Article

Numerical study of fake news propagation

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Abstract: In today's digital era, social networks serve as powerful platforms for instantaneous information dissemination, posing risks of misinformation spread. This article captures the main points of an ongoing research study that quantifies information propagation. Through literature review, theoretical study, model implementation and real-world data testing, it explores dynamics and mitigation strategies. Understanding the dynamics of fake news is crucial for developing effective preventive measures in an increasingly digital worlds where combating misinformation is imperative for societal well-being.

Keywords: fake news; information; social media; propagation; epidemiological models

1. Introduction

The widespread accessibility of social media allows individuals to create and share digital content effortlessly, influencing decisions across various domains such as economics, politics, and health [1], [2].

This ease of dissemination comes with inherent risks: while government institutions may utilize social media to effectively communicate, nefarious actors can exploit it to spread false information, significantly impacting public opinion and trust in institutions. Major social networks often grapple with the rampant spread of misinformation lacking factual basis, leading to detrimental consequences like financial losses and endangering lives [3], [4].

Notably, events like the COVID-19 pandemic and the United States Capitol Riots underscore the profound impact of misinformation on public health and societal stability. Factors like media coverage quality and scientific literacy further exacerbate the propagation of false information. Moreover, the rise of Artificial Intelligence (AI) introduces new challenges, as AI-equipped systems can generate and manipulate digital content with unprecedented sophistication. Instances of media manipulation, such as replacing faces or altering speeches, highlight the potential for AI to facilitate misinformation dissemination [5].

Understanding the dynamics of fake news propagation is critical, requiring the development of effective preventive and corrective measures. This includes algorithms for detecting fake news, systems for assessing information source reliability, and intervention strategies to mitigate misinformation spread. Numerical approaches offer valuable insights into this complex phenomenon, enabling the creation of robust solutions to safeguard information integrity and enhance societal resilience against manipulation [1], [3].

As society becomes increasingly digital, managing misinformation emerges as a global social concern, impacting financial markets, consumer behavior, social stability, and public safety. Thus, the development of techniques to combat the transmission of false information is imperative for preserving societal well-being and fostering a trustworthy information environment [2], [4].

2. Objectives

The main objective of this research is to study the propagation of fake news or rumours in both time and space. Furthermore, it aims to investigate which aspects influence the most in the spreading of information, such as gender, culture, and education. The main objective is to answer the following research question: Can the spread of information be quantified both in time and space? To better organise this research, this question can be split into several smaller questions:

1) **Influencing factors:** What factors influence the propagation of information?
2) **Numerical Models:** What existing models are most suitable for the spread of fake news?
3) **Control strategies:** What strategies can be implemented to delay/control/stop the spread of misinformation?
4) **Timing and Implementation of mitigation strategies:** When/how should those mitigation strategies be applied?
5) **Cost and viability:** What is the overall cost of those strategies and, most importantly, is the investment worth it?

This project will be developed within a multidisciplinary team, specifically with the support of professors with experience and knowledge in Optimization, Epidemiological Models, and Differential Equations, which are subjects that will be fundamental for the development of this research study.

3. State of the Art

In the dynamic landscape of contemporary challenges, interdisciplinary collaboration is essential for unraveling complex phenomena. The study described in the present article focuses on Epidemiological Models as propagation models of information, exploring Control Strategies, Mitigation and Intervention Strategies, Human Behavior Dynamics, and the geographical spread of misinformation.

Ultimately this literature review aims to navigate these intertwined subjects. It delves into the complexities of epidemiological models as information propagation models, alongside strategies for control and intervention. Understanding how human behavior dynamics influence propagation provides a basis for crafting more effective mitigation strategies. Additionally, the geographical dimension adds complexity, enhancing comprehension of local dynamics and enabling tailored interventions for region-specific challenges.

3.1. Epidemiological models

Epidemiological models divide the total population into several compartments which reflect the disease status of an individual. So, it is important to understand the basic terminology for the model compartments: Susceptible (S) that represents individuals who are susceptible to contract the disease after contact with an infected individual; Infected (I) which represents the compartment of individuals who are currently infected and can transmit the disease to individuals in class S - it is important to understand that the individuals in this compartment can or not develop immunity against reinfection; Recovered or Removed (R), that represents individuals who were infected but recovered from the disease.

With these definitions in mind, we can now advance to the most traditional disease propagation model which is detailed next.

3.1.1. SIR Model

In the SIR Model (Figure 1), the individual develops immunity against reinfection meaning that, after being infected, it is highly unlikely that he becomes infected again (e.g., Smallpox). The SIR model enables individuals to recover (R) unlike simpler models such as the SIS Model, where individuals do not develop immunity against reinfection.

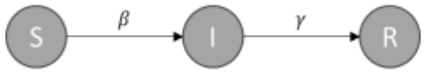


Figure 1. SIR Model [6]

Where, β: contact rate; α: recovery rate.

