SOCIAL NETWORK ANALYTICS

Diffusion through networks and Processes on networks

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SOCIAL NETWORK ANALYTICS

Diffusion through networks: Introduction

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Diffusion through networks: Introduction

- **What is Diffusion?**
  - The spreading of something (diseases, information, opinions, adoption of new technologies/behaviors) more widely through a network.

- **Viral** - An image, video, piece of information, etc. that is circulated rapidly and widely on the Internet.

Diffusion through networks: Introduction

- **Rumor** – A piece of unverified/unconfirmed information(may be true or false) that is usually spread from person to person. They can be spread by word of mouth, text message on OSN.

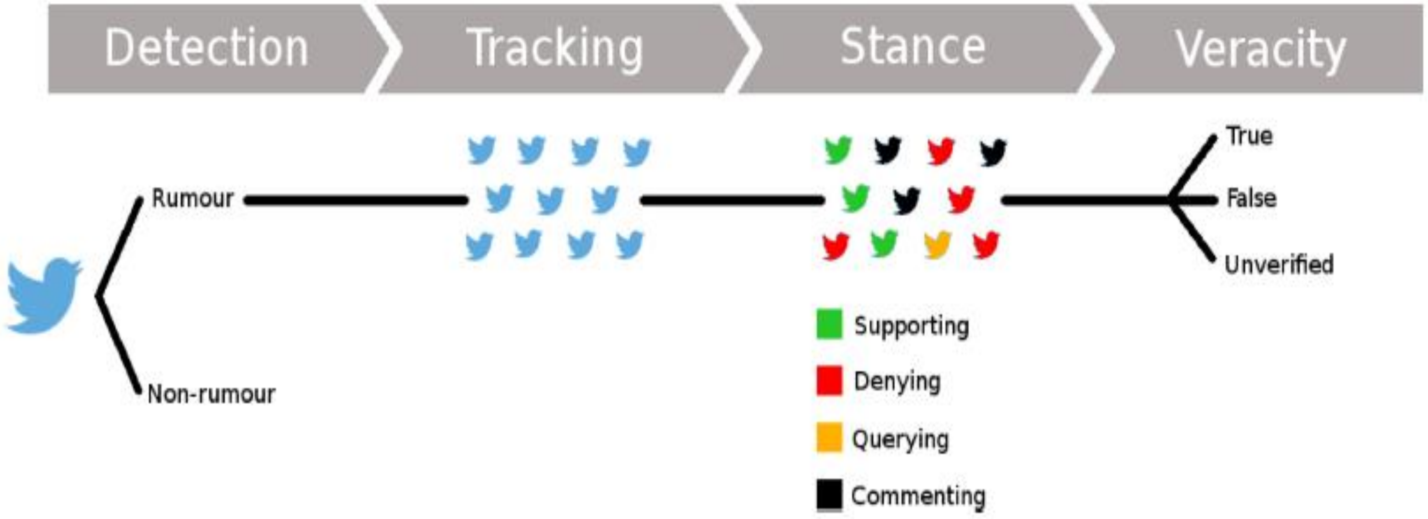

Fig. 1. Architecture of a rumour classification system.

Diffusion through networks: Introduction

- **What is Contagion?**
  - The communication of disease from one person or organism to another by close contact.
- **Pathogen**: a bacterium, virus, or other microorganism that can cause disease

Diffusion through networks: Introduction

- An **EPIDEMIC** is a disease that affects a large number of people within a community, population, or region.
- A **PANDEMIC** is an epidemic that's spread over multiple countries or continents. For example, when COVID-19 was limited to Wuhan, China, it was an epidemic. The geographical spread turned it into a pandemic.
- **ENDEMIC** is something that belongs to a particular people or country. Endemics, are a constant presence in a specific location.
- An **OUTBREAK** is a greater-than-anticipated increase in the number of endemic cases. **It can also be a single case in a new area. If it's not quickly controlled, an outbreak can become an epidemic.**

Diffusion through networks: Introduction

- The **patterns by which epidemics spread through a society** is determined **not just by the properties of the pathogen carrying it** (including its contagiousness, the length of its infectious period, and severity), **but also by the network structure within the population.**

- Opportunities for a disease to spread from one person to another is given by the **contact network**, indicating who has contact with whom on a regular basis.

Diffusion through networks: Introduction

- The Diffusion problem is relevant to
  - **transmission of diseases/information/opinions through a network**

    and
  - **adoption of new technologies/behaviors through a network.**

SOCIAL NETWORK ANALYTICS

Diffusion of Innovation(DOI) Theory

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Diffusion of Innovation Theory

- Diffusion of Innovation (DOI) theory, developed by E.M. Rogers in 1962, is one of the oldest social science theories.
- **DOI originated in communication to explain how, over a time, an idea or behaviour or product or technology gains momentum and diffuses (or spreads) through a specific population or social system.**
- **The end result of this diffusion** is that **people, as part of a social system, adopt a new idea, behavior, or product.**
- **Adoption means** that a person does something differently than what they had previously (i.e., purchase or use a new product, acquire and perform a new behavior, etc.).
- **The key to adoption** is that the person must perceive the idea, behavior, or product as new or innovative. It is through this that diffusion is possible.

E.M. Rogers

Diffusion of Innovation Theory

- Adoption of a new idea, behavior, or product (i.e., "innovation") does not happen simultaneously in a social system; rather it is a process whereby some people are more apt to adopt the innovation than others.

