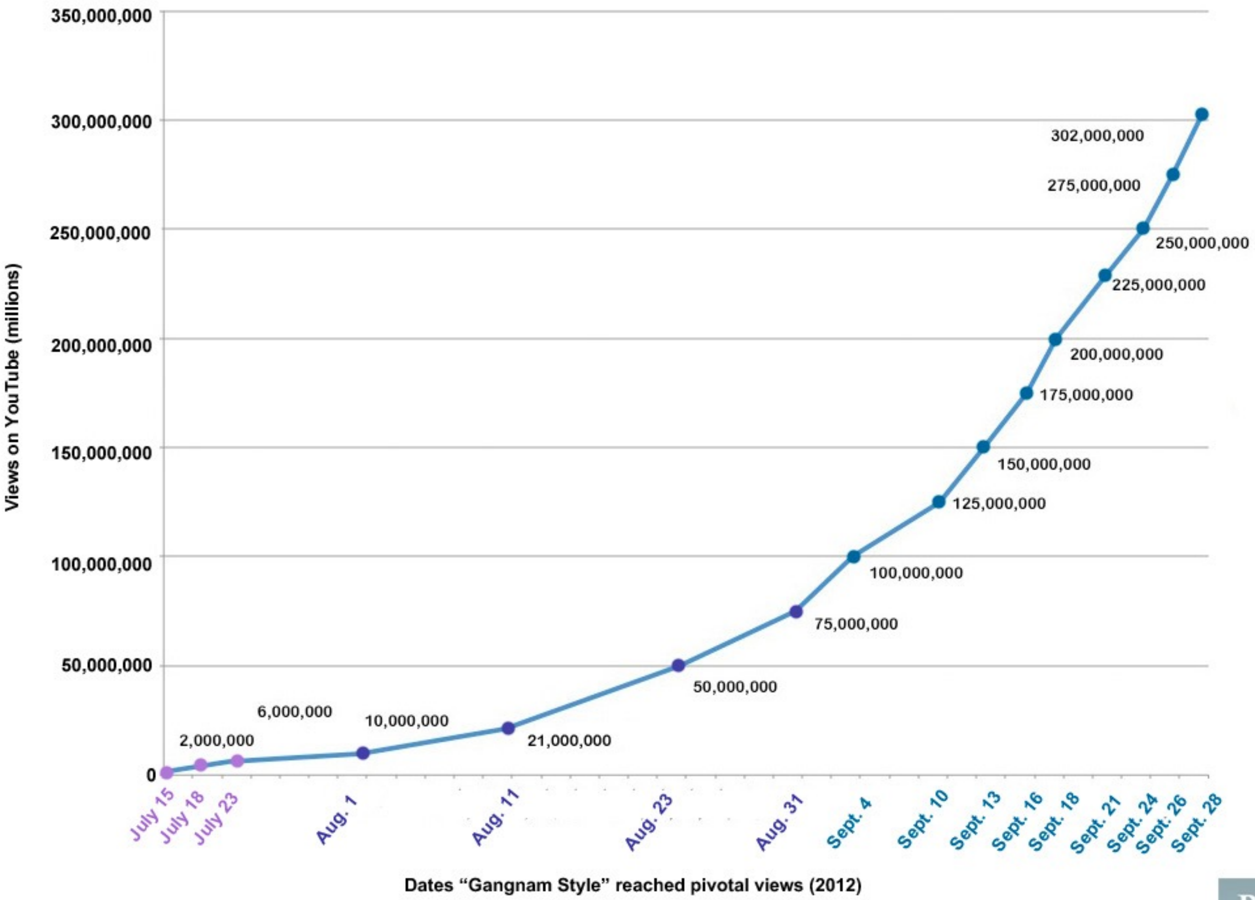
DEI
DEPARTAMENTO
DE ENGENHARIA INFORMÁTICA
TÉCNICO LISBOA

Can we resort to similar techniques to address social systems?

Spread of information

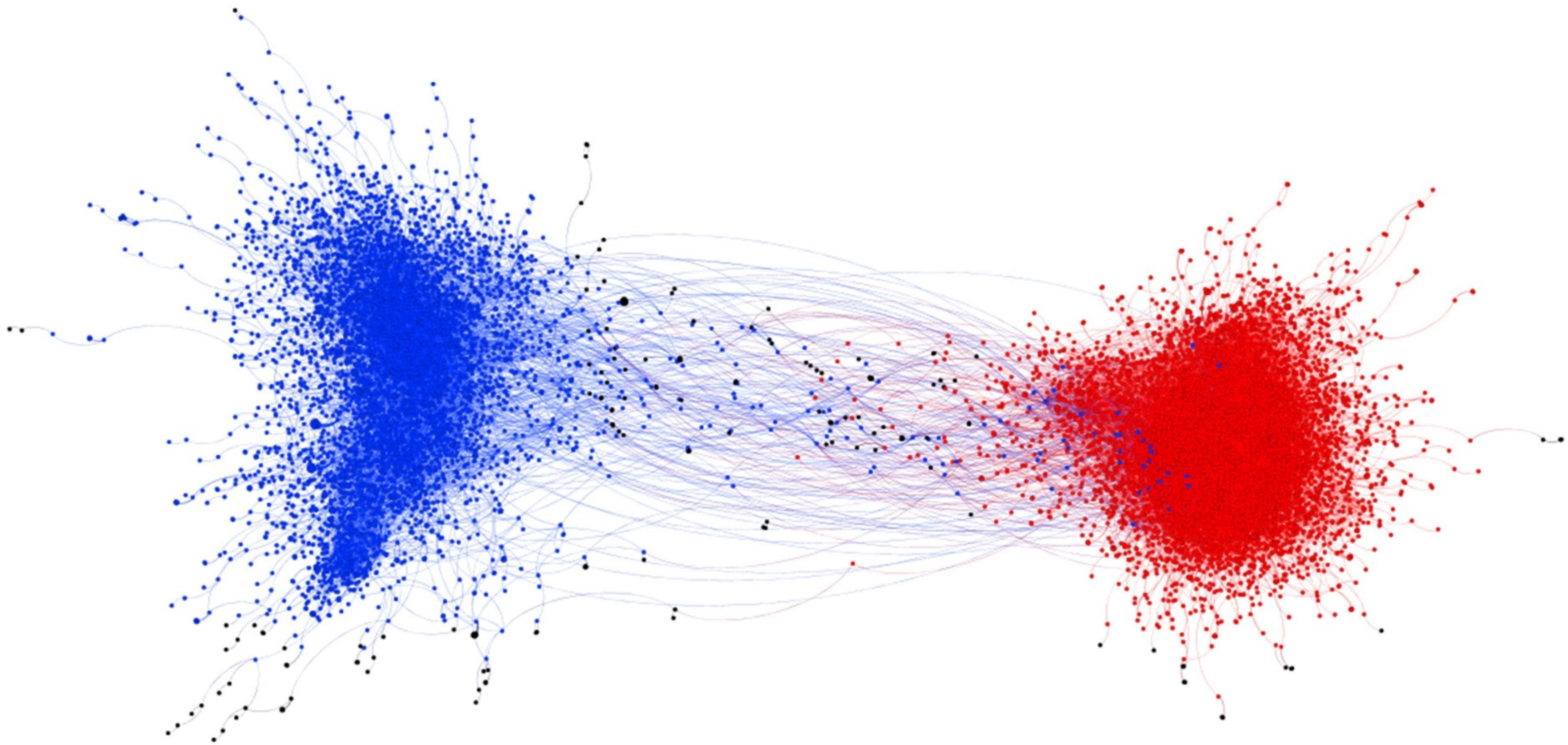
What turns a video viral?
Can we formally explain this type of dynamics?

Growth of ‘Gangnam Style’ Views On YouTube



Sources: Yahoo, NY Times, Korea Times, WSJ

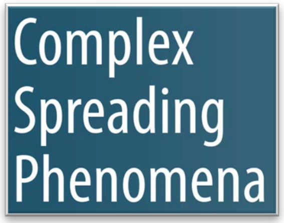
How are human preferences shaped?



From: Brady, W. J., et al. "Emotion shapes the diffusion of moralized content in social networks." Proc. Natl. Acad. Sci USA 114.28 (2017): 7313-7318.

The complexity of social behavior

•Diffusion of memes, ideas or innovations often follows a similar trend as disease spreading.



• However, often opinions are adopted from the assessment of aggregates and not from a single contact.

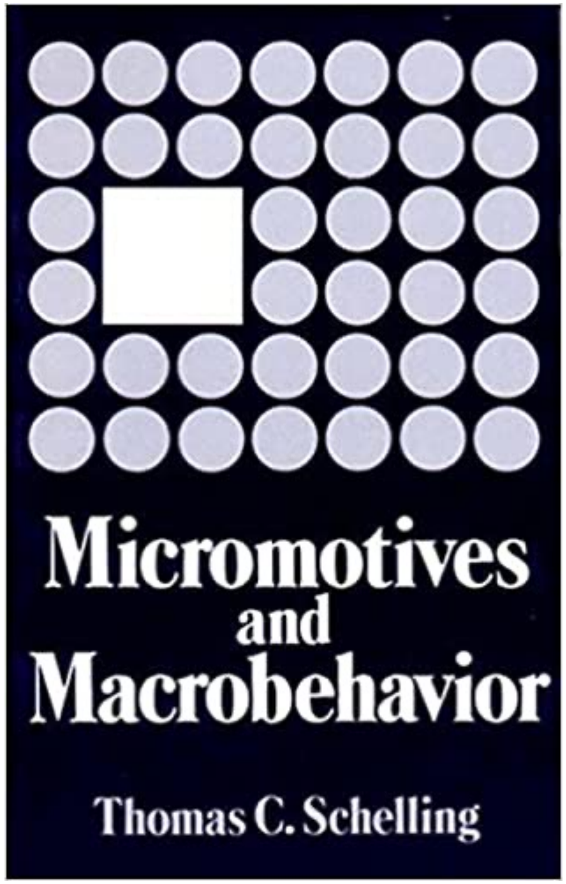
• Moreover, spread of information, adoption of new trends, habits, opinions, etc., may be intentional acts, unlike disease spreading. Some behaviors, trends and ideas may bring more benefits than others…

Contrary to disease spreading, there's much more around than "contact processes"

But let me start from the classics…

The begin of (agent-based) computational economics
(see, e.g., T. Schelling, Micromotives and macrobehavior (1978))

Thomas Schelling, Nobel Prize 2005



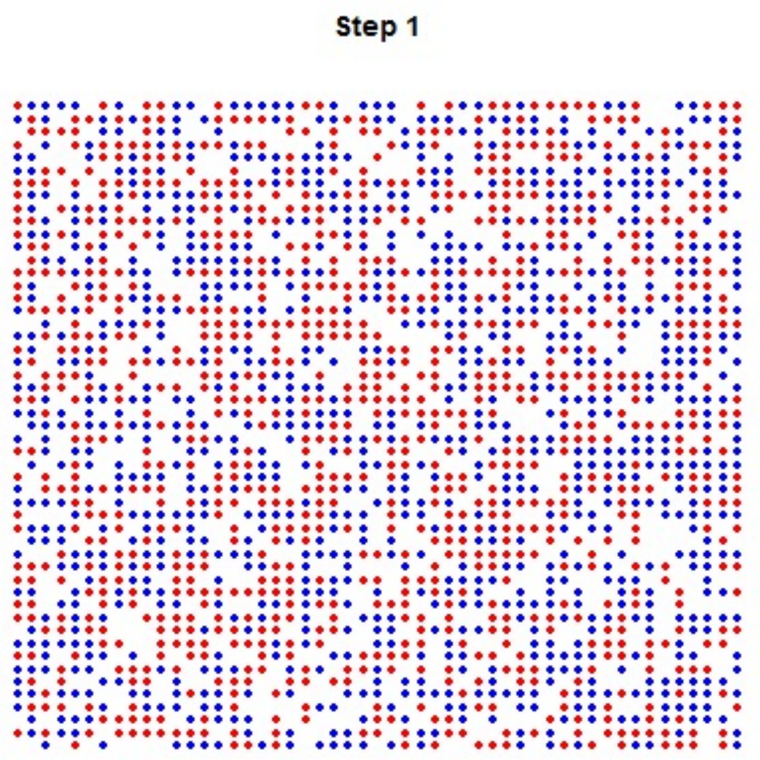
Example: racial segregation

Schelling model of urban racial segregation

The begin of (agent-based) computational economics
(see, e.g., T. Schelling, Micromotives and macrobehaviors (1978))

Thomas Schelling, Nobel Prize 2005

Example: racial segregation

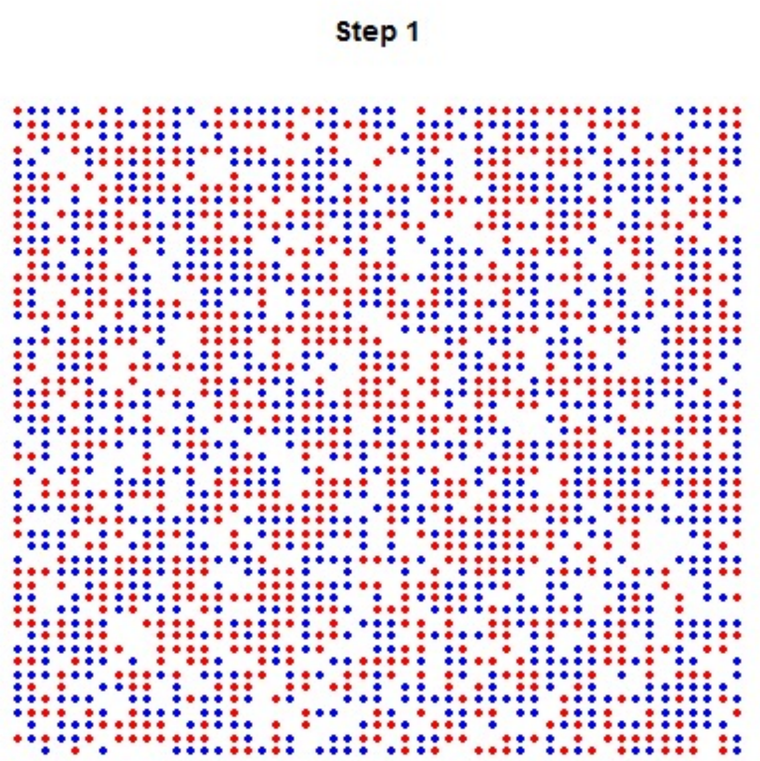


Rules:
- Suppose there are two types of agents, each representing different ethnic groups, economic status, etc.
- A satisfied agent is one that is surrounded by at least T percent of agents that are like itself.
- T can be quite low… and still we get segregation.