3.1.2. SIRS Model

The SIRS Model (Figure 2) can be described as an intermediate between the SIS and SIR models. SIRS considers that individuals can lose their immunity and enter the Susceptible (S) compartment once again (e.g., Influenza). Here, the immune state lasts for a limited time.

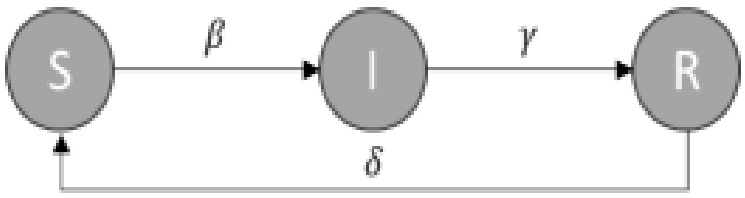


Figure 2. SIRS Model [6]

Where, δ - rate at which recovered individuals return to the susceptible compartment due to loss of immunity.

3.2. Epidemiological models as propagation models of information

By proposing a mathematical model towards the idea of the propagation of contagion in a population on online social networks, we can acquire potentially useful information about its spread, much like a disease. Consequently, most scholars built the misinformation and rumour control models based on disease spreading due to the similarity between misinformation propagation and epidemic spreading. Considering traditional disease propagation epidemic models, several rumour propagation models were formulated for digital networks which helped to explain the diffusion of fake news. Consequently, we can set the stage for the subsequent implementation of beneficial approaches to control this dissemination [7], [8].

The SIR model is considered the most classical model used in this context. The population is divided into three groups but with different definitions, applied to the context in study: The susceptible individuals are those who have not yet been exposed to the fake information but can be exposed to it later on, becoming infected; the infectious individuals are the ones that have received the false information and spread it, just like in an infectious disease scenario; the recovered individuals are those who become sceptical or aware of the falseness of the information and do not spread it.

In several fields, the concept of spreading is applied, and, in a pragmatic point of view, the SIR model is a beginning point. However, with more understanding and complexity, it is possible to enrich the model and put more details in the formulation. One example is the SEIZ Model (Figure 3) which, unlike the traditional epidemiological models has the additional Exposed compartment (E) which consists of individuals who need some time before they begin to believe in a story (i.e., get infected), and then deciding to react to it by either commenting on it or spreading it. Furthermore, this model has an additional Skeptic compartment (Z), which consists of users who have heard about the misinformation item but decided not to engage in any reaction to it. These two scenarios are possible but are not covered by the basic SIS and SIR models [9].

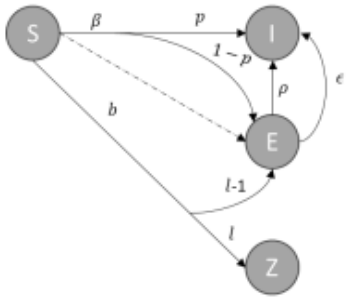


Figure 3. SEIZ Model [10]

Where, β: contact rate between S and I; b: contact rate between S and Z; ρ: contact rate between E and I p: probability of S to I given contact with I; $1 - p$: probability of S to E given contact with I; ϵ: transition rate of E to I (incubation rate); l: probability of S to Z given contact with Z; l_-1: probability of S to E given contact with Z.

SEIZ Model rules are now outlined: The Skeptic users (Z) - who have heard about the misinformation item but choose not to spread it - are recruited from the Susceptible compartment at a rate b _and this activity can cause two different possibilities:

- The first one is that it can cause turning the user into another Skeptic (with the probability l). This means that the user decides not to spread the misinformation item maybe because they don't believe it or believe it but decide not to pass it on.

- The second possibility is that it can cause the inadvertent result of sending the user into the Exposed compartment (E) with the probability $1 - l$.

A susceptible individual (S), who has not yet heard about the misinformation item, encounters Infected users (I) with the rate of β _and can immediately believe the story or rumour with probability p, or that person may have some doubts and need time to analyse the misinformation item, moving to the Exposed status (E) with a probability $1 - p$. There are two different possibilities for the transfer of users from the Exposed compartment (E) to the Infected state (I):

An individual in the exposed class has further contact with an infected individual (with contact rate ρ), and this additional contact promotes him to infected, moving to Infected class (I).

An individual in the exposed class may become infected purely by self-adoption (with rate ϵ), and not from additional contact with those already infected. One of the most important improvements of the SEIZ model over the SIR and SIS models lies in its understanding that it is possible for people to encounter a misinformation item on twitter and not execute any reaction. Furthermore, in the SEIZ model, individuals can be Exposed to a misinformation item but not spread it immediately [10], [11].

It is important to understand that most models consider assumptions such as constant population, no immigration or no deaths and births since the dynamics of the epidemics is much faster than the dynamics of births and deaths making it reasonable to neglect these variations.