- **Researchers have found that people who adopt an innovation early have different characteristics than people who adopt an innovation later**.

- **When promoting an innovation to a target population, it is important to understand the characteristics of the target population that will help or hinder adoption of the innovation.**

Diffusion of Innovation Theory

- **Rogers proposes that four main elements influence the spread of a new idea:**
  1. **the innovation itself,**
  2. **communication channels,**
  3. **time,** and
  4. **a social system.**
- This process relies heavily on human capital(Human capital is the stock of habits, knowledge, social and personality attributes embodied in the ability to perform labour so as to produce economic value.).
- The innovation must be widely adopted in order to self-sustain. Within the rate of adoption, there is a point at which an innovation reaches critical mass.

Diffusion of Innovation Theory

- There are **five established adopter categories**, and while the majority of the general population tends to fall in the middle categories, it is still necessary to understand the characteristics of the target population.

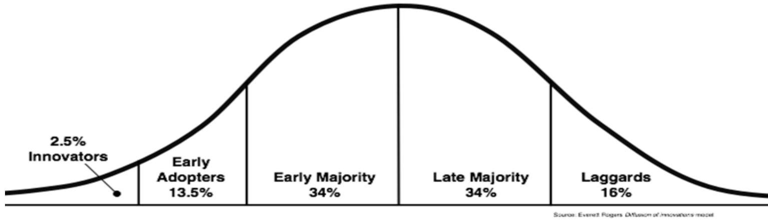
   1. **Innovators**
   2. **Early Adopters**
   3. **Early Majority**
   4. **Late Majority**
   5. **Laggards**

- When promoting an innovation, there are different strategies used to appeal to the different adopter categories.

Diffusion of Innovation Theory

1. Innovators:

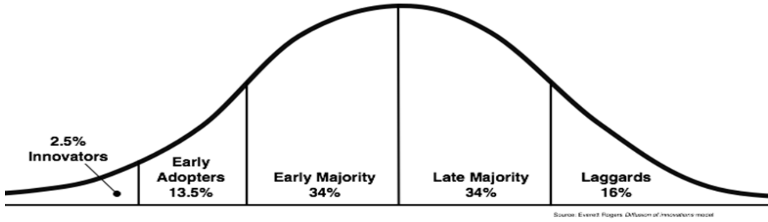
- These are people who want to be the first to try the innovation.
- They are venturesome and interested in new ideas.
- These people are very willing to take risks, and are often the first to develop new ideas. Very little, if anything, needs to be done to appeal to this population.



Diffusion of Innovation Theory

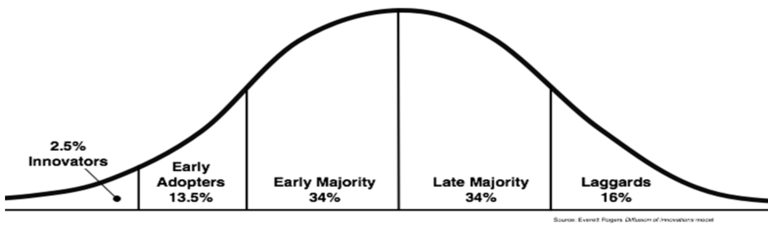
2. Early Adopters:

- These are people who represent opinion leaders.
- They enjoy leadership roles, and embrace change opportunities.
- They are already aware of the need to change and so are very comfortable adopting new ideas.
- Strategies to appeal to this population include how-to manuals and information sheets on implementation.
- They do not need information to convince them to change.



Diffusion of Innovation Theory

3. Early Majority:



- These people are rarely leaders, but they do adopt new ideas before the average person.

  That said, they typically need to see evidence that the innovation works before they are willing to adopt it.

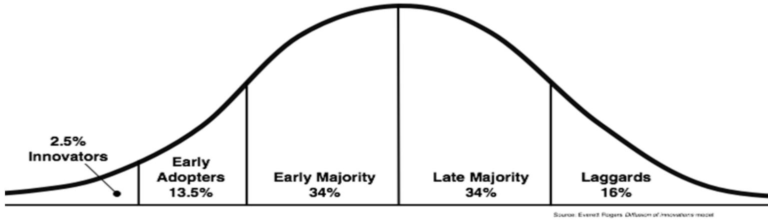
- Strategies to appeal to this population include success stories and evidence of the innovation's effectiveness.

SOCIAL NETWORK ANALYTICS

Diffusion of Innovation Theory

4. Late Majority:

- These people are skeptical of change, and will only adopt an innovation after it has been tried by the majority.
- Strategies to appeal to this population include information on how many other people have tried the innovation and have adopted it successfully.



5. Laggards:

- These people are bound by tradition and very conservative.
- They are very skeptical of change and are the hardest group to bring on board.
- Strategies to appeal to this population include statistics, fear appeals, and pressure from people in the other adopter groups.

Diffusion of Innovation Theory

- **The stages by which a person adopts an innovation**, and **whereby diffusion is accomplished, include**

  1. awareness of the need for an innovation,
  2. decision to adopt (or reject) the innovation,
  3. initial use of the innovation to test it, and
  4. continued use of the innovation.

Diffusion of Innovation Theory

- There are **five main factors that influence adoption of an innovation**, and each of these factors is at play to a different extent in the five adopter categories.
  1. **Relative Advantage** - The degree to which an innovation is seen as better than the idea, program, or product it replaces.
  2. **Compatibility** - How consistent the innovation is with the values, experiences, and needs of the potential adopters.
  3. **Complexity** - How difficult the innovation is to understand and/or use.
  4. **Triability** - The extent to which the innovation can be tested or experimented with before a commitment to adopt is made.
  5. **Observability** - The extent to which the innovation provides tangible results.