Implementation in Python: http://lectures.quantecon.org/jl/schelling.html

Schelling model of urban racial segregation

The begin of (agent-based) computational economics
(see, e.g., T. Schelling, Micromotives and macrobehaviors (1978))



Thomas Schelling, Nobel Prize 2005

Even when agents didn't mind living next agents of a different group, they would still choose to segregate themselves from other agents over time!

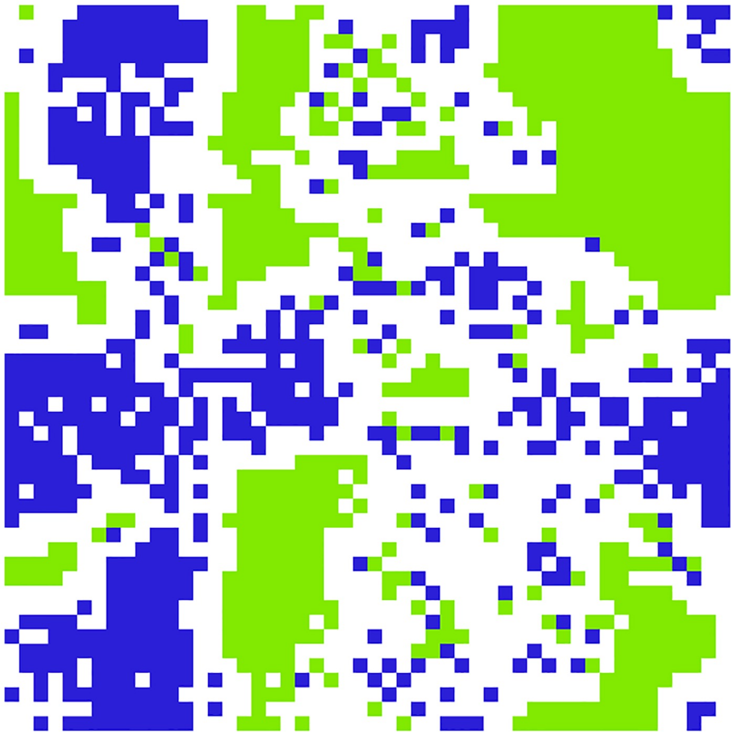
Although the model is quite simple, it gives a fascinating look at how individuals might self-segregate, even when they have no explicit desire to do so.

Implementation in Python: http://lectures.quantecon.org/jl/schelling.html

Schelling model of urban racial segregation

The begin of (agent-based) computational economics
(see, e.g., T. Schelling, Micromotives and macrobehaviors (1978))

Thomas Schelling, Nobel Prize 2005



Challenge: What if we allow agents to adapt their tolerance to others in response to their local environment?

Let's say that when agents are exposed to the out-group their tolerance increases if they are currently satisfied with their environment, but otherwise it decreases.

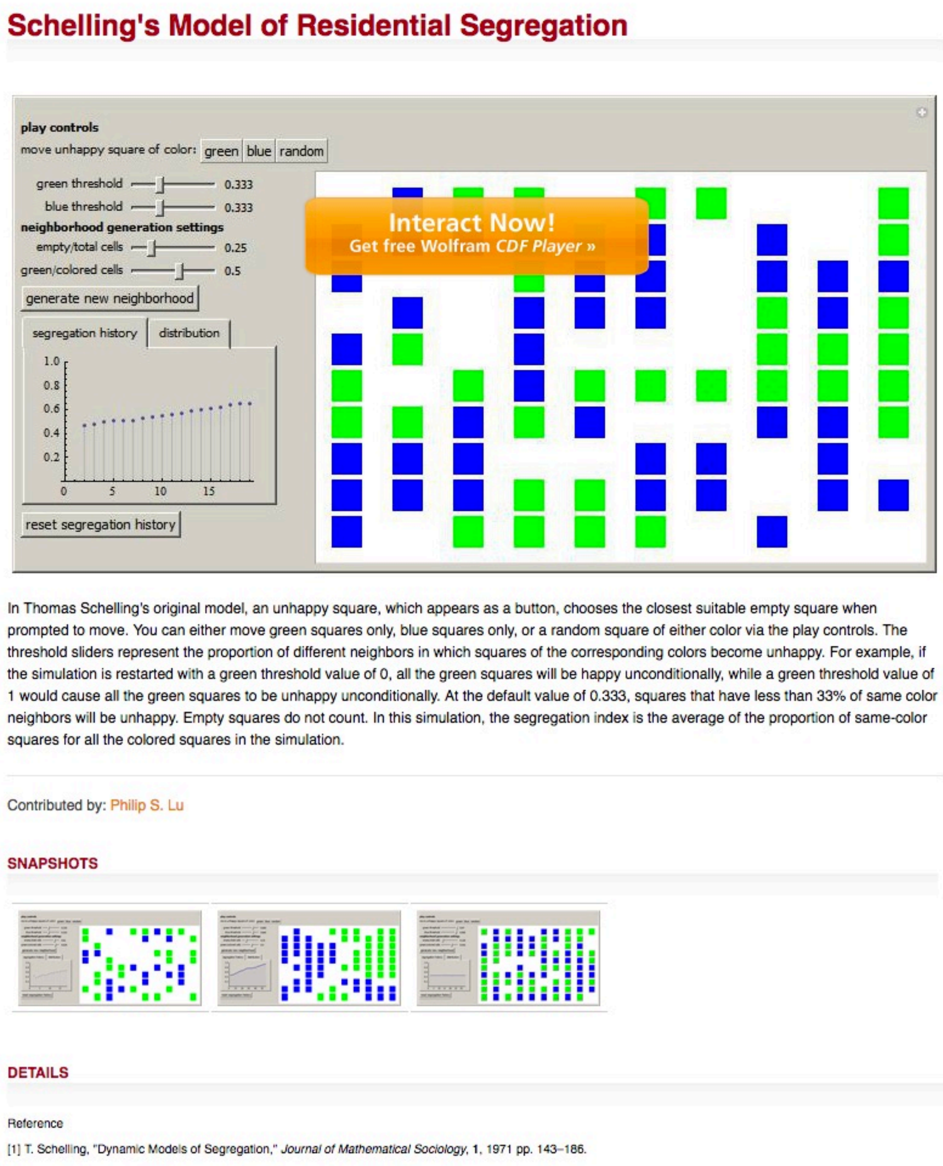
Does adaptive tolerance increases segregation?

Urselmans L, Phelps S (2018) A Schelling model with adaptive tolerance. PLoS ONE 13(3): e0193950.

Schelling model of urban racial segregation

Wolfram Demonstrations Project™

http://demonstrations.wolfram.com/SchellingsModelOfResidentialSegregation/



See also generalized version of this idea using game theoretical concepts: In *Schelling games*, agents strategically strive to maximize their utilities by relocating to a new position

Opinions as diseases (DK model)

Daley and Kendall (1964)

Example: SIR model of rumor propagation

S

Susceptible or ignorant

$1\text{-}x\text{-}r$

$\xrightarrow{\lambda}$

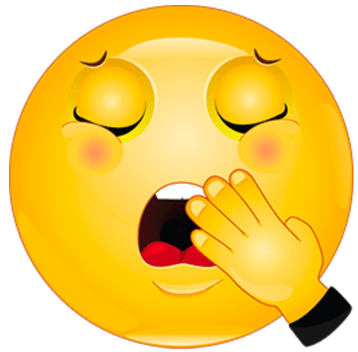
I

Informed who spread the information

x

$\xrightarrow{\alpha}$

R



Stiflers

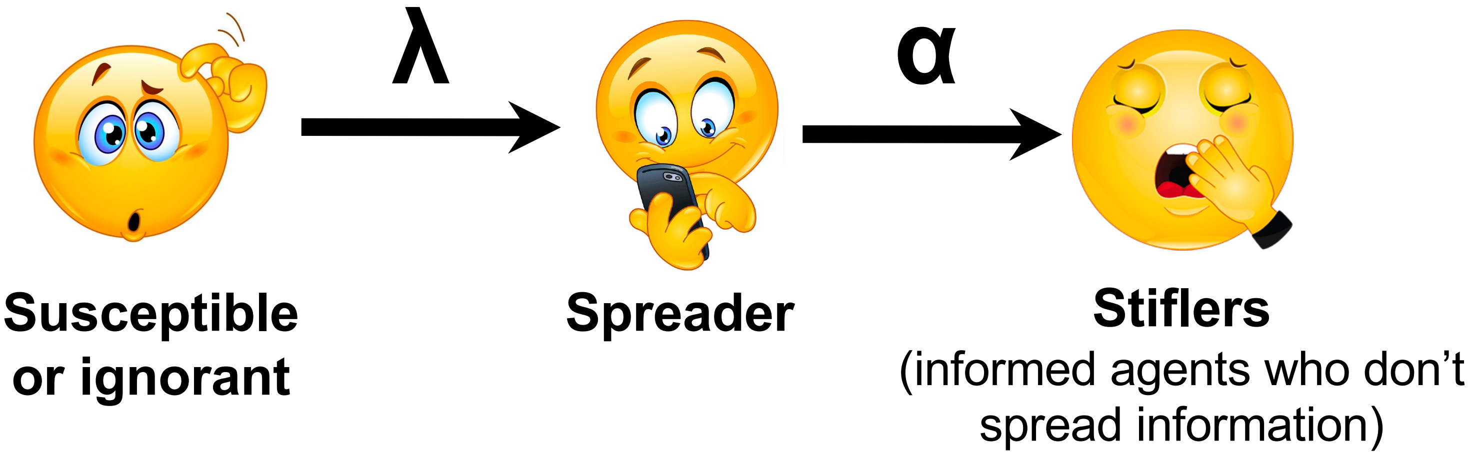
(informed agents who don't spread information)

r

Rumor & information spreading (DK model)

Daley and Kendall (1964)

SIR model of rumor propagation



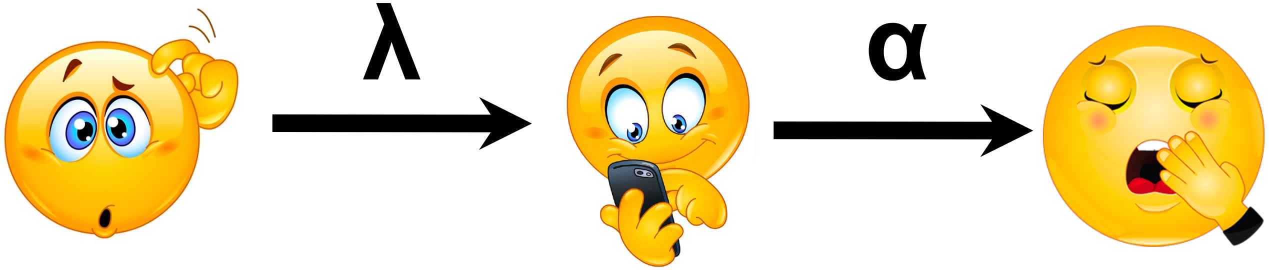
Contrary to disease spreading, I➔R the recovery occurs only because of the contact of a spreader with either other spreaders or stiflers

Dissemination of information in the internet
Development of marketing strategies, *aka*, viral marketing, etc.
GOAL: Compute the efficiency of rumor spreading

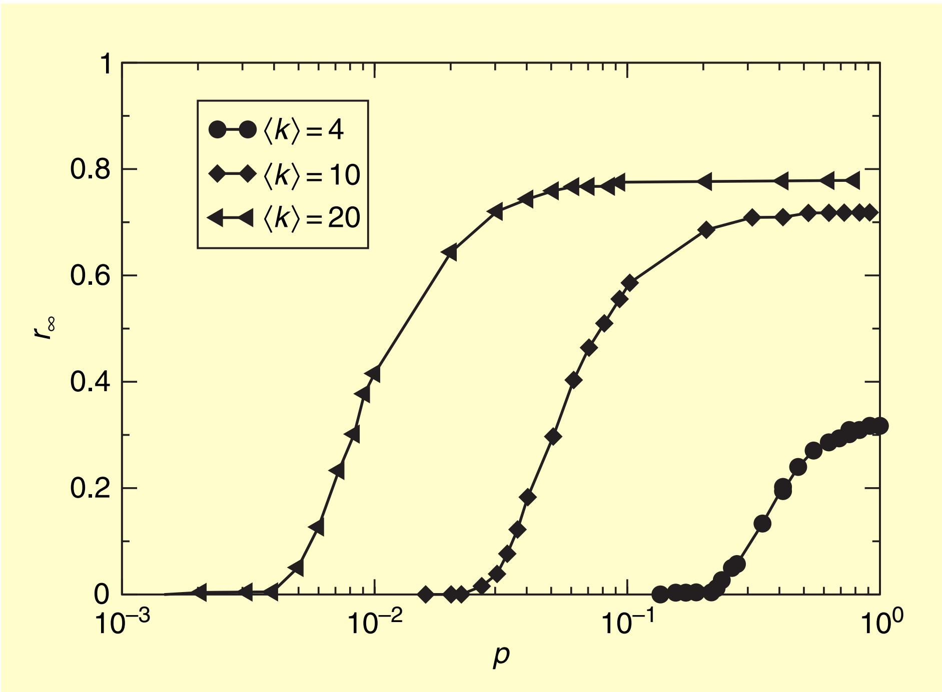
Rumor & information spreading (DK model)

