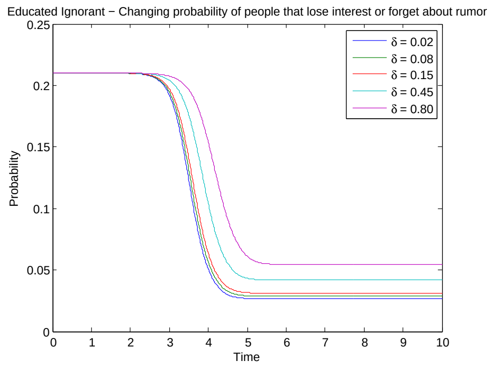


Figure 3: Population Shrinkage Trends in Ignorant Groups

The value of δ has a noticeable effect on the trend in shrinkage for both educated and uneducated ignorant individuals. Figure 4 shows that for both groups, as the value of δ increases, the population of ignorant individuals shrinks less and more slowly. This is because δ directly affects the rate at which spreaders become stiflers. This, by extension, stunts the growth of the spreader populations, which also by extension slows and lessens the shrinkage of ignorant populations. For the educated ignorant populations, the general rate of the shrinkage is faster for all respective values of δ than for uneducated populations. The direct effect of δ on both populations is, however, quite the same; with the highest value of delta showing the slowest shrinkage and the lowest value of delta showing the fastest shrinkage.



(a) Uneducated Ignorant



(b) Educated Ignorant

Figure 4: Effects of Varying Delta on Ignorant Groups

4.3. Spreaders

The rate at which ignorant individuals become spreaders is largely dependent on how many spreaders there already are. As the number of spreaders increases from its initial value of 1, the number of ignorant individuals becoming uneducated or educated spreaders is at a rate of $\bar{k}_u * s_u$ and $\bar{k}_e * s_e$ respectively, where s_u is the number of uneducated spreaders and $s_e$is the number of educated spreaders. The trends of both groups of spreaders are visualized in Figure 5.

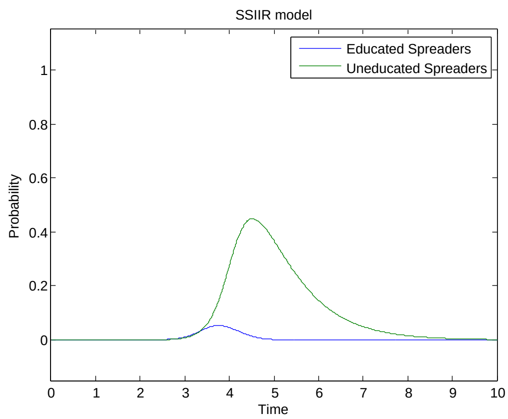
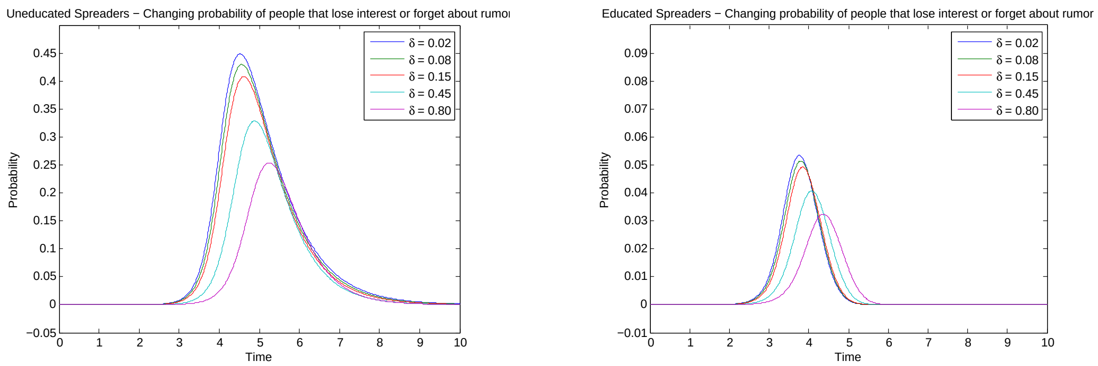


Figure 5: Population Trends in Spreader Groups

Due to the vastly greater population of uneducated ignorant individuals, there is a greater impact on the model by the uneducated population than the educated. The peak of the trend of educated individuals, however, occurs earlier in the timespan of the model. This can be attributed to the respective value of $\bar{k}$, where the value of $\bar{k}$ for educated individuals is significantly greater than that of the uneducated. Since it is assumed that educated people use methods of online networking, pace of the trends in the model for the educated group is greatly accelerated from that of the uneducated group.