Diffusion of Innovation Theory

- **Diffusion of Innovation theory has been used successfully in many fields including communication, agriculture, public health, criminal justice, social work, and marketing.**

- **In public health, Diffusion of Innovation Theory is used to accelerate the adoption of important public health programs that typically aim to change the behavior of a social system**.

- For example, an intervention to address a public health problem is developed, and the intervention is promoted to people in a social system with the goal of adoption (based on Diffusion of Innovation Theory).

- The most successful adoption of a public health program results from understanding the target population and the factors influencing their rate of adoption.

SOCIAL NETWORK ANALYTICS

The Bass Models

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Diffusion through networks: Introduction

- Following the work on diffusion of innovations (Rogers, 1962), Frank M. Bass (1963) proposed the theoretical development for **T**he **B**ass **M**odel(**TBM**) and Frank M. Bass (1969) provided empirical verification for TBM.

- The Bass Model designed to answer the question:

  How many customers will eventually adopt the new product and when?

The Bass Model - papers

Frank M. Bass (1926 – 2006)

He made important contributions to econometrics, stochastic brand choice, and new-product diffusion modeling.

His classic paper on the "Bass Model" was named by INFORMS as one of the **Ten Most Influential Papers published in the 50-year history of *Management Science***.

- A new product growth for model consumer durables - Frank M. Bass
- Comments on - A New Product Growth for Model Consumer Durables - The Bass Model - Frank M. Bass

Diffusion: Bass Model

- **The Bass Model**(TBM) or **Bass Diffusion Model** was developed by Frank M Bass and it **consists of a simple differential equation that describes the process of how new products get adopted in a population.**

$$d\ F(T)/dt = [\ p + q\ F(t)\ ]\ (1 - F(t))$$

- The Bass model presents a rationale of how current adopters and potential adopters of a new product interact.

http://www.bassbasement.org/bassmodel/Default.aspx

Diffusion: Bass Model

- **The basic principle of the Bass model** is that
  - **Adopters can be classified as**
    - innovators or
    - imitators
  - **The speed and timing of adoption depends on**
    - their degree of innovativeness and
    - the degree of imitation among adopters.
- **The Bass model has been widely used in**
  - new products' sales forecasting and technology forecasting.

Diffusion: Bass Model-1

- Examining the purchases of a consumer durable over time, **Bass (1969) distinguished between two types of buyers**:

  1. **innovators** and
  2. **Imitators**

- **Innovators are not influenced in the timing of their initial purchase by the number of people who have already bought the product,**

  while **imitators are influenced by the number of previous buyers**.

  Imitators "learn" in some sense, from those who have already bought.

Diffusion: Bass Model-1

- Innovators and imitators form the basis for innovation and imitation coefficients in TBM (See Figure 1).
- **The innovation coefficient(p):**
  - **p** is argued to **represent innovation in the population**.
  - **p reflects the extent to which adopters are influenced by their own intrinsic tendency to innovate** and by factors beyond the population (including members of other populations and influences from “mass media” that affects all the populations).
- **The imitation coefficient(q):**
  - **q** is argued to **represent the extent to which the adopters emulate other members of the same population**.