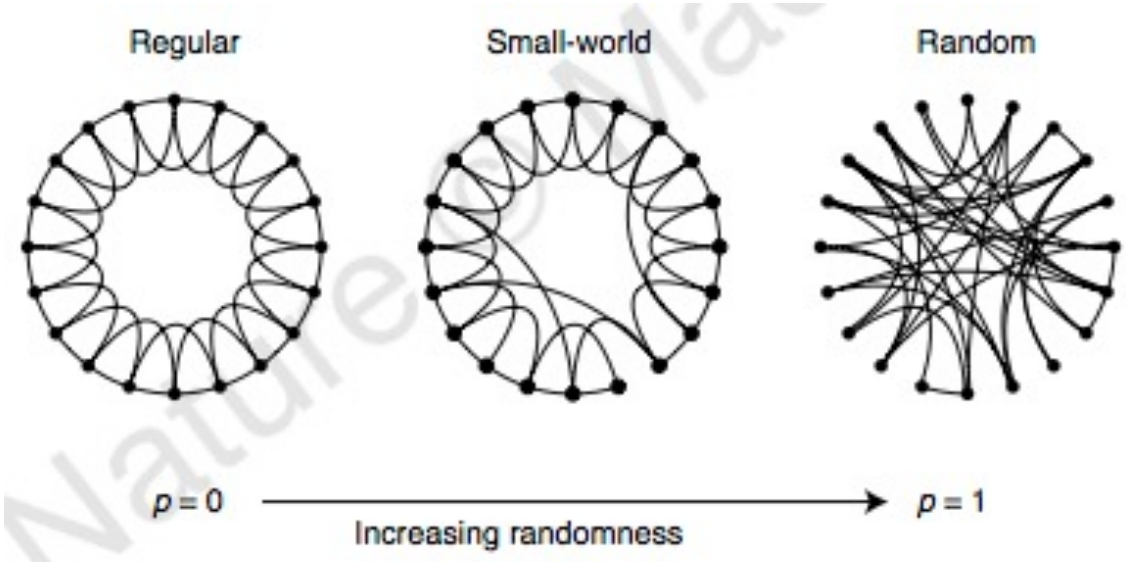
SIR model of rumor propagation

Barrat, Barthelemy & Vespignani,
Dynamical Processes On Complex
Networks, CUP, 2008, Chapter 10



Susceptible or ignorant — **Spreader** — **Stiflers** (informed agents who don't spread information)

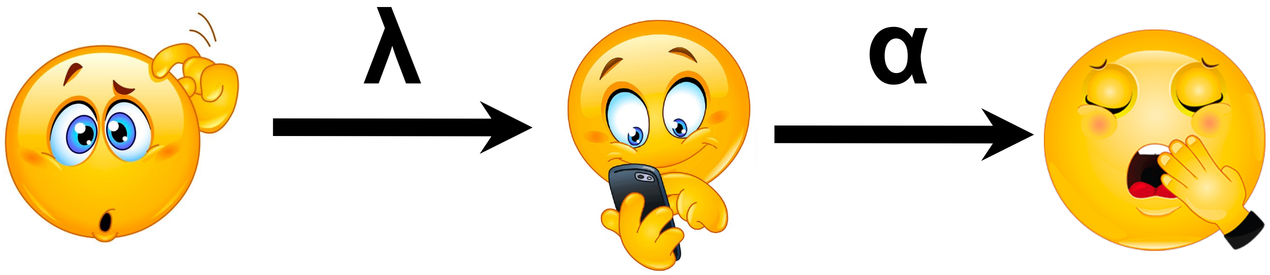




Rumor & information spreading (DK model)

SIR model of rumor propagation

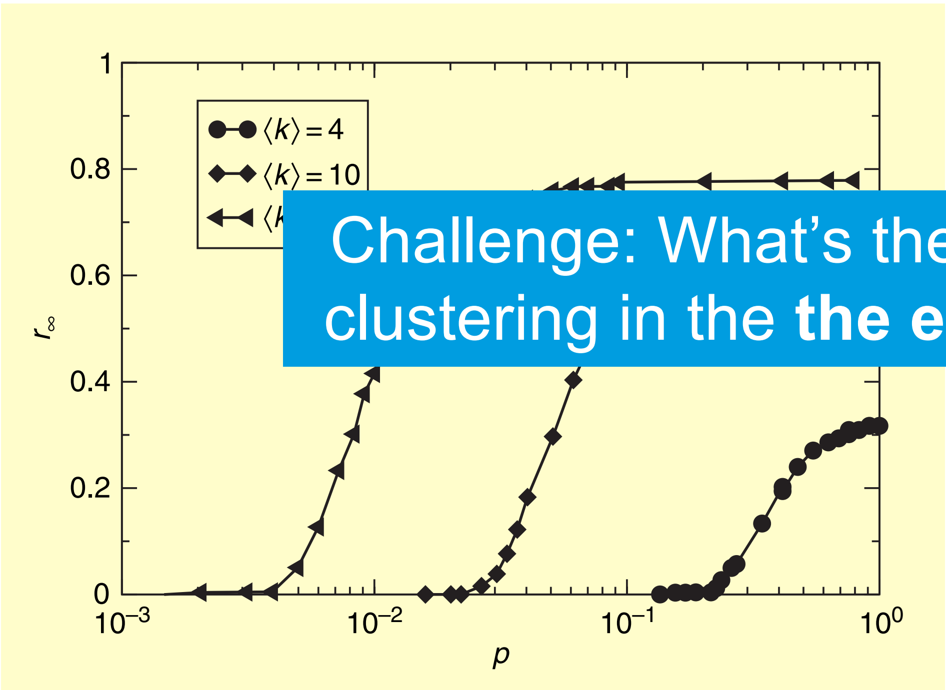
Barrat, Barthelemy & Vespignani, Dynamical Processes On Complex Networks, CUP, 2008, Chapter 10

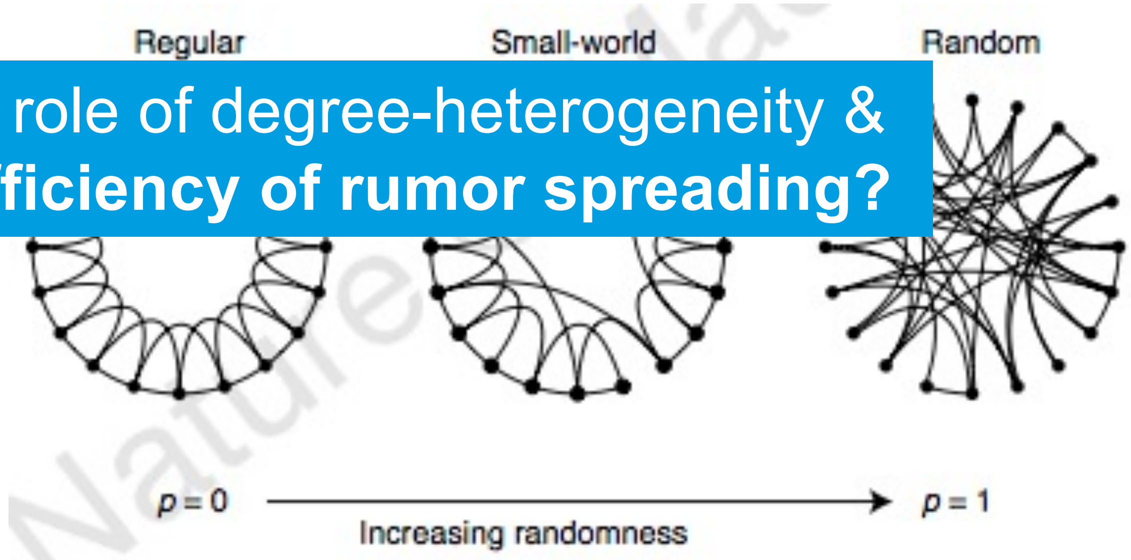


Susceptible or ignorant

Spreader

Stiflers
(informed agents who don't spread information)



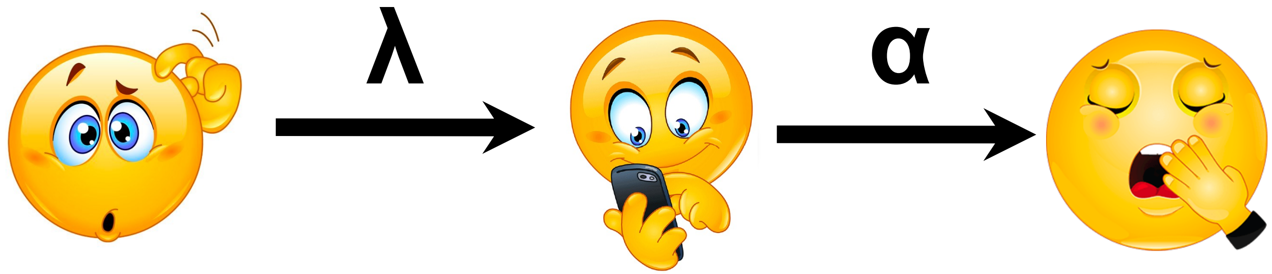


Challenge: What's the role of degree-heterogeneity & clustering in the **the efficiency of rumor spreading?**

Rumor & information spreading (DK model)

Barrat, Barthelemy & Vespignani, Dynamical Processes On Complex Networks, CUP, 2008, Chapter 10

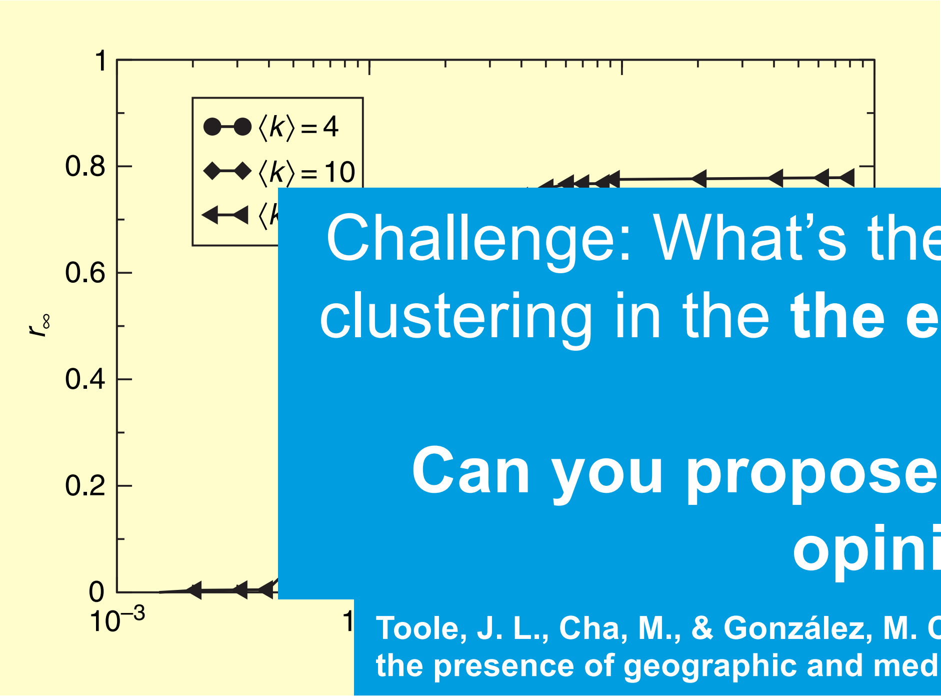
SIR model of rumor propagation

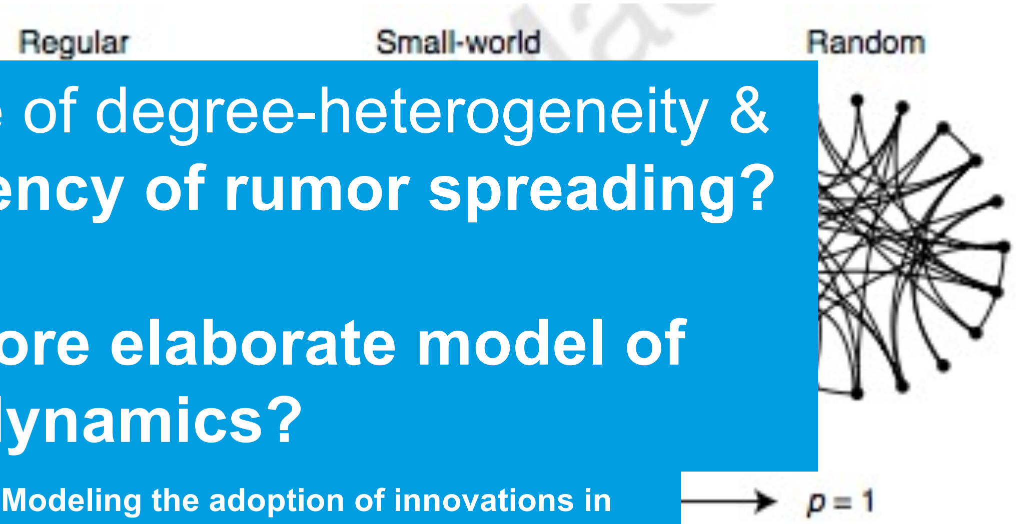


Susceptible or ignorant

Spreader

Stiflers
(informed agents who don't spread information)





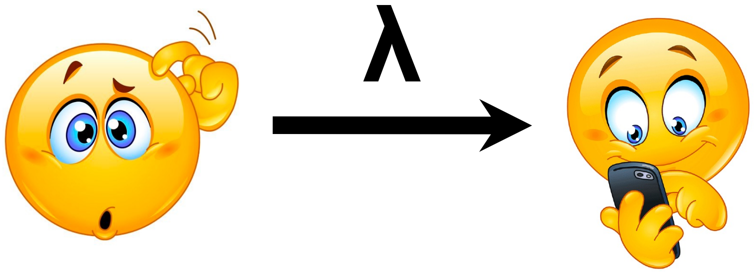
Challenge: What's the role of degree-heterogeneity & clustering in the **the efficiency of rumor spreading?**

Can you propose a more elaborate model of opinion dynamics?