The rate of delta has a significant impact on the growth of the spreader population in the model. A higher value of delta directly correlates with a lower peak value of spreaders in the model. This peak value is just under 44.9% of the total population for the lowest value of delta and just under 25.0% for the highest value of delta. It may also be



(a) Uneducated Spreaders

(b) Educated Spreaders

Figure 6: Effects of Varying Delta on Spreader Groups

noted that the peak values occur later for higher delta values. This is because higher delta values correlate to a higher chance of conversion of spreaders to stiflers. Since the growth of spreaders is largely dependent on the size of the spreaders which are already in the group, increasing delta is likely to cause a both slower and smaller growth in both the educated and uneducated spreaders.

4.4. *Stiflers*

The growth of the stifler population, seen in Figure 7, is largely dependent upon both its own population as well as the population of spreaders and ignorant individuals. As the number of spreaders grows, the number of spreaders choosing to become stiflers grows proportionately. As the number of stiflers grows, the number of interactions between stiflers and both spreader groups grows.

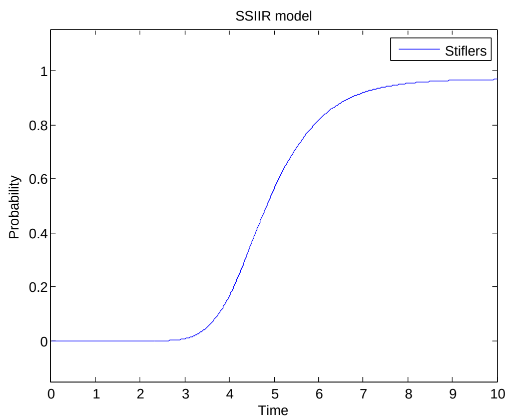


Figure 7: Population Growth Trends in Stifler Group

Each of these interactions represents a chance for a spreader to become a stifler. It should also be noted that during each interaction between an ignorant individual and a spreader, there is a chance of the ignorant individual becoming a stifler as opposed to a spreader. The chance of ignorants becoming spreaders is much larger however, and therefore the impact of ignorant becoming stiflers directly after hearing the rumor is minimal.

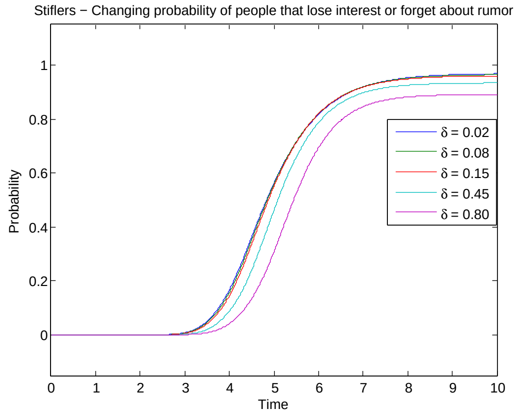


Figure 8: Varying Effects of Delta on Stifler Growth

The value of delta has an unexpected effect on the peak population of stiflers, in that a higher value of δ actually lessens the total population percentage of stiflers. This can be attributed to the size of the stifler group being dependent upon the sizes of the spreader groups. Since a larger value of δ stunts the spreaders growth, it also limits the shrinkage of the ignorant group. Because of this, there is a lower number of stiflers and a higher number of ignorant individuals for a higher δ value on the tenth day.

4.5. *Gauging the Effects of Education*

In order to understand the effect of education levels on a population, the simulation was also run on the populations of the Czech Republic and Russia. Here, the Czech Republic has a population of approximately 10.6 million and the percentage of non-internet users is 25.0%. For Russia, the population is 75.9 million of which 53.3% are internet users.