Diffusion: Bass Model-1

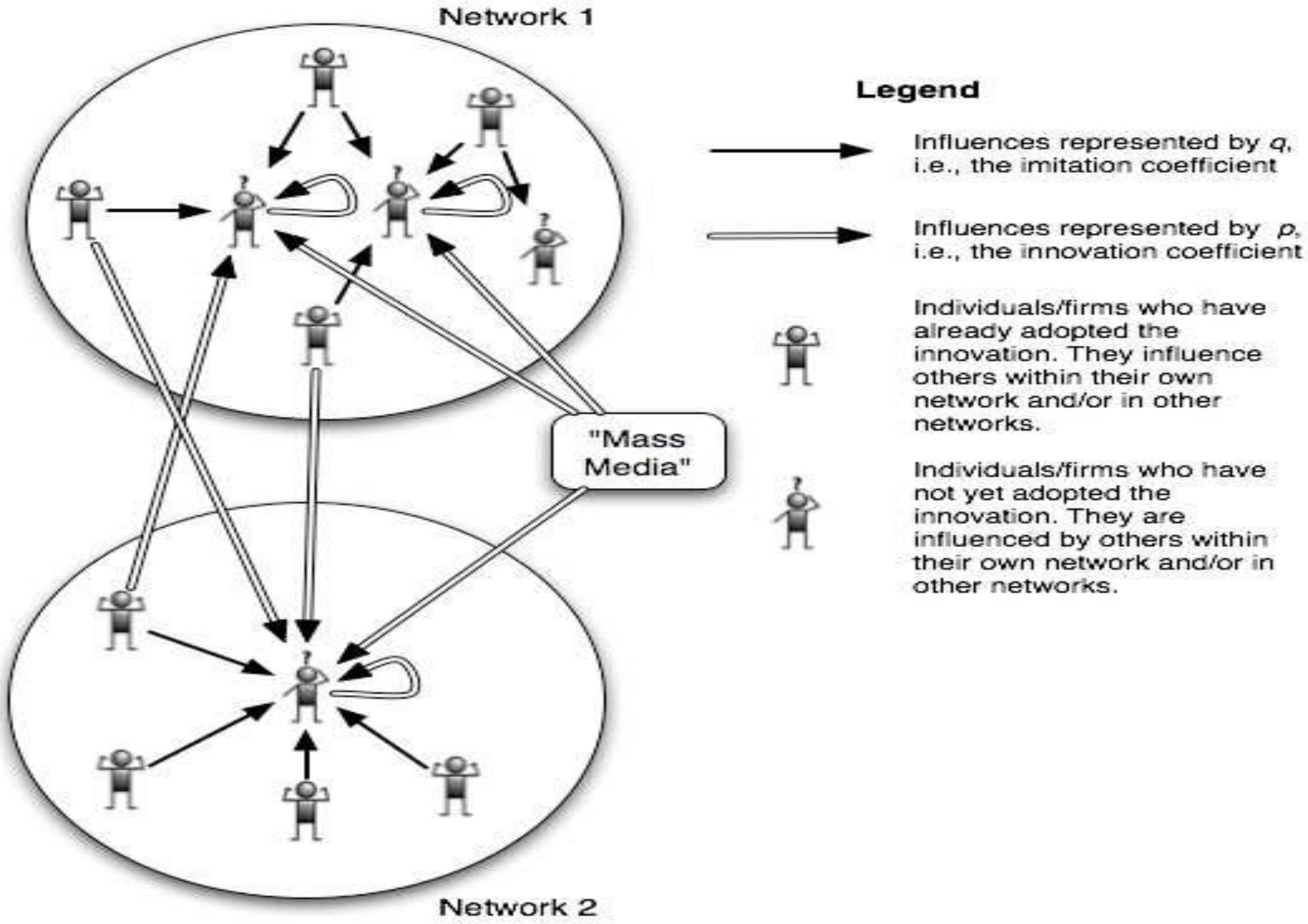

Figure 1: Innovation and Imitation coefficients

Diffusion: Bass Model-1

- **In the context of adoption of technologies,**
  - **p** can be interpreted as the **rate of innovation**

    Parameter **p** captures the rate at which agents innovate or spontaneously adopt

  - **q** can be interpreted as the **rate of imitation** due to social effects.

    Parameter **q** captures the rate at which they imitate other agents or adopt because others have.

Diffusion: Bass Model-1

- Consider discrete-time periods **t** and let **F(t)** be the fraction of agents in a society those who have adopted a new product or behavior at time t.
- The Bass model is described by the difference equation:

$$F(t) = F(t-1) + p\ (1-F(t-1)) + q\ (1-F(t-1))\ F(t-1)$$

  - where **p** is a rate of innovation and **q** is a rate of imitation.
  - The expression $p(1-F(t-1))$ is the rate of innovation times the fraction of people who have not yet adopted.
  - The expression $q\ (1-F(t-1))\ F(t-1)$ captures the imitation process where the rate of imitation is multiplied by two factors. The first factor, (1 - F(t - 1)), is again the fraction of people who have not yet adopted, and the second expression F(t-1) is the fraction of agents who have adopted and can therefore be imitated.

Diffusion: Bass Model-1

- **If *q*>*p***, then imitation effects dominate the innovation effects.
- **If *q*<*p***, then innovation effects will dominate and the highest sales will occur at introduction and sales will decline in every period after that (e.g., blockbuster movies).
- Furthermore, **the lower the value of *p***, the longer it takes to realize sales growth for the innovation.
- When **both *p* and *q* are large**, product sales take off rapidly and fall off quickly after reaching a maximum.
- **By varying *p* and *q***, we can represent many different patterns of diffusion of innovations quite well.

http://www.bassbasement.org/bassmodel/Calculator.aspx

Diffusion: Bass Model-1

In the context of Diffusion of diseases,

- **The bass model parameters:**
  - **p** captures the rate at which agents spontaneously get infections (in response to outside stimuli); and
  - **q** captures the rate at which agents get infected through others (secondary infections).

Diffusion: Bass Model-1

- Consider a **discrete-time model** and let **F(t)** be the fraction of agents in a society infected at time t.

- The Bass model is described by the difference equation:

$$F(t) = F(t-1) + p\,(1 - F(t-1)) + q\,(1 - F(t-1))\,F(t-1)$$

- The term **p (1-F(t-1))** is the **infection rate** times the **fraction of uninfected agents.**
- The term **q (1-F(t-1)) F(t-1)** is the **contagion rate** times the frequency of encounters between healthy and infected agents.

Diffusion: Bass Model

- **Why Bass model can exhibit the S-shape?**
  Note that initially there are no agents in the population to imitate. Thus, the first adopters are almost entirely those who adopt from their own spontaneous innovation.
- when F(t) is close to zero the equation is approximated by p. As the process progresses, there are more agents around to be imitated and this leads to an increase in the rate of diffusion since now agents adopt through imitation as well as innovation.
- There is a balance that occurs as the process progresses, since there are more agents around to imitate, but fewer around to do the imitating.
- Eventually, the process has to slow down simply because there are no longer agents left around who might innovate or imitate.