Toole, J. L., Cha, M., & González, M. C. (2012). Modeling the adoption of innovations in the presence of geographic and media influences. PloS one, 7(1), e29528.

Adoption of innovations in the presence of geographic and media influences

SI model of rumor propagation + media influence



Susceptible or ignorant **Spreader**

PLOS ONE

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Modeling the Adoption of Innovations in the Presence of Geographic and Media Influences

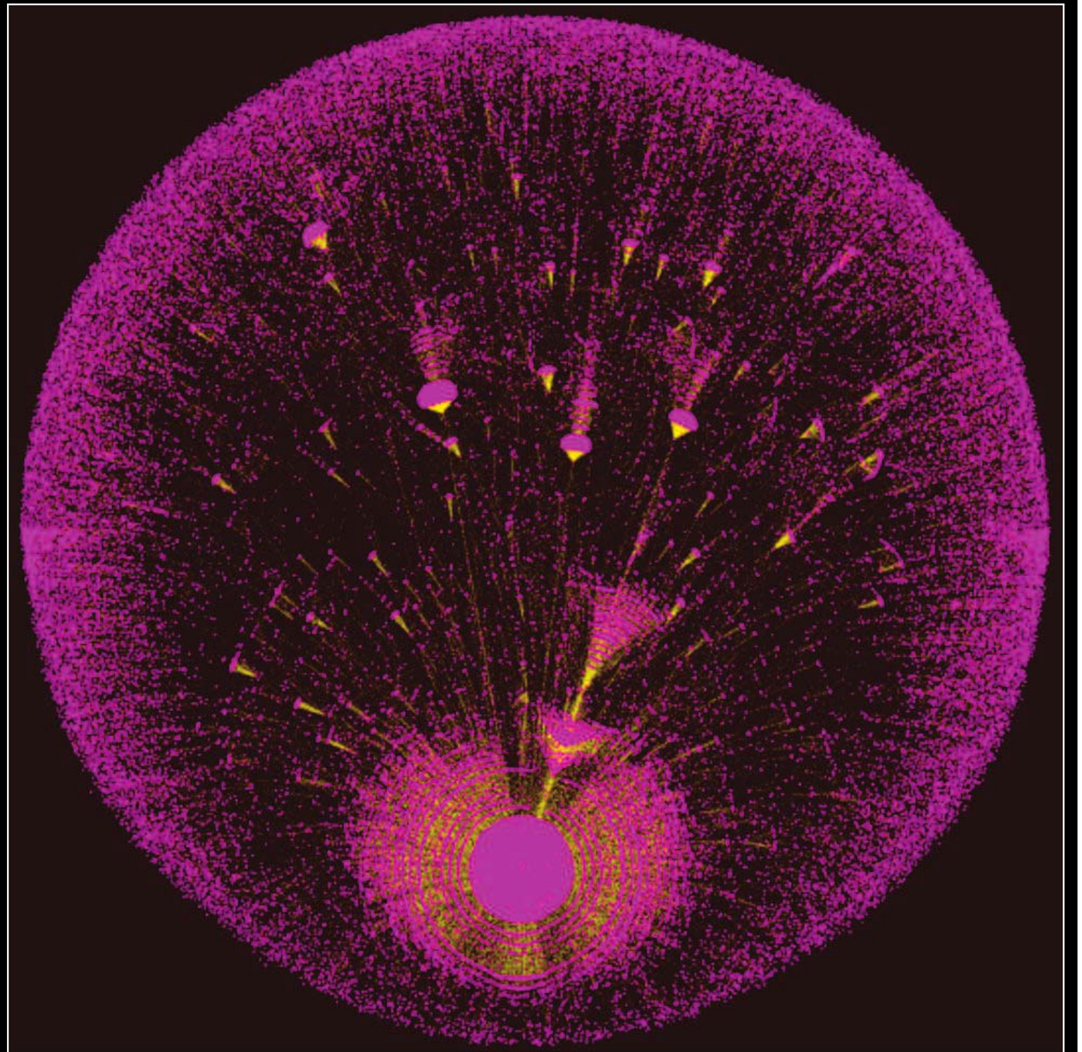
Jameson L. Toole, Meeyoung Cha, Marta C. González

Published: January 19, 2012 • https://doi.org/10.1371/journal.pone.0029528

Social media under information overload conditions

Empirical data (e.g., Sina Weibo, a Chinese microblogging website) shows that an individual with more friends needs more repeated exposures to spread the information.

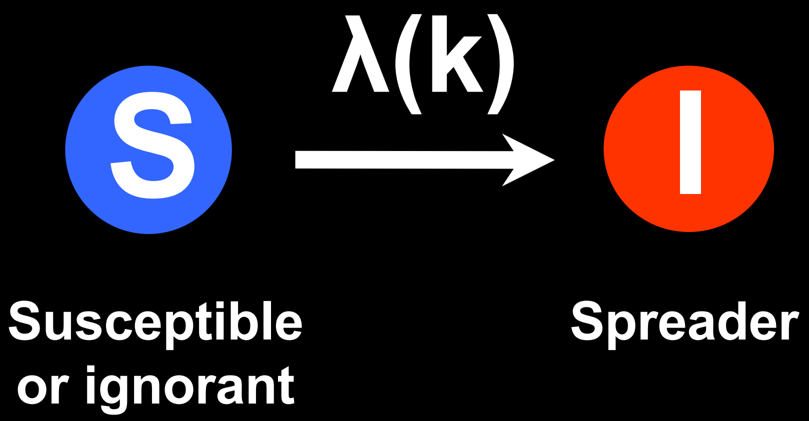
Feng, L., Hu, Y., Li, B., Stanley, H. E., Havlin, S., & Braunstein, L. A. (2015). Competing for attention in social media under information overload conditions. *PloS One*, *10*(7), e0126090.



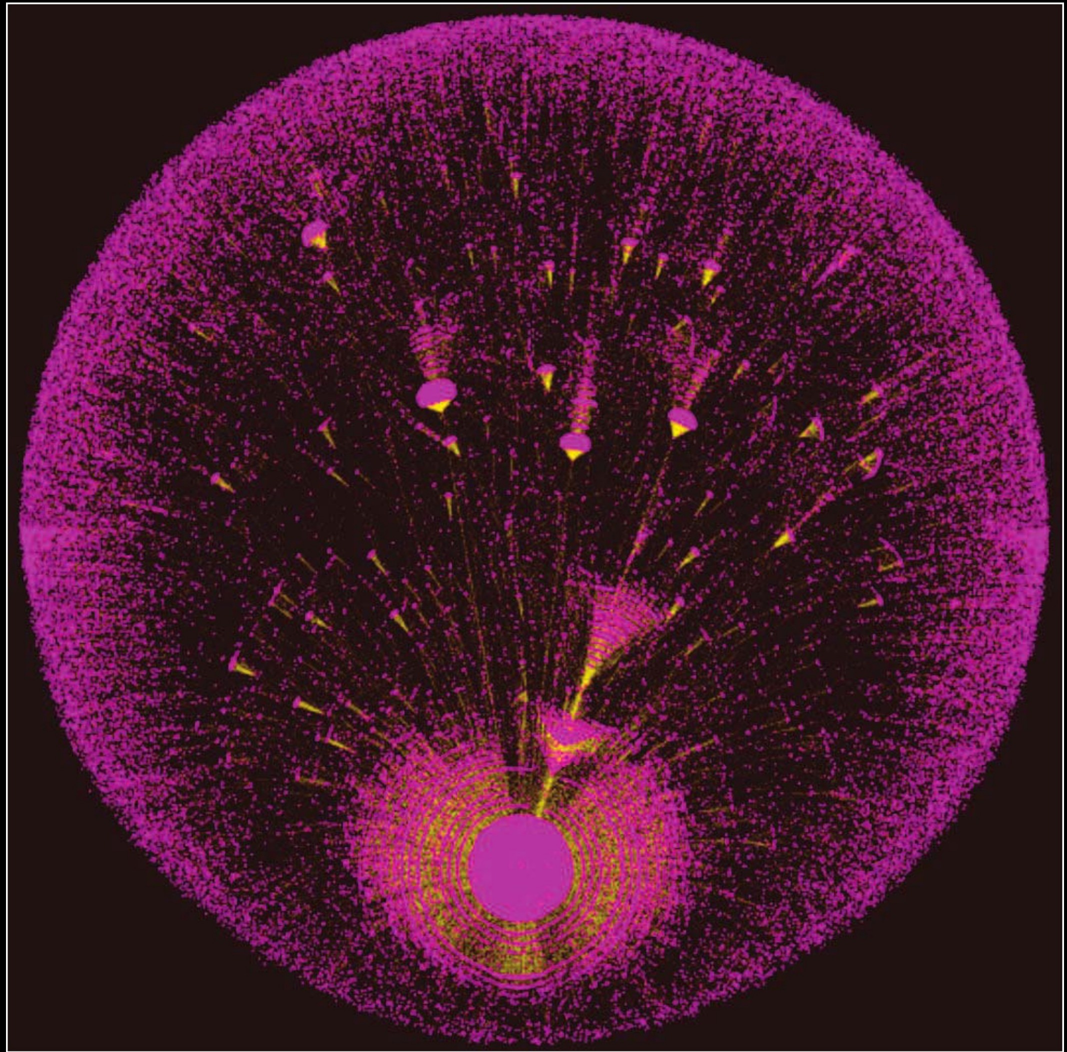
graphic representation for one of the popular messages on Weibo, and its branching process. It has been shared more than 190,000 times.

Social media under information overload conditions

SIR with a twist: Fractional-SIR



Feng, L., Hu, Y., Li, B., Stanley, H. E., Havlin, S., & Braunstein, L. A. (2015). Competing for attention in social media under information overload conditions. *PloS One*, *10*(7), e0126090.



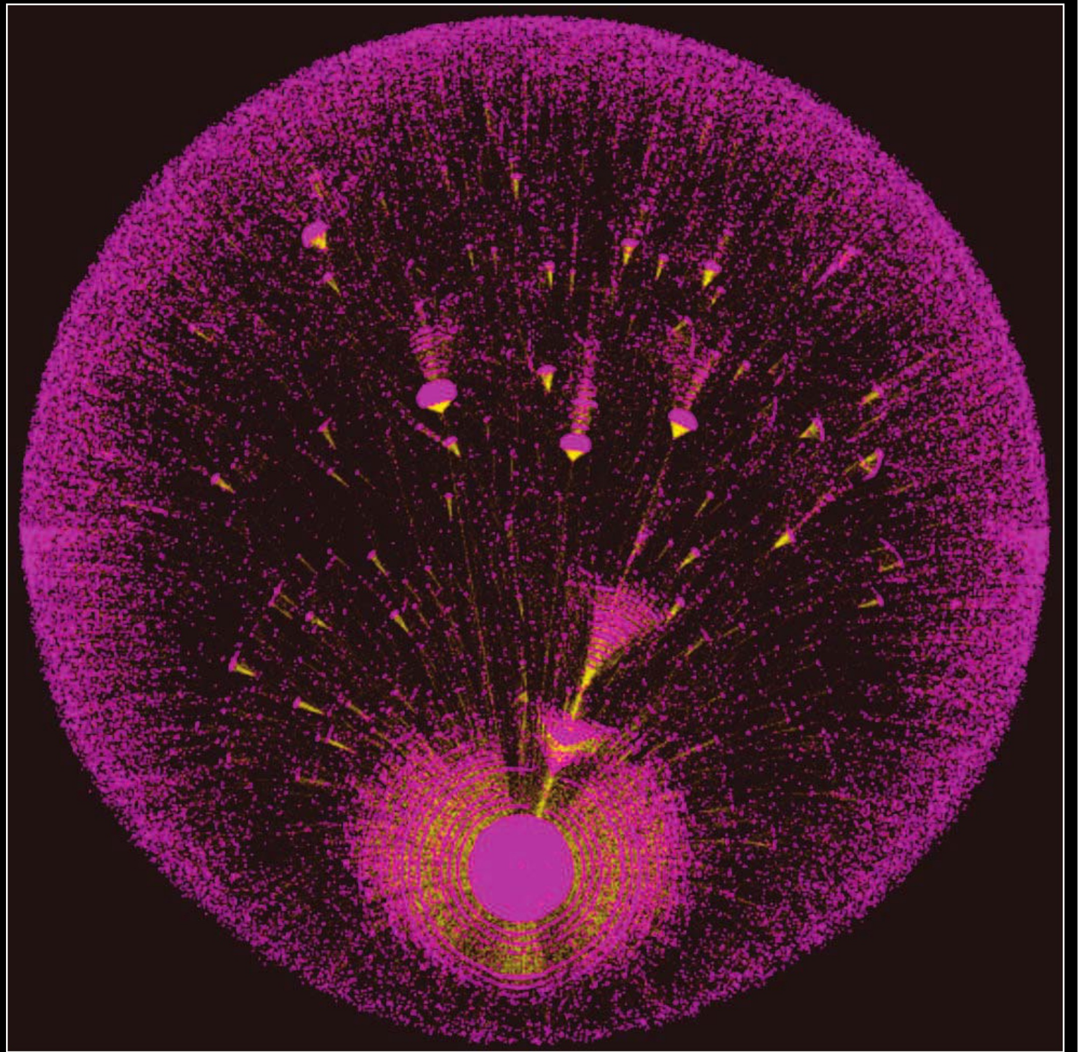
graphic representation for one of the popular messages on Weibo, and its branching process. It has been shared more than 190,000 times.