3.3. Control strategies

The Optimal Control problem is a trade-off that aims to optimize an objective function depending on state and control variables, subject to a set of different types of constraints. To solve Optimal Control problems, it is possible to use direct or indirect methods. The direct method focuses on the discretization of the problem making it a Non-Linear Problem (NLP), while the indirect method includes, for example, the Pontryagin's Maximum Principle (PMP) [12] or the Backward-Forward sweep method [13]. NLP is easier to solve mainly due to the sparsity of the NLP and the multitude of software programs that can handle this feature. As a result, the range of problems that can be solved using direct methods is significantly larger than the range of problems that can be solved via indirect methods. In indirect methods, the PMP is used to determine the first-order optimality conditions of the original Optimal Control problem. This indirect approach leads to a multiple-point boundary-value problem that is

solved to determine candidate optimal trajectories called extremals. To be able to use this method it is necessary to get the adjoint, control equations as well as the transversality conditions, if these exist.

The Optimal Control theory was also applied when studying the deconfinement in Portugal during the COVID-19 pandemic [14]. The objective was to maximize the number of people returning to their "normal lives" while minimizing the number of active infected individuals with minimal economical cost while guaranteeing a low level of hospitalizations.

3.4. Mitigation and Intervention strategies

The effectiveness of three types of strategies was investigated for mitigating the spread of fake news, namely content moderation, education, and counter-campaigns [15].

These strategies were implemented in a modified binary agreement model and the main results are listed below:

- Content moderation achieved by removing randomly selected agents who spread misinformation is comparable to the results achieved by removing highly influential agents. This means that removing disinformation anywhere in a network could be an effective wat to counter its propagation.

- Education strategy whose objective is to increase the public scepticism was more effective than one that targets already biased agents. Thus, a campaign that focuses on increasing the public scepticism was more successful than a campaign that focus on making people aware of disinformation.

- Counter-campaign strategies required a substantial population of agents to influence other agents to oppose disinformation. This means that small campaigns were infective at combating the spread of disinformation. However, the author advises that there is a vast number of other policies and strategies, or even the combination of the two, that could be explored and analysed.

3.5. Human behaviour dynamics

As mentioned previously, online social networks are valuable tools for information diffusion among their users. During this diffusion process, social influence occurs when a person's opinions and emotions are affected by other people. Consequently, changes may happen in an individual's attitudes, thoughts, or behaviours when upon interaction with other people. Lack of access to high-quality information may not necessarily be the main causer of the formation of misinformation; there is a range of cognitive, social, and affective factors are also influencers [16], [17]. Analysing social influence can help to understand people's social behaviours and provide theoretical support to influence public opinion, promoting the dissemination of various activities or information. More importantly, can help find interventions to combat the misinformation.

This subject was also studied in [18] and it was found that even a brief one-time exposure (as is typical online) to a fake news article can modify the unconscious behaviour of individuals. The author also discovered that there is no evidence that the participants of the study were aware of any changes in their behaviour.

This obviously raises deep concerns, especially since deliberately produced and targeted disinformation aimed at behaviour modification worsens the situation. With the normalisation of the artificial intelligence the risks are even greater because the means of producing misinformation are more evolved making it easier for individuals to believe it and, thus, change their views and behaviours.

4. Methodology

The methodology for this research project involves a systematic approach aimed at quantifying the spread of information. The proposed plan encompasses various stages to achieve this objective:

1) **Literature review:** A thorough examination of existing literature serves as the foundation for the research study. This continuous review process aids in refining the understanding of the subject matter and guiding the direction of the study.

2) **Study and application of background concepts:** This phase involves deepening the knowledge on critical subjects relevant to the research. It encompasses understanding and applying concepts such as Epidemiological Models and Optimal Control Theory. Additionally, it involves exploring relevant software platforms and methodologies for numerical simulation and optimization.

3) **Model implementation:** The theoretical framework developed in the previous phase are translated into practical models using software tools such as Matlab. The implementation process is iteratives, allowing for the incorporation of new assumptions and adjustments to ensure the model's accuracy and functionality.

4) **Model testing with real data:** Real-world data ius collected and used to validate the developed models. Evaluation metrics are established to assess the model's performance and suitability in representing human behaviour and information spread dynamics. Any necessary refinements to the model are made based on the outcomes of these tests.

5) **Continuous review and adaptation:** Throughout the project, regular reviews are conducted in order to reassess the research plan. This allows for adjustments to be made in response to interim findings, emerging challenges, or evolving research requirements.

This methodology provides a structured framework for conducting the research project, ensuring a systematic and rigorous approach to addressing the research problem.

4. Final considerations

Recognizing misinformation as a societal threat, control strategies have become imperative, requiring both mitigation and intervention. These strategies are crucial not only in virtual spaces but also in tangible geographical dimensions where misinformation's impact is tangible.

This research project represents a significant step towards comprehensively understanding and addressing the challenges posed by information spread in modern society. By leveraging interdisciplinary approaches and rigorous methodologies, we can continue to advance our knowledge in this critical area and develop strategies to foster informed decision-making and societal well-being. Although, it is also important to acknowledge the limitations of the current research, including simplifying assumptions made in the modelling process and potential biases in the interpretation of real-world data. Addressing these limitations will be crucial for refining future research endeavors and ensuring the robustness of findings.

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