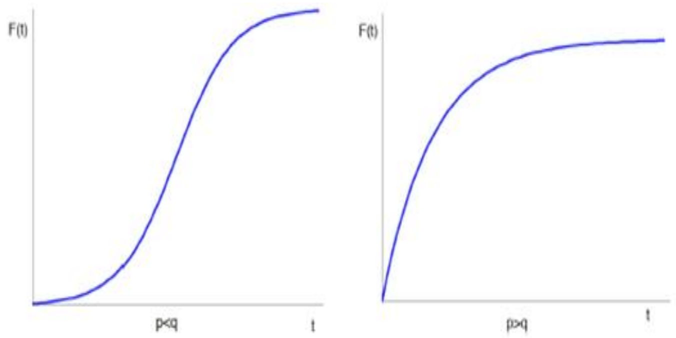

Figure: Diffusion curves: left is for $p < q$ and right is for $p > q$.

The Bass Model - Calculator

- http://www.bassbasement.org/bassmodel/Calculator.aspx

This Web page requires Internet Explorer and Silverlight.

Diffusion: Bass Model

Assignment: Paper Reading

1. Information Diffusion in Online Social Networks: A Survey
2. Information Diffusion on Online Social Networks - Lilian Weng

Diffusion

1. The hidden influence of social networks -NicholasChristakis_TED Talk
2. How social networks predict epidemics -NicholasChristakis_2010
3. https://www.ted.com/talks/robert_waldinger_what_makes_a_good_life_lessons_from_the_longest_study_on_happiness#t-754799

Diffusion - Research challenges in OSN

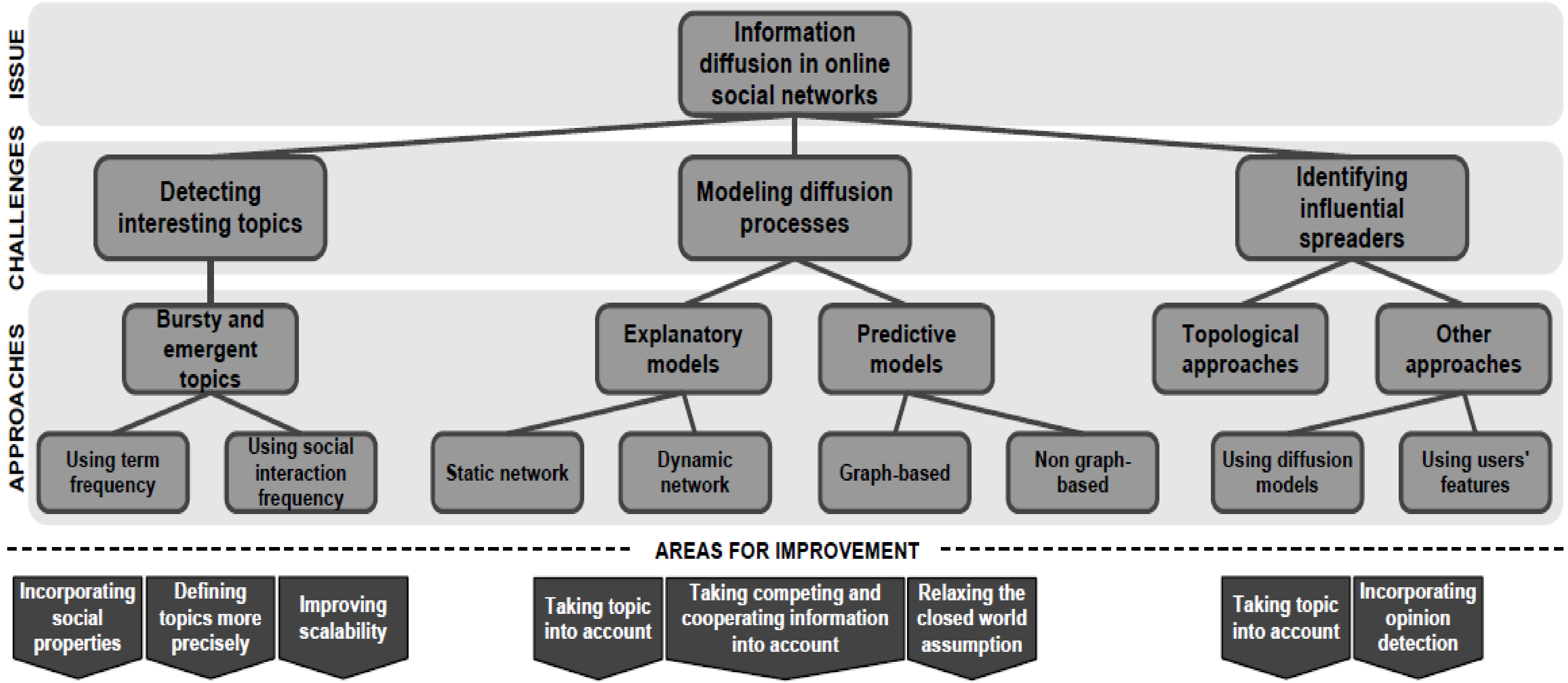

Figure 8: The above taxonomy presents the three main research challenges arising from information diffusion in online social networks and the related types of approaches, annotated with areas for improvement.