4.5.1. *Czech Republic*

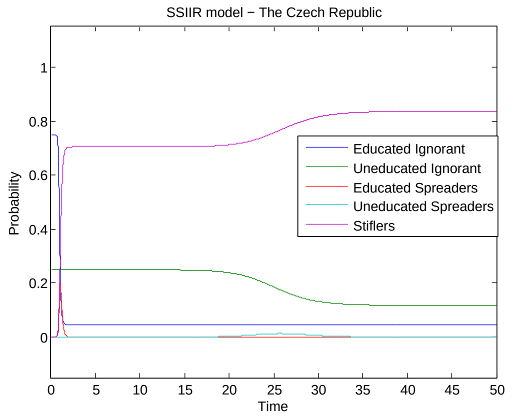
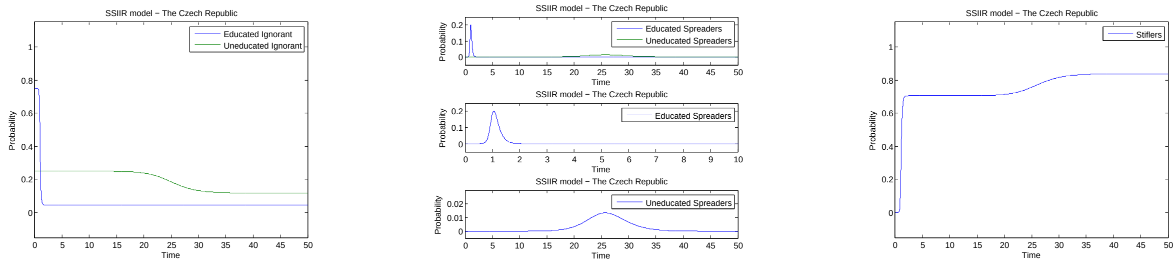


Figure 9: Rumor Spreading Trends in Czech Republic

The time-frame during which the majority of the changes occur in the model are different for the educated and uneducated populations. For the educated groups, a steady state is reached in under five days. This can be attributed to how education facilitates the spread of the rumor. Since around 75% of the population is knowledgeable in social media, the spread of information among this group is very rapid. In contrast, the uneducated groups reach a steady state around day 40.



(a) Uneducated Spreaders (b) Educated Spreaders (c) Educated Spreaders

Figure 10: Ignorant, Spreader, and Stifler Trends in Czech Republic

The limited growth of the spreaders in the uneducated population is mostly due to how fast the ignorant population is shrunken by the growth of educated spreaders. Because of this, the majority of the growth of the stiflers can be directly attributed to the effects the educated population has on the model. The majority of this growth can be observed withtin the first two days and can be attributed to the educated groups in the population. However, there is another surge of growth in the stiflers between the twentieth and thirtieth days. This growth is due to the uneducated groups in the population. The time-frames of the growth coincide with the timeframes the majority of the changes occur in educated and uneducated spreaders and stiflers respectively.

4.5.2. Russia

The distribution of the population between educated and uneducated individuals is nearly even in Russia. The effects on the time-frame during which the changes occur are similar to the Czech Republic but to less of an extreme. The steady state is reached in around 4 days for educated groups and 16 days for uneducated.

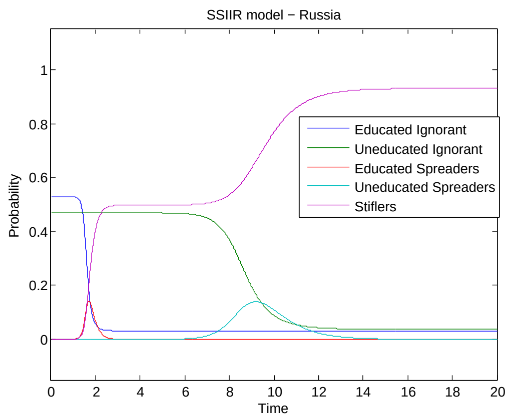
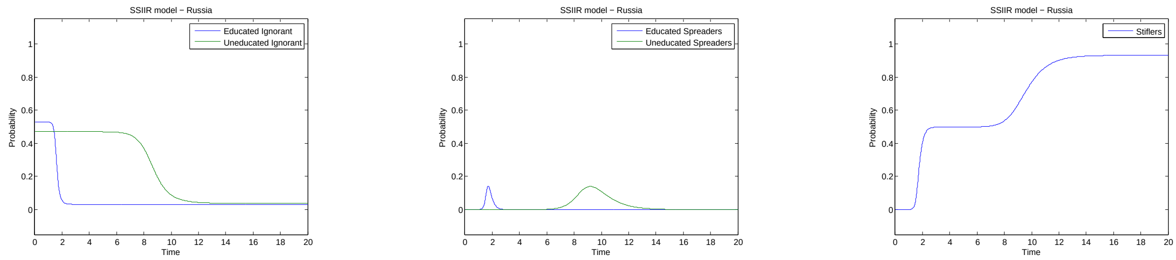