Social media under information overload conditions

SIR with a twist: Fractional-SIR

In this case, real-world social networks have a finite epidemic threshold in contrast to the zero threshold in disease epidemic models.

Feng, L., Hu, Y., Li, B., Stanley, H. E., Havlin, S., & Braunstein, L. A. (2015). Competing for attention in social media under information overload conditions. *PloS One*, *10*(7), e0126090.



graphic representation for one of the popular messages on Weibo, and its branching process. It has been shared more than 190,000 times.

The complexity of social behavior

- Diffusion of memes, ideas or innovations often follows a similar trend as disease spreading.

- **Often opinions are adopted from the assessment of aggregates and not from a single contact.**

- Moreover, spread of information, adoption of new trends, habits, opinions, etc., may be intentional acts, unlike disease spreading. Some behaviors, trends and ideas may bring more benefits than others… For instance, we are free to choose among different opinions and behaviors, or even create new ones…

- Contrary to disease spreading, there's much more around than "contact processes"

Virality prediction in social networks: *Complex vs Simple contagion*

- ***Simple contagion***: It is sufficient to come into contact with an infected individual to be infected (same as epidemics).

- The spread of memes, products and behaviors is often described by ***complex contagion***. Adoption of a new meme, product or behavioural pattern does not occur at the first contact. Rather, adoption requires contact with several individuals who have already adopted.

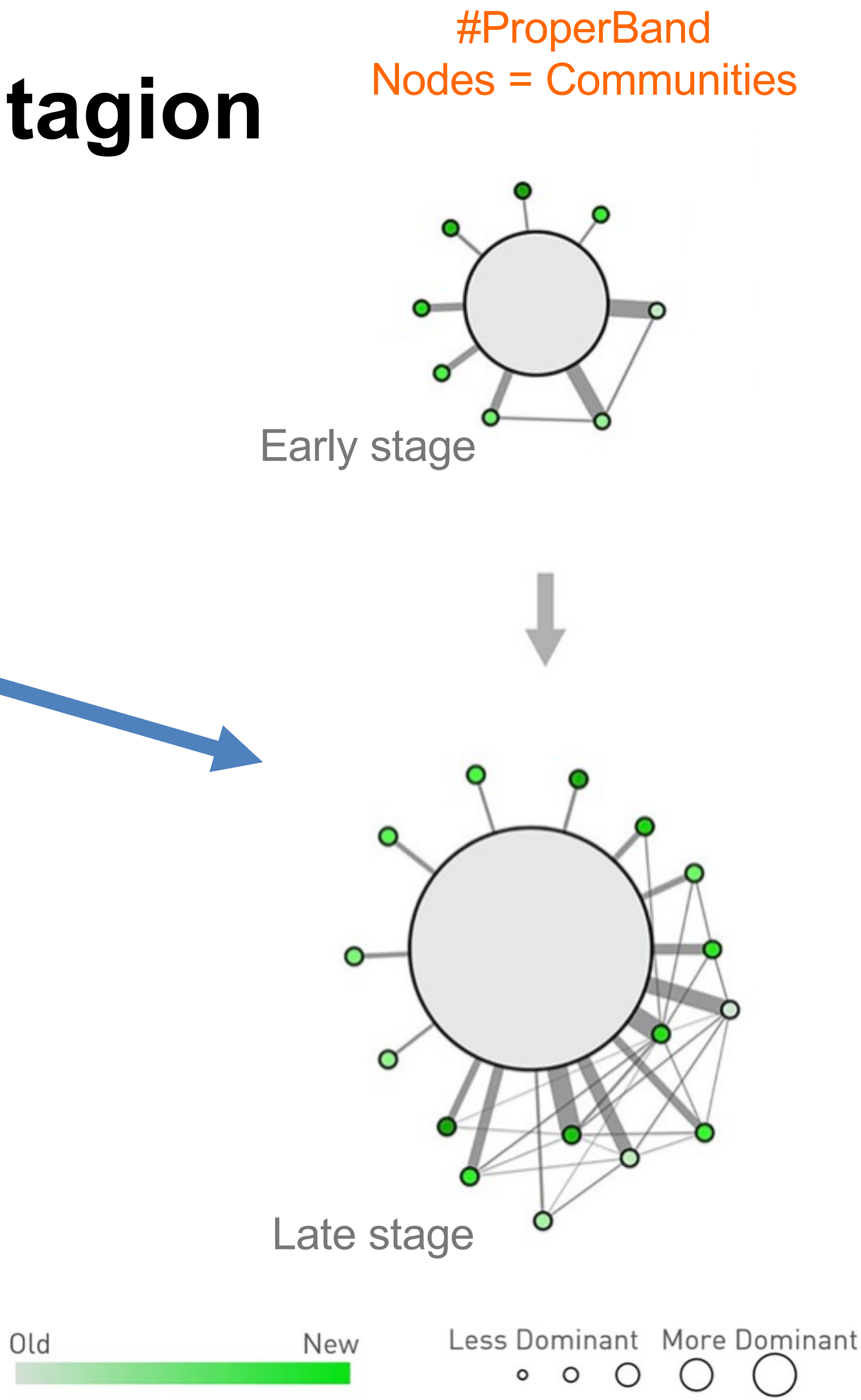
- For example, often one needs a critical number of friends sharing an opinion about a product to nudge someone to also buy the same product.

Complex vs Simple contagion & structural trapping

•The difference between simple and complex contagion is well captured by Twitter data.

• If hashtags are “trapped” in specific communities, this is a signature of complex contagion, or non-viral “memes”.

• If memes jump easily between communities, infecting many of them, it means that we face a viral meme or simple contagion pattern, like the ones found in the case of biological pathogens.



L. Weng, F. Menczer and Y.-Y. Ahn.
Virality Prediction and Community Structure in Social Networks.
Scientific Reports, 3:2522, 2013.

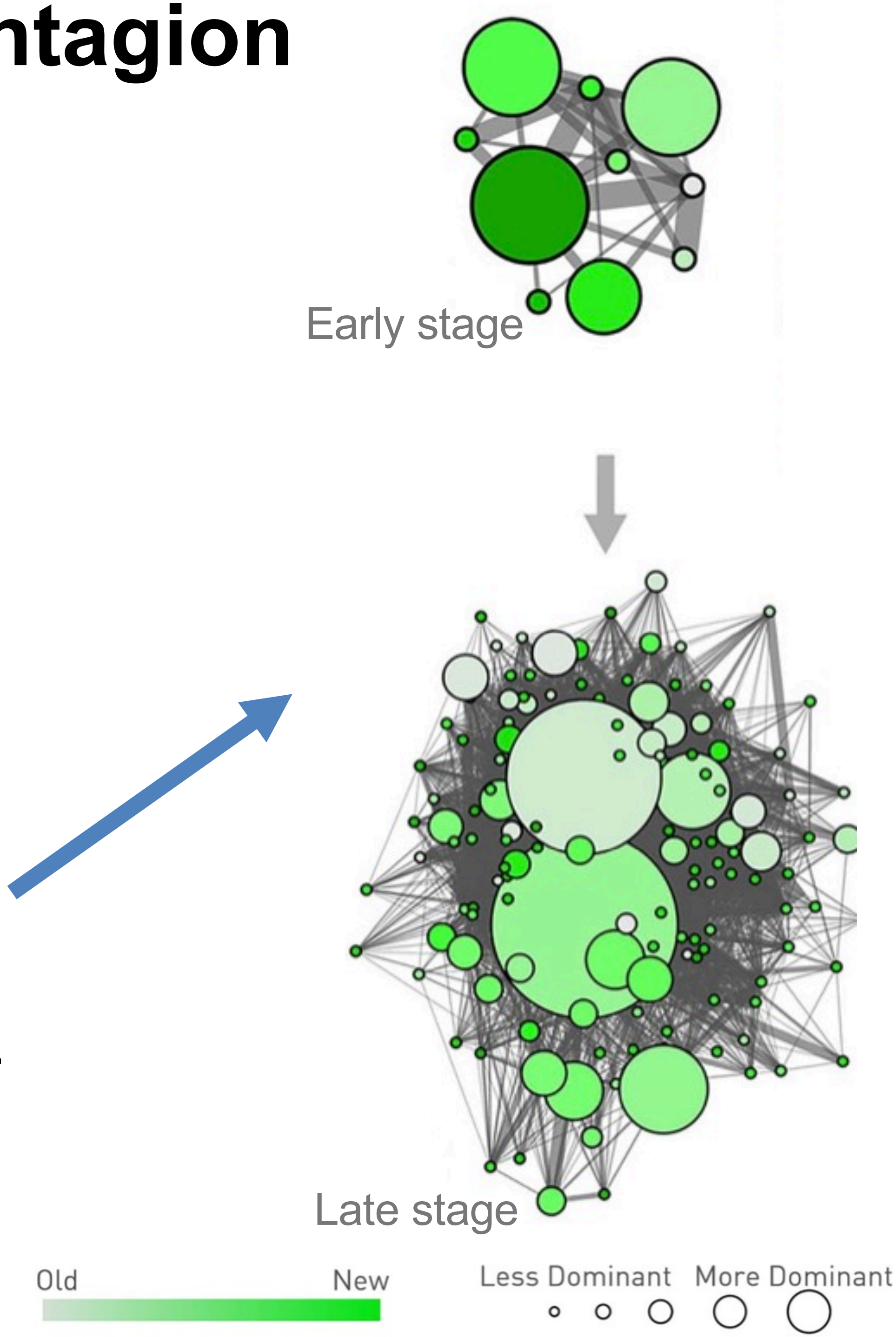
#ThoughtsDuringScool
Nodes = Communities

Complex vs Simple contagion
& structural trapping

•The difference between simple and complex contagion is well captured by Twitter data.

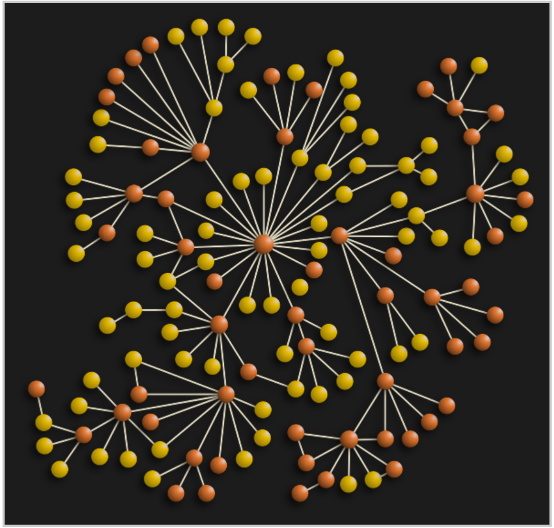
• If hashtags are “trapped” in specific communities, this is a signature of complex contagion, or non-viral “memes”.

• If memes jump easily between communities, infecting many of them, it means that we face a viral meme or simple contagion pattern, like the ones found in the case of biological pathogens.



L. Weng, F. Menczer and Y.-Y. Ahn.
Virality Prediction and Community Structure in Social Networks.
Scientific Reports, 3:2522, 2013.

Consensus dynamics & the Voter model



Challenge :
When do we have
co-existence of opinions?

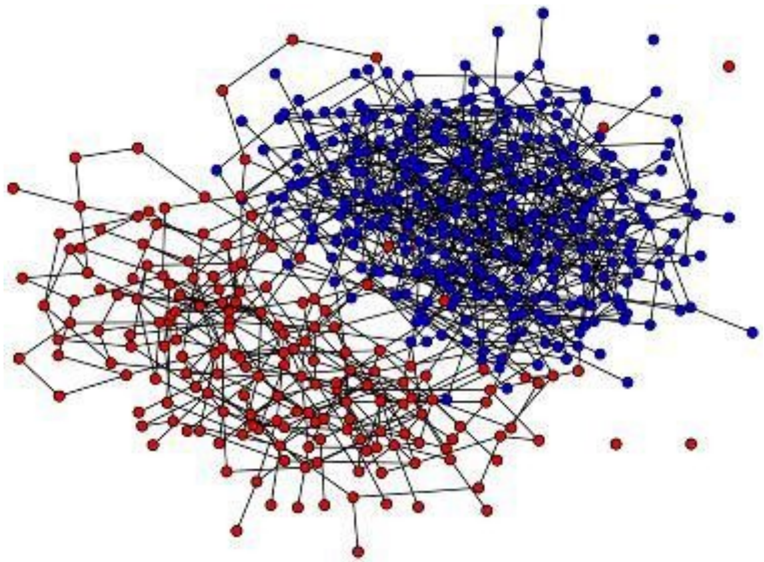
•voters are located at the nodes of a network

•each voter has an opinion (in the simplest case, 0 or 1, but in the general case, n),

•a randomly chosen voter assumes the opinion of one of its neighbors.