SOCIAL NETWORK ANALYTICS

Processes on Networks

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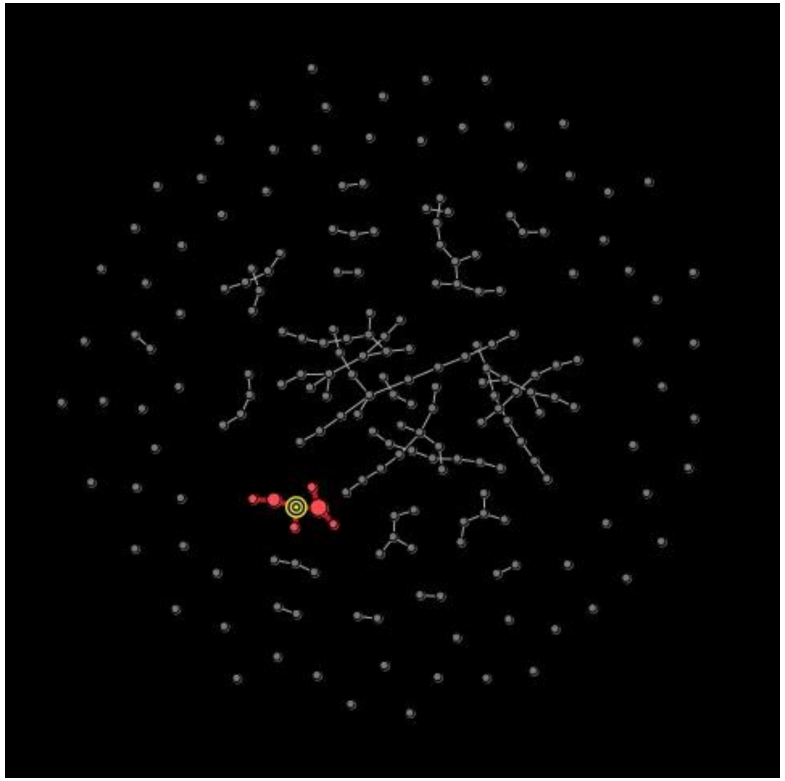
Processes on networks

- Diffusion in networks:
  - ER graphs
  - Scale-free graphs
  - Small-world topologies

Diffusion in networks: ER graphs

review: diffusion in ER graphs

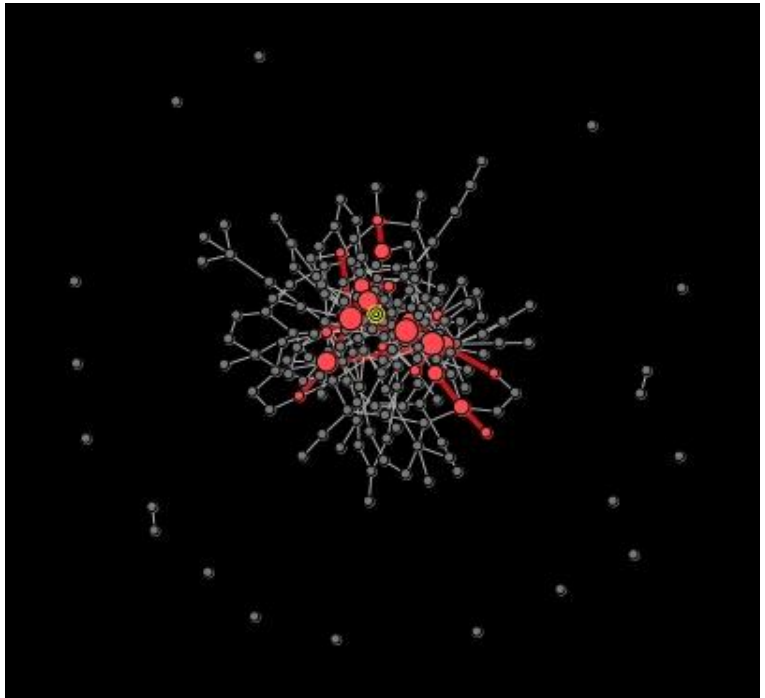


http://www.ladamic.com/netlearn/NetLogo501/ERDiffusion.html (Netlogo 5.3.1)