Figure 11: Rumor Spreading Trends in Russia

The majority of the shrinkage in the ignorant population occurs within the second day in the educated group and between the eighth and tenth days in the uneducated group. The peaks of the spreaders occur during this same time frame for the educated and uneducated groups respectively. For both spreader groups, the final population percentage of the groups is nearly the same. For the ignorant groups, the final population percentage of the uneducated ignorant population is slightly greater than the educated population.



(a) Uneducated Spreaders (b) Educated Spreaders (c) Educated Spreaders

Figure 12: Ignorant, Spreader, and Stifler Trends in Russia

This is because by the time the uneducated ignorant group begins shrinking, the stifler group is already nearing 50% of the total population. This large number of stiflers causes a small stunt in the total growth of the uneducated spreaders and thus slightly lessens the overall shrinkage of the ignorant population. The spreader group shows two general periods of growth which coincide with the timeframes during which the majority of change occurs in the educated and uneducated groups respectively. The educated ignorant individuals and educated spreaders become stiflers mostly during the second day. The uneducated ignorant individuals and uneducated spreaders become stiflers between the eighth and tenth days.

5. Discussion and Future work

The results of the work show that education levels have a significant impact on both the rate of the propagation of the rumor and the impact of the rumor on a population. By taking into account individuals' technological proficiency, the projected trend for how a rumor spreads through a population is greatly accellerated. This can be easily observed in the SSIIR model, where the educated ignorant group shrinks more rapidly and the educated spreader group peaks more rapidly. This effect can also be noted in the stifler group of the Czech Republic as opposed to Russia's and Sudan's stifler groups. Here a greater percentage of education can be correlated with more rapid growth in the stifler group.

The impact of each countries' educated and uneducated groups on their total populations can be attributed to the ratio of educated to uneducated individuals. In Sudan, the uneducated individuals greatly outnumber the educated individuals and therefore the majority of the trends of the model can be attributed to the trends within uneducated groups. In Russia, ratio of educated to uneducated individuals is nearly 1:1. This can be observed by noting that the population percentage of uneducated and educated spreaders as well as uneducated and educated ignorant individuals is nearly equal. The peak values for both uneducated and educated spreaders are nearly equal as well. In the Czech Republic, the ratio of educated to uneducated individuals is approximately the inverse Sudan's. As such, the educated population more greatly impacts the trends of the model.

As an extension to this work, it may be interesting to see how continuous, as opposed to categorical, levels of education can impact rumor spreading in a population. In this extension, individuals would not be explicitly educated or uneducated. Instead, individuals would fall on a continous range of education, each with their own particular level of education. Additional factors could also be considered in this extension, such as an individual's level of preference in the use of social technologies. This factor could be defined categorically, or like the level of education, could also be defined continuously.

Additionally, the model could be extended to consider differnent types of rumors with pertainence to different subsections of the total population. In this theoretical model, a rumor pertaining to one particular grouping of the population would have less of a chance of being spread by members of other groups within the population but would almost certainly be circulated within its own population. In this model there could be even be a factor defined for co-relevance between groups for a rumor which is equally pertainent to different groups.

6. Conclusion

Rumors are aspects of social interaction in which unverified information is circulated among a population. Rumors generally have an observable life-cycle, and are often modelled using disease-spreading models. The model discussed in this work, the SSIIR model, is a variation of the SIR epidemic model. This variation takes into account the effects which education have on the spreading of a population. From the SSIIR model, mean-field equations were derived to describe the dynamics of rumor spreading in the population. Along with the effect of education on the population, the effect of the rate at which indivudals forget the rumor was also taken into consideration. The results of this work show that education has a great effect on the rate of circulation of the rumor as well as the total length of its life-span. The same results indicate that a greater forgetting rate can be correlated with a a higher peak value of individuals spreading the rumor, but also of a lower total value of individuals who have known the rumor by the end of its life cycle. These results can help researchers better understand how these factors affect trends within the life-cycle of a rumor, and therefore, create better models to predict the trending of future rumors.

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