Complex contagion variants: majority rule, threshold voter model, etc.

Consensus dynamics & the Voter model



Co-existence on graphs with two clusters

•voters are located at the nodes of a network

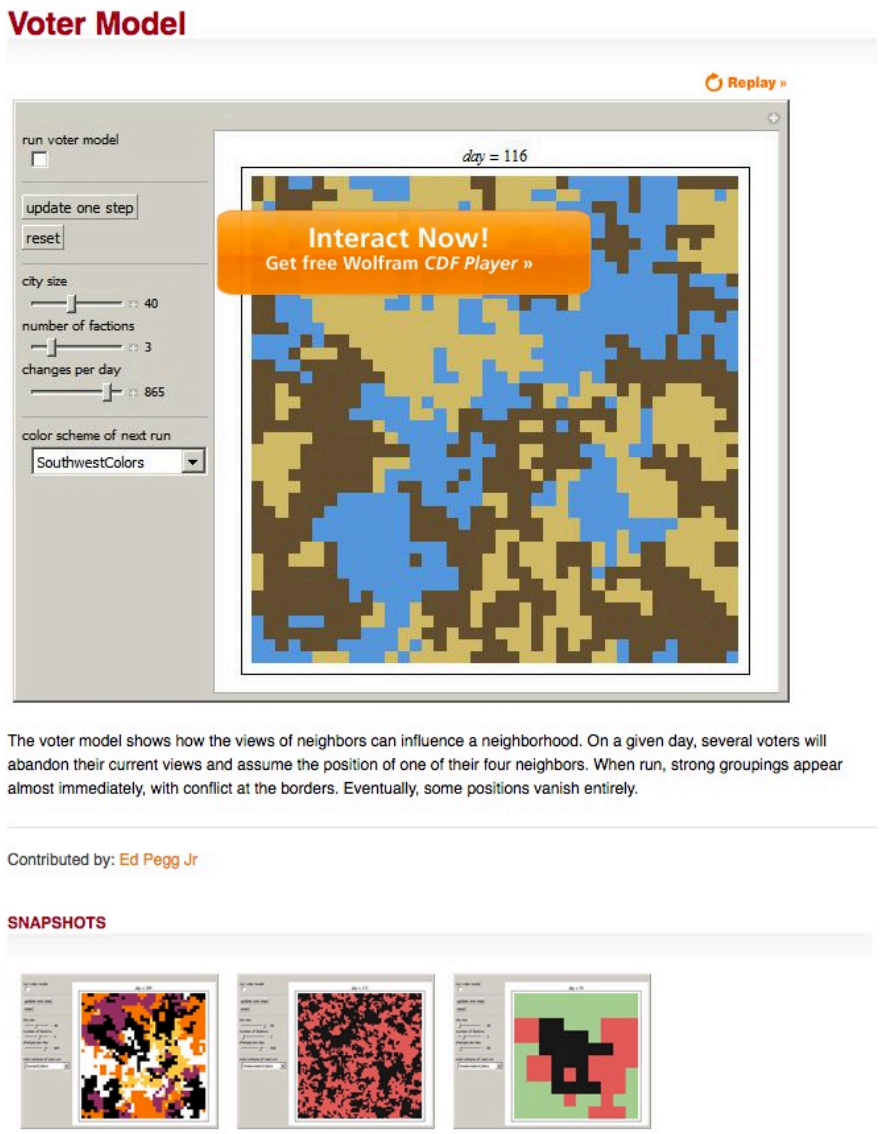
•each voter has an opinion (in the simplest case, 0 or 1, but in the general case, n),

•a randomly chosen voter assumes the opinion of one of its neighbors.

Complex contagion variants: majority rule, threshold voter model, etc.

Consensus dynamics & the Voter model

Wolfram Demonstrations Project™

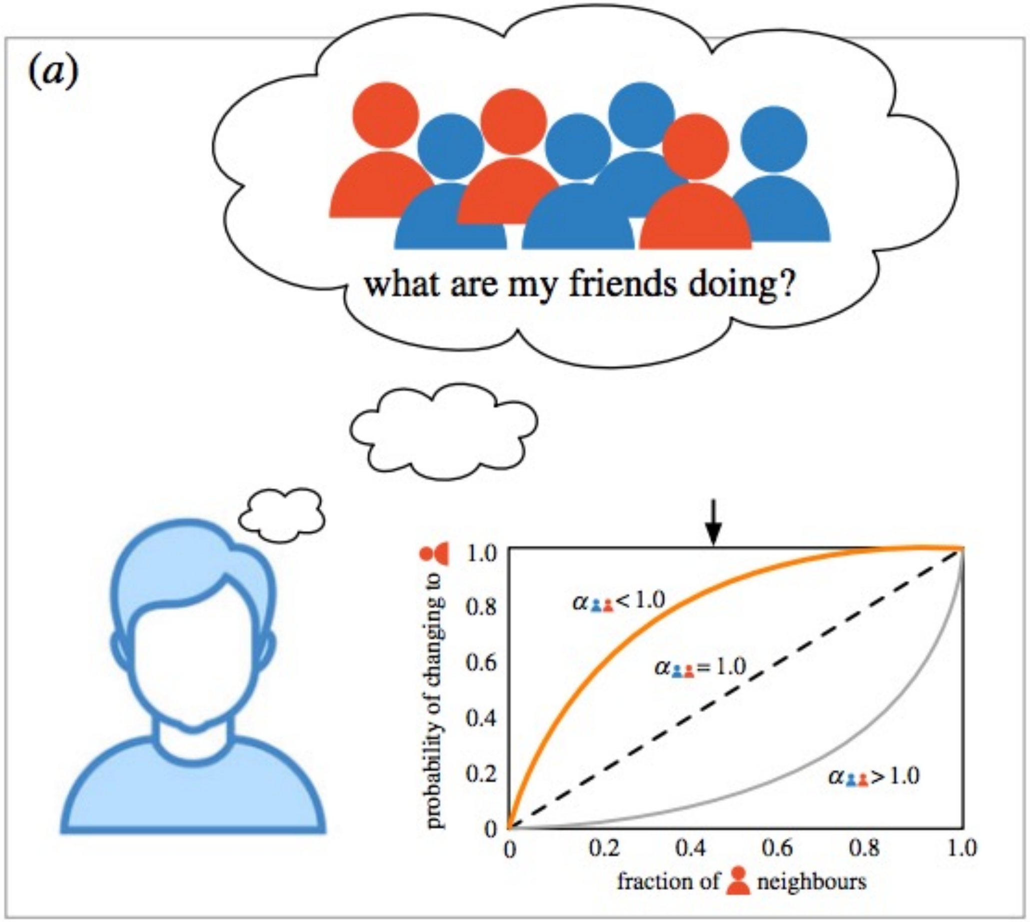


http://demonstrations.wolfram.com/VoterModel/

Generalized Voter Models and competing rumors

In practice, we can assume any peer-influence function

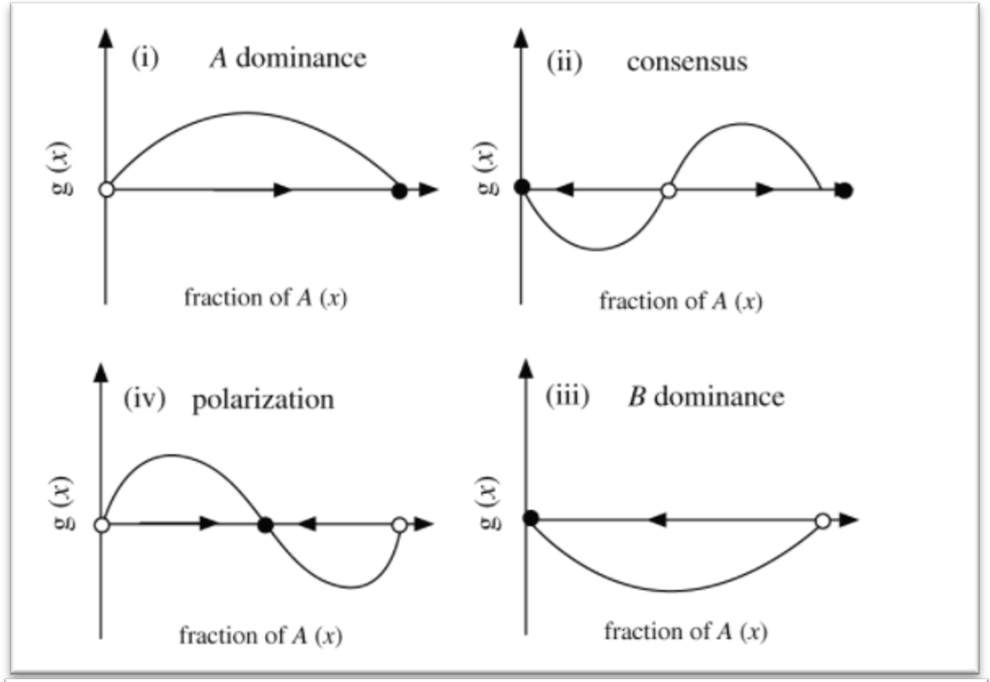
Individuals revise their state taking into consideration those of their friends, which, jointly with the complexity of the diffusing information, define the likelihood of an update

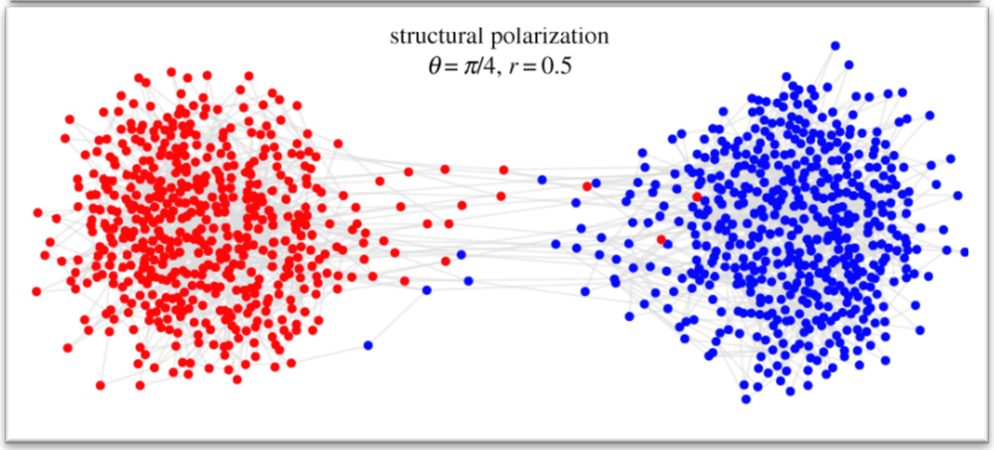


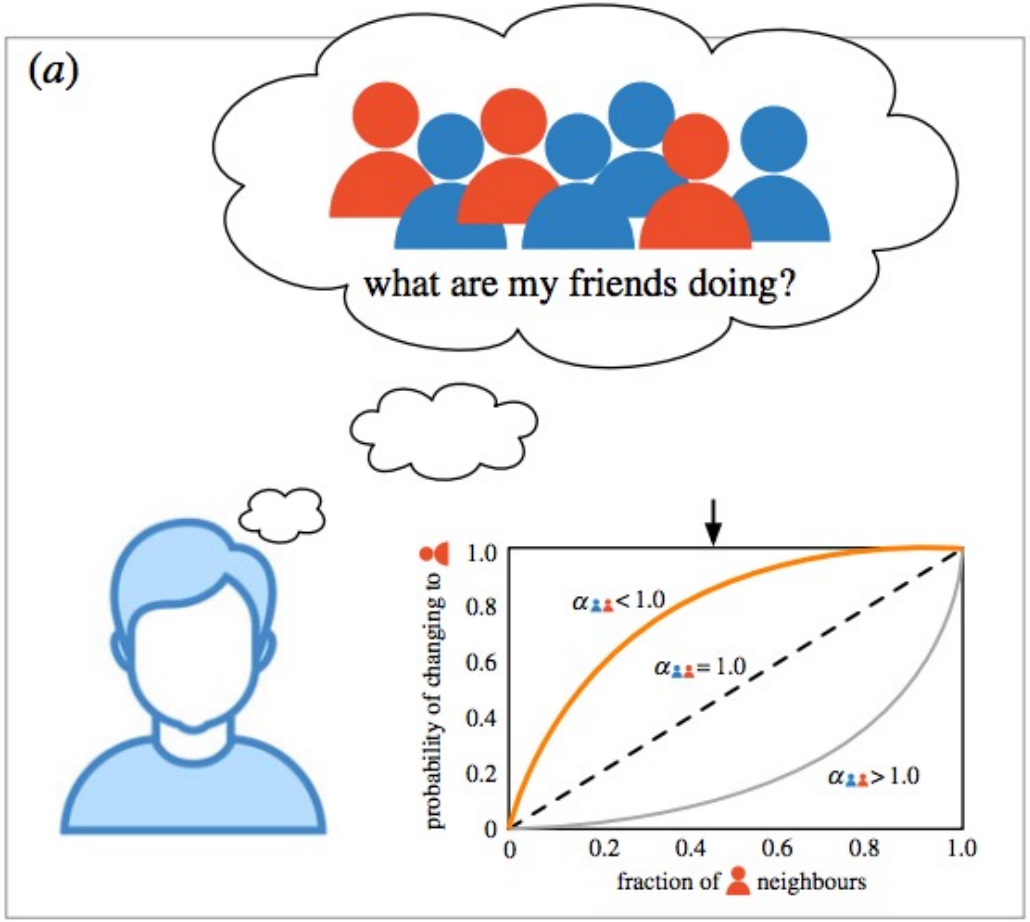
V. V. Vasconcelos, S. A. Levin, F. L. Pinheiro, Consensus and polarization in competing complex contagion processes J. R. Soc. Interface (2019)