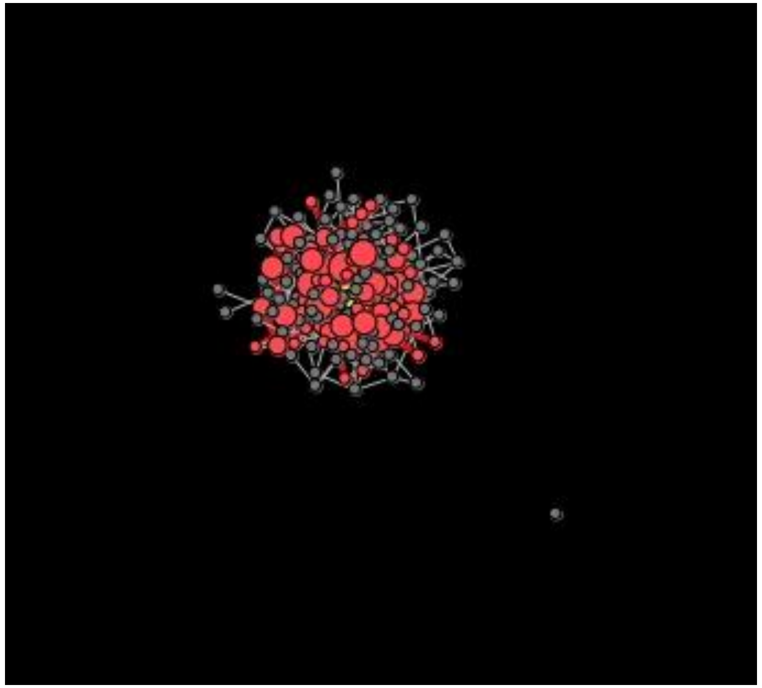
ER graphs: connectivity and density

nodes infected after 10 steps, infection rate = 0.15

average degree = 2.5



average degree = 10



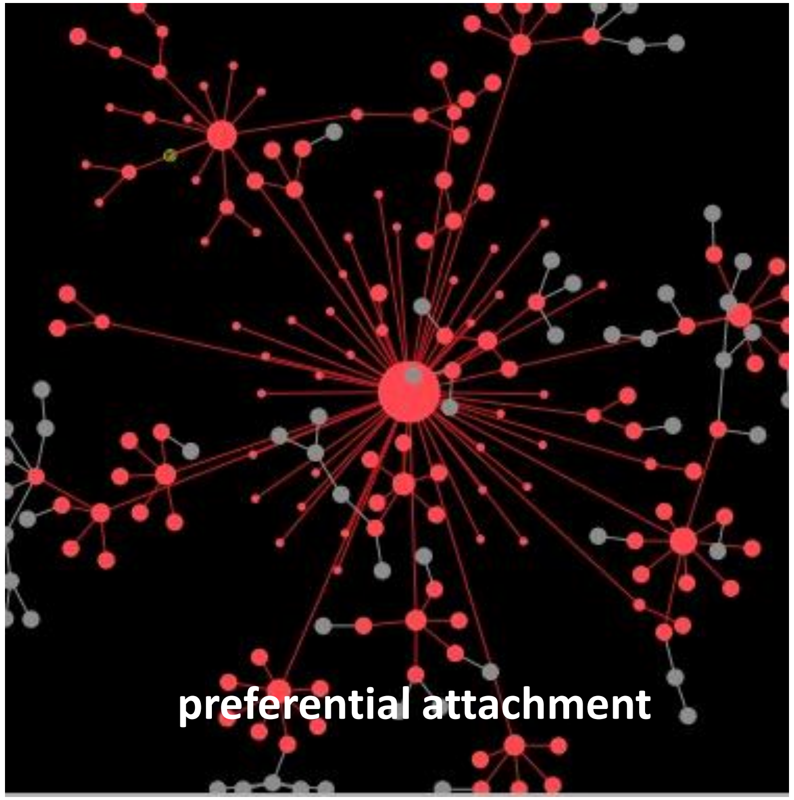
Quiz Q:

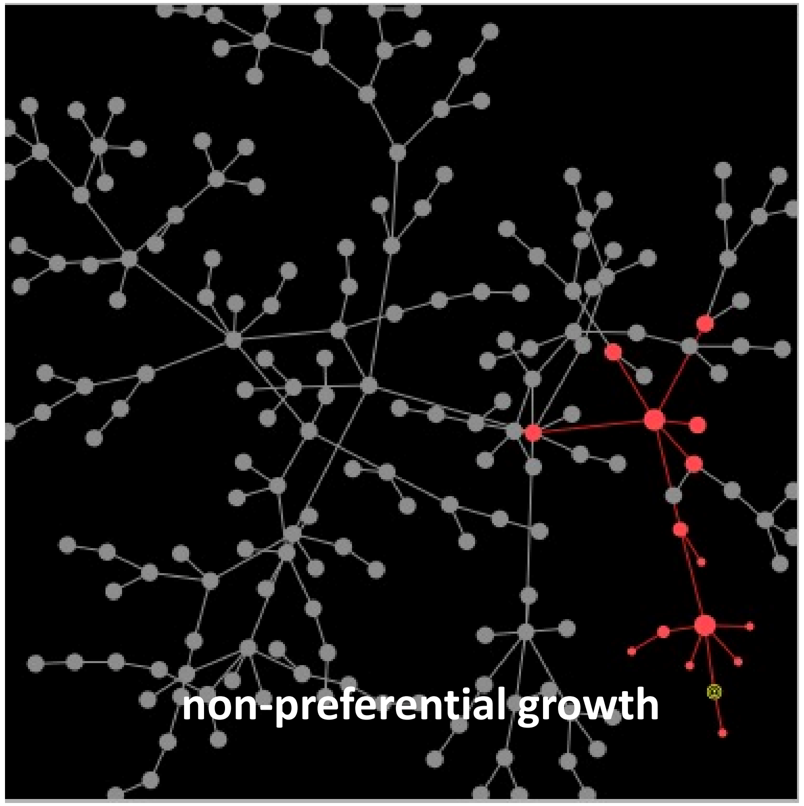
- When the density of the network increases, diffusion in the network is

  1. faster
  2. slower
  3. unaffected

Diffusion in “growing networks”

- nodes infected after 4 steps, infection rate = 1





http://www.ladamic.com/netlearn/NetLogo501/BADiffusion.html (Netlogo 5.3.1)

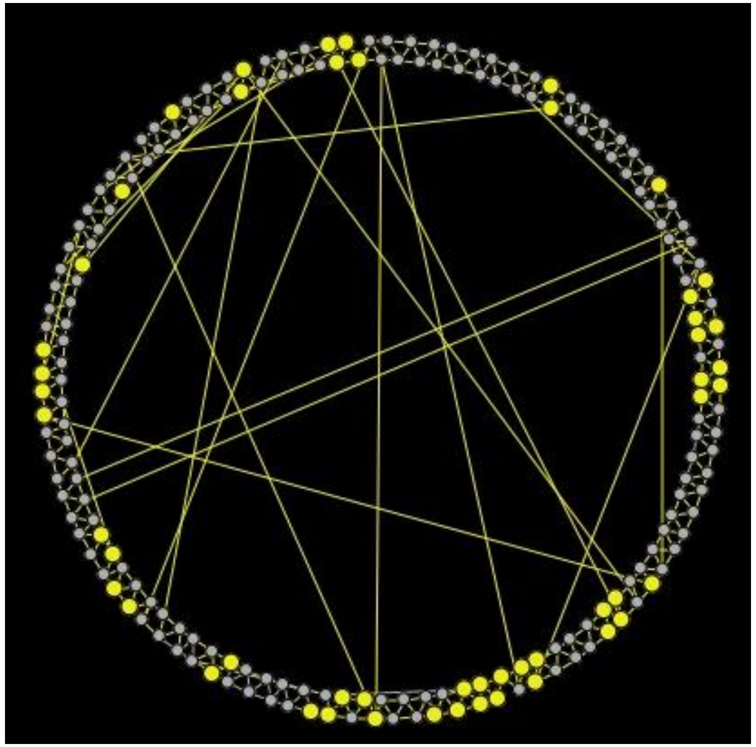
Processes on networks

Quiz Q:

- When nodes preferentially attach to high degree nodes, the diffusion over the network is
  1. faster
  2. slower
  3. unaffected

Diffusion in small worlds

- What is the role of the long-range links in diffusion over small world topologies?



http://www.ladamic.com/netlearn/NetLogo4/SmallWorldDiffusionSIS.html (Netlogo 5.3.1)

Quiz Q:

- As the probability of rewiring increases, the speed with which the infection spreads

  1. increases
  2. decreases
  3. remains the same

References

- Social Network Analysis: **Lada Adamic,** University of Michigan.
- Lecture 8: Diffusion through Networks - Daron Acemoglu and Asu Ozdaglar - MIT
- Wikipedia – Current Literature

THANK YOU

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Diffusion through networks: Introduction

- **We are interested in the following questions:**

  1. Under what conditions will an initial outbreak spread to a nontrivial portion of the population?

  2. What percentage of the population will eventually become infected?

  3. What is the effect of immunization policies?

Diffusion: Bass Model-2

- The other representation of the Bass Model is described by

$$\frac{d\,F(t)}{dt} = (p + qF(t))(1 - F(t)),$$

- Solving this when p > 0 and with a condition that F(0) = 0, leads to an expression of

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}}.$$

- **As the parameters p and q are varied, the Bass model can fit a wide variety of diffusion curves**, and as such has been **used in both forecasting diffusion** and **in empirical analyses of diffusion**, where one can estimate q and p from fitting the model to data.

Diffusion: Bass Model-2

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}}.$$

- **There are also a number of extensions of the model to include things such as pricing and advertising.**

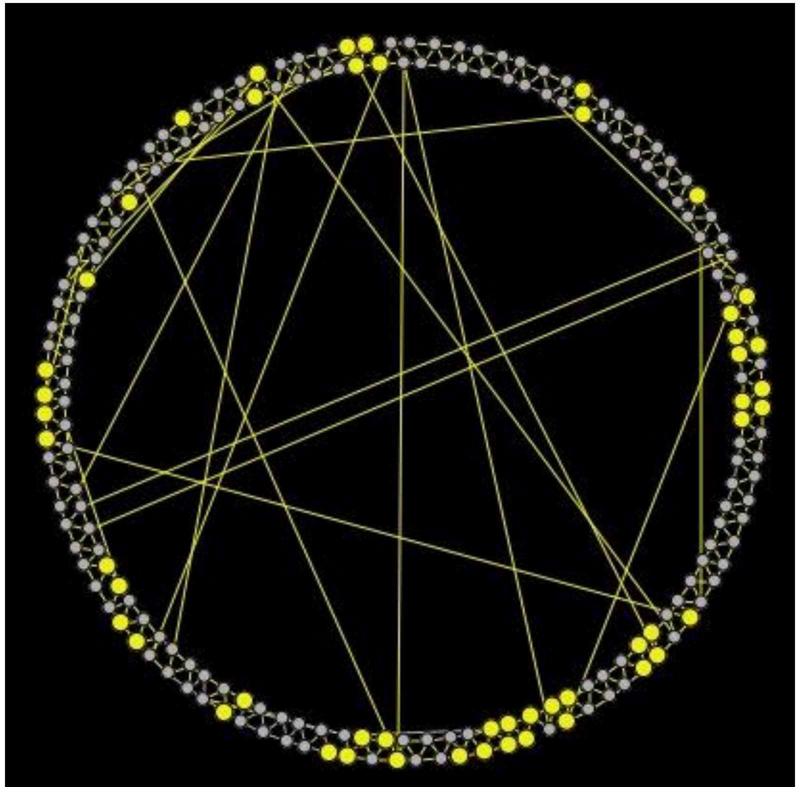
- **Note that the levels of p and q simply multiply time, and the ratio of q to p is the critical parameter that determines the overall shape of the curve.**
  Thus, up to rescalings of time, the curves can be thought of as generated by a single parameter which captures the relative ratio of imitators to innovators.

Simple vs. complex contagion

- **Simple contagion**: each friend infects you with some probability for each unit of time
- **Complex contagion**: you will only take action if a certain number or fraction of your neighbors do.

What is the role of the shortcuts?

- long range links unlikely to coincide in influence



Quiz Q:

- Relative to the simple contagion process the complex contagion process:
  1. is better able to use shortcuts
  2. advances more rapidly through the network
  3. infects a greater number of nodes

Processes on networks

recap

- network topology influences processes occurring on networks
  - what state the nodes converge to
  - how quickly they get there
- process mechanism matters:
  - simple vs. complex contagion
  - coordination
  - learning