Generalized Voter Models and competing rumors



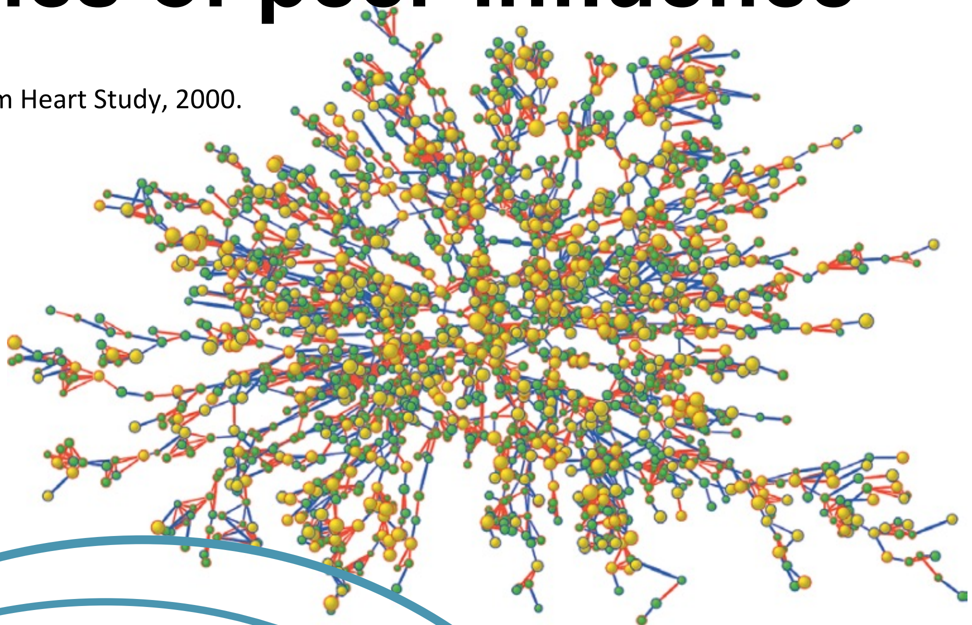


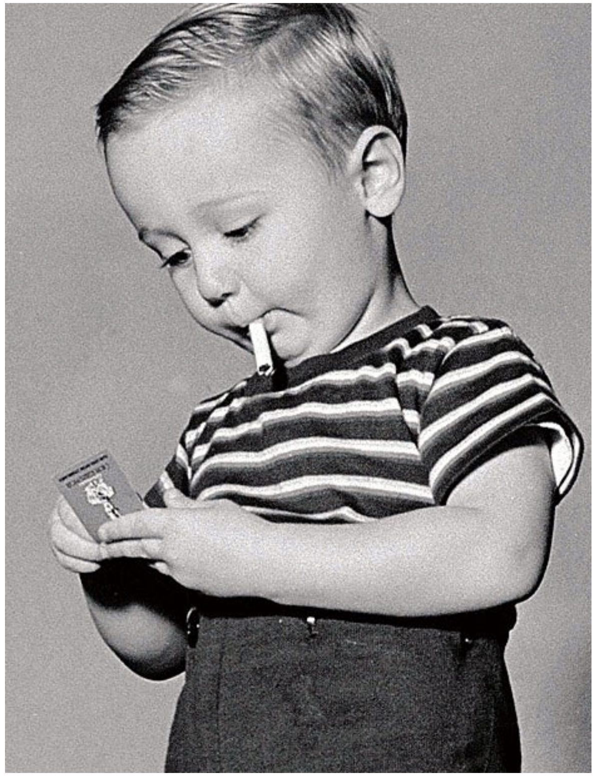


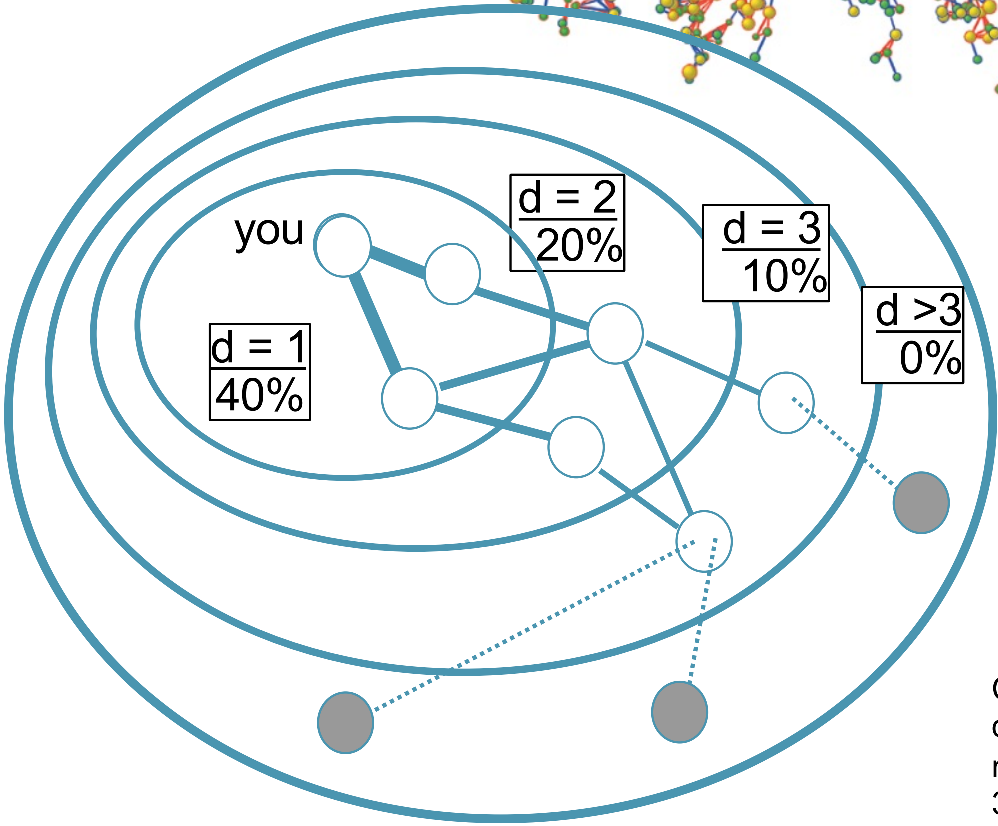
V. V. Vasconcelos, S. A. Levin, F. L. Pinheiro, Consensus and polarization in competing complex contagion processes J. R. Soc. Interface (2019)

Dynamics of peer-influence

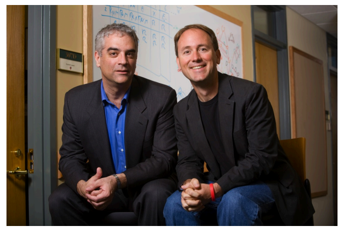
Framingham Heart Study, 2000.



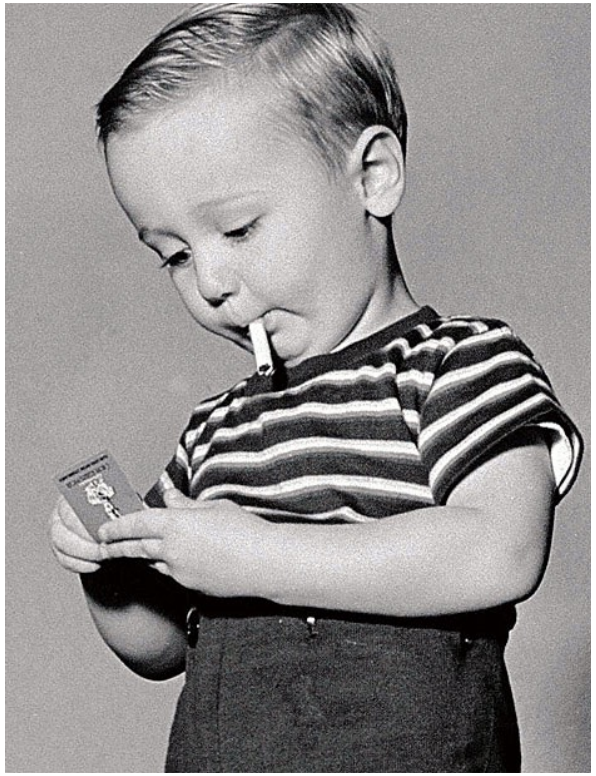


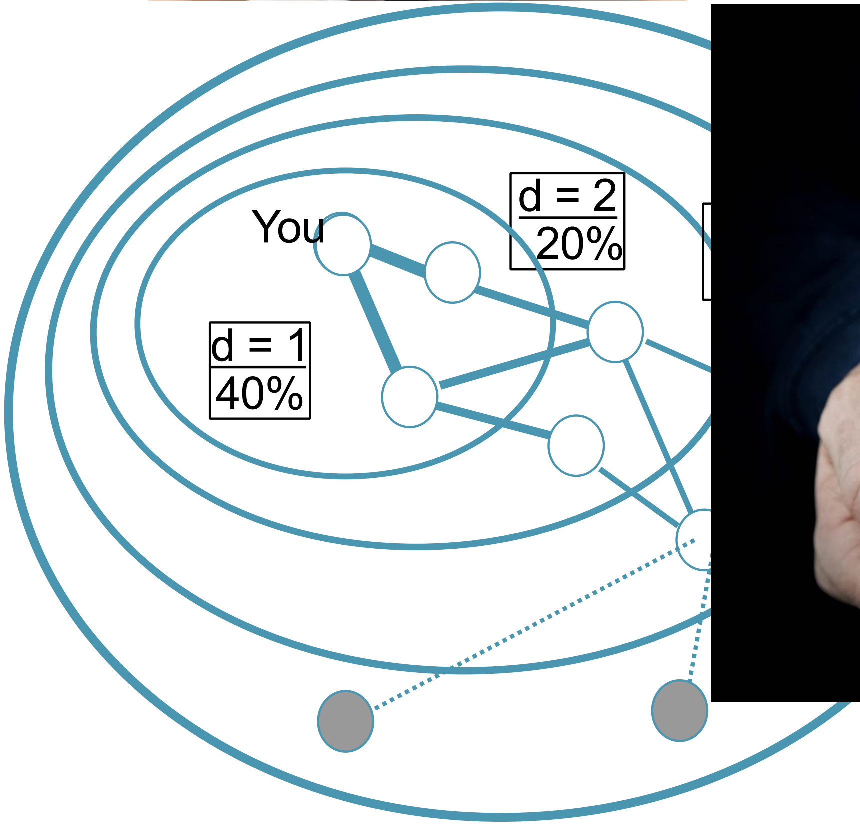


Christakis & Fowler (2008). The collective dynamics of smoking in a large social network. New England Journal of Medicine, 358(21), 2249-2258.



Dynamics of peer-influence





Fowler, J. H., & Christakis, N. A. (2010). Cooperative behavior cascades in human social networks. PNAS, 107(12), 5334-5338.

Happiness is contagious ☺

- On average, the probability of feeling happy increases 15% if I have a happy friend (distance = 1)

- Increases 10% if I have a friend of a friend who is happy (distance = 2)

- Increases 5% if I have a friend of a friend of a friend who's happy (distance = 3)

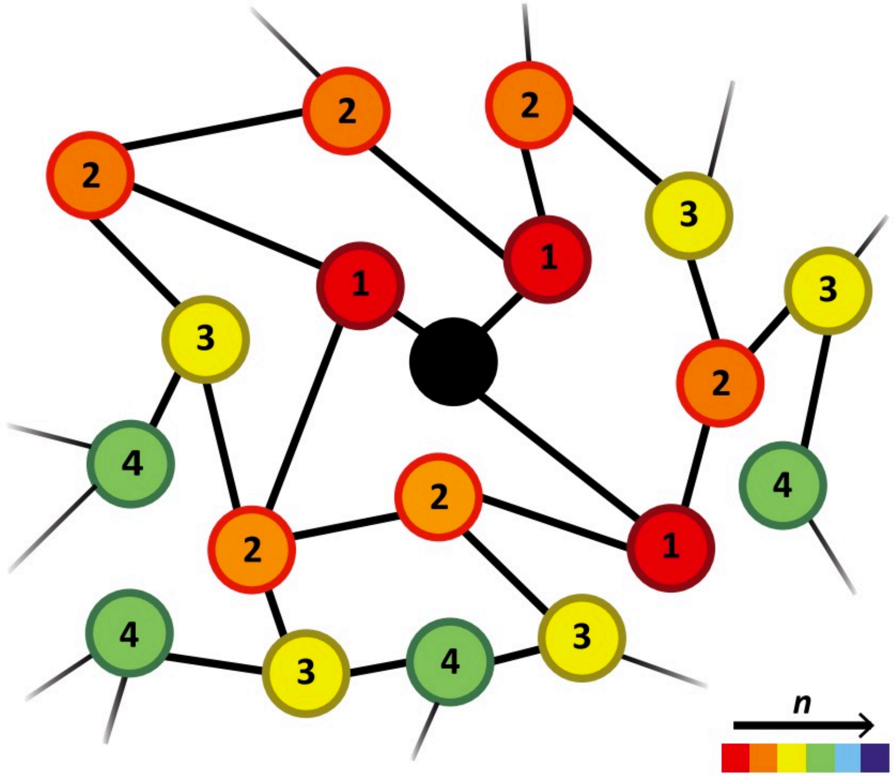
- Each unhappy friend reduces this probability by 7%.

Fowler, J. H., & Christakis, N. A. (2008). Dynamic spread of happiness in a large social network: longitudinal analysis over 20 years in the Framingham Heart Study. *BMJ*, *337*.

Coviello, L., Sohn, Y., Kramer, A. D., Marlow, C., Franceschetti, M., Christakis, N. A., & Fowler, J. H. (2014). Detecting emotional contagion in massive social networks. PloS One, 9(3), e90315.

Kramer, A. D., Guillory, J. E., & Hancock, J. T. (2014). Experimental evidence of massive-scale emotional contagion through social networks. *Proc. Natl Acad Sci USA*, *111*(24), 8788-8790.

Given what you learned, how would you model this type of phenomena?

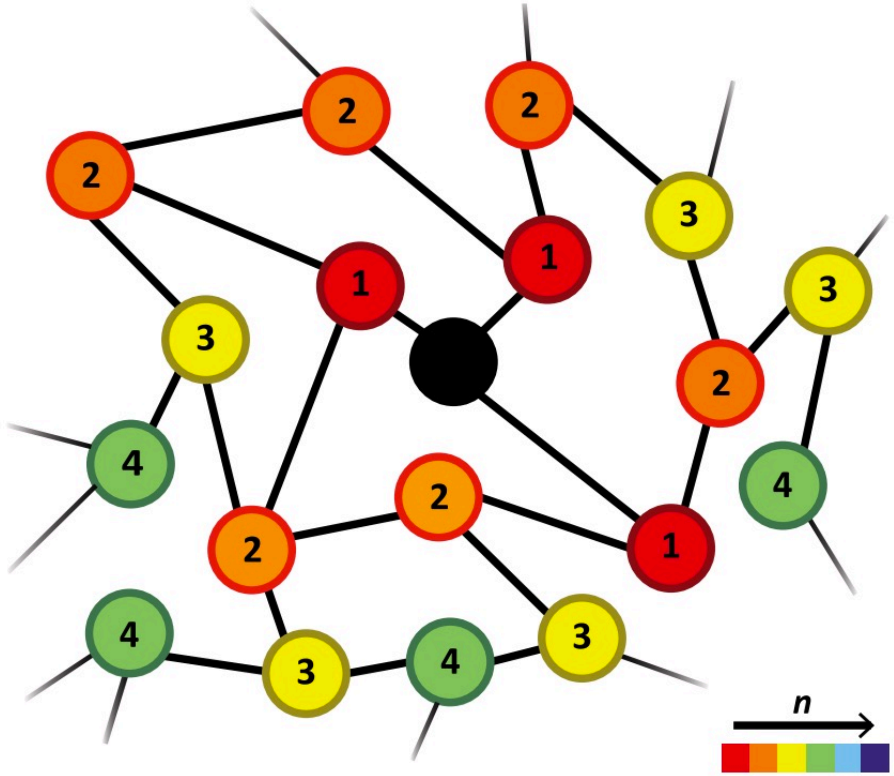


What's the origin of these peer-influence patterns?

Given what you learned,
how would you model this type of phenomena?

Can we describe it as an epidemic?

Can we describe these traits as opinions?



What’s the origin of these peer-influence patterns?

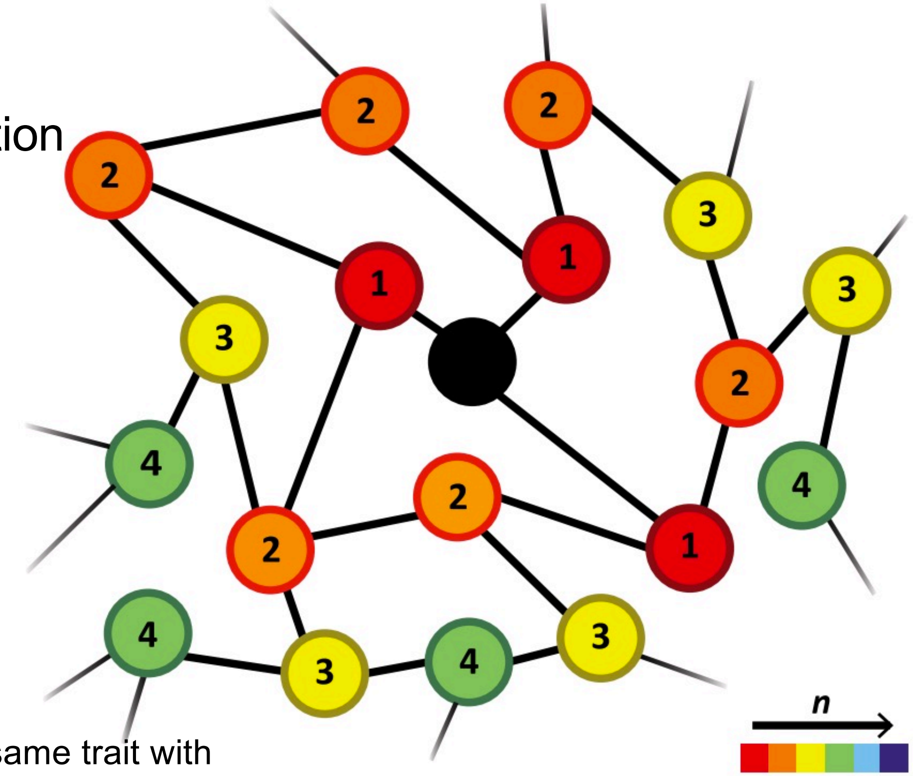
Pinheiro, F. L., Santos, M. D., Santos, F. C., & Pacheco, J. M. (2014).
Origin of peer influence in social networks. *Physical Review Letters*, *112*(9), 098702.

Given what you learned, how would you model this type of phenomena?

For each dynamical process (e.g., 2 states, blue and red) and each number *j* of blues in a population of size *Z*, we may determine the propensity

$$\delta_n(j/Z) = \frac{\varepsilon_n(j/Z)}{\varepsilon_n^{Rand}(j/Z)} - 1$$

that that 2 individuals at a distance n self-organize in the same trait relative to a random distribution of traits.

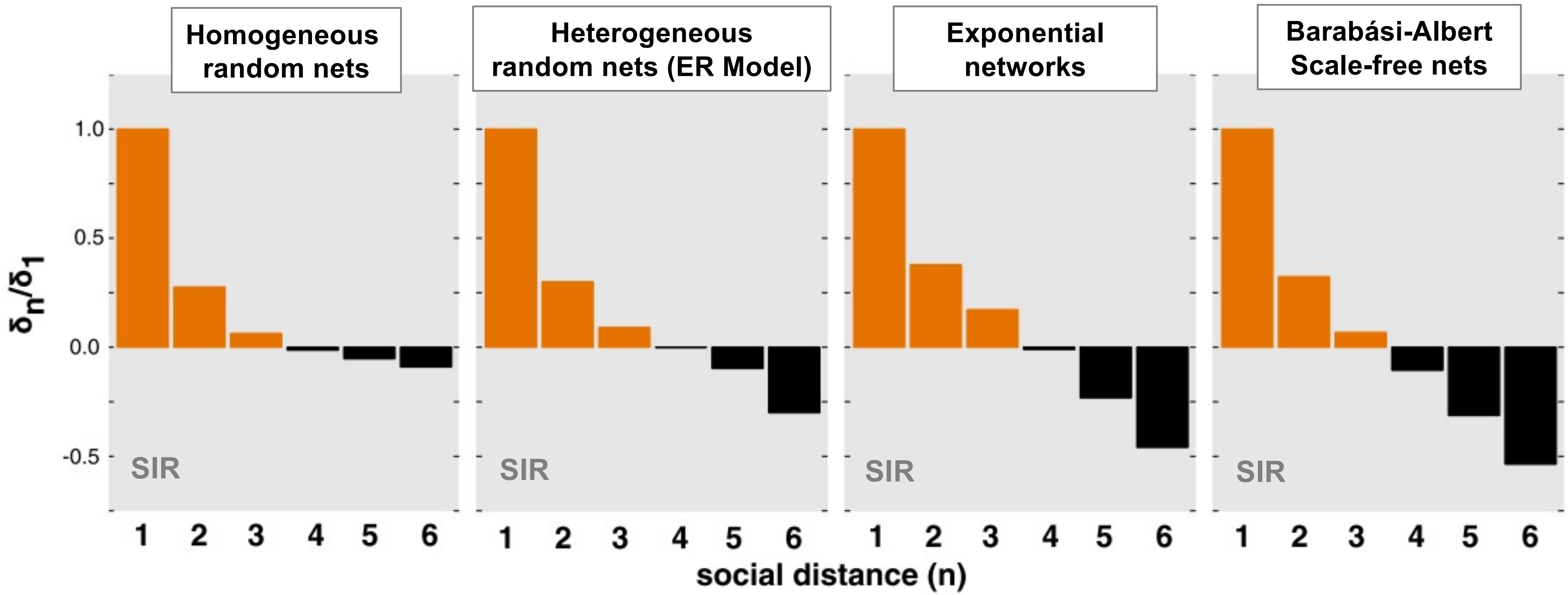


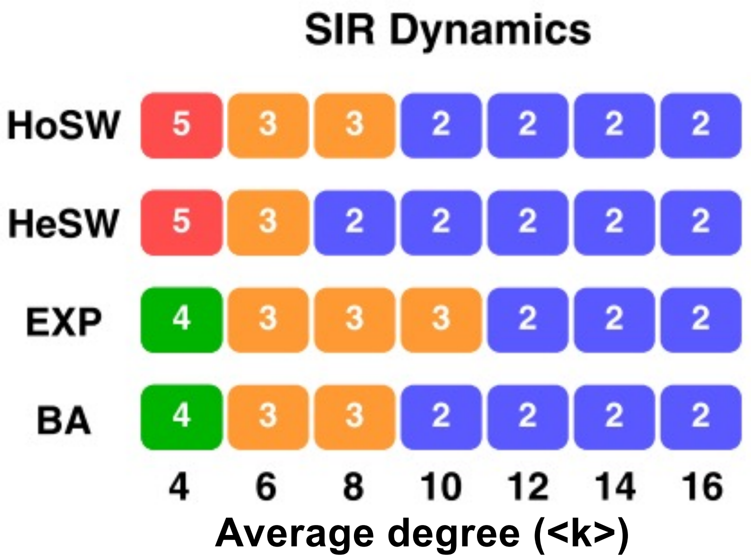
$\varepsilon_n(j/Z)$: the average probability that a node shares the same trait with nodes located at a network distance n

$\varepsilon_n^{Rand}(j/Z)$: the same quantity associated with a random distribution of traits, given j/Z

Pinheiro, F. L., Santos, M. D., Santos, F. C., & Pacheco, J. M. (2014). Origin of peer influence in social networks. *Physical Review Letters*, *112*(9), 098702.

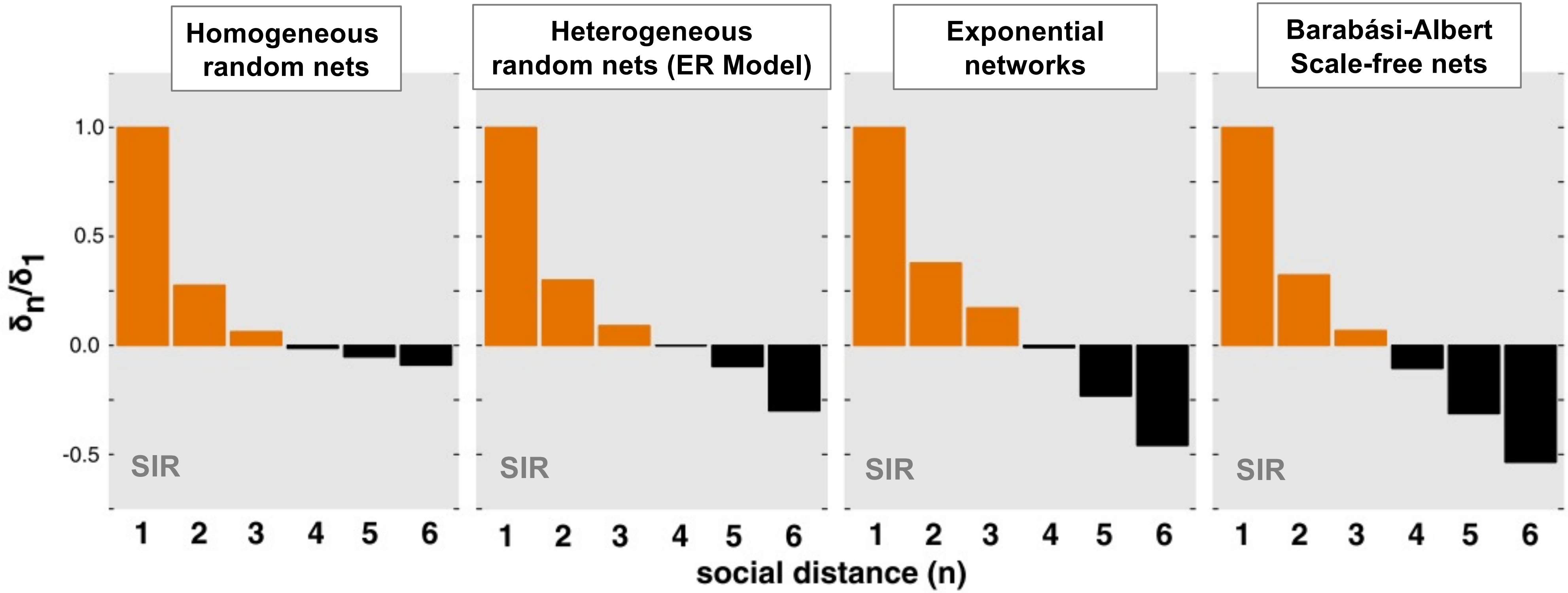
The power of large-scale simulations of multi-agent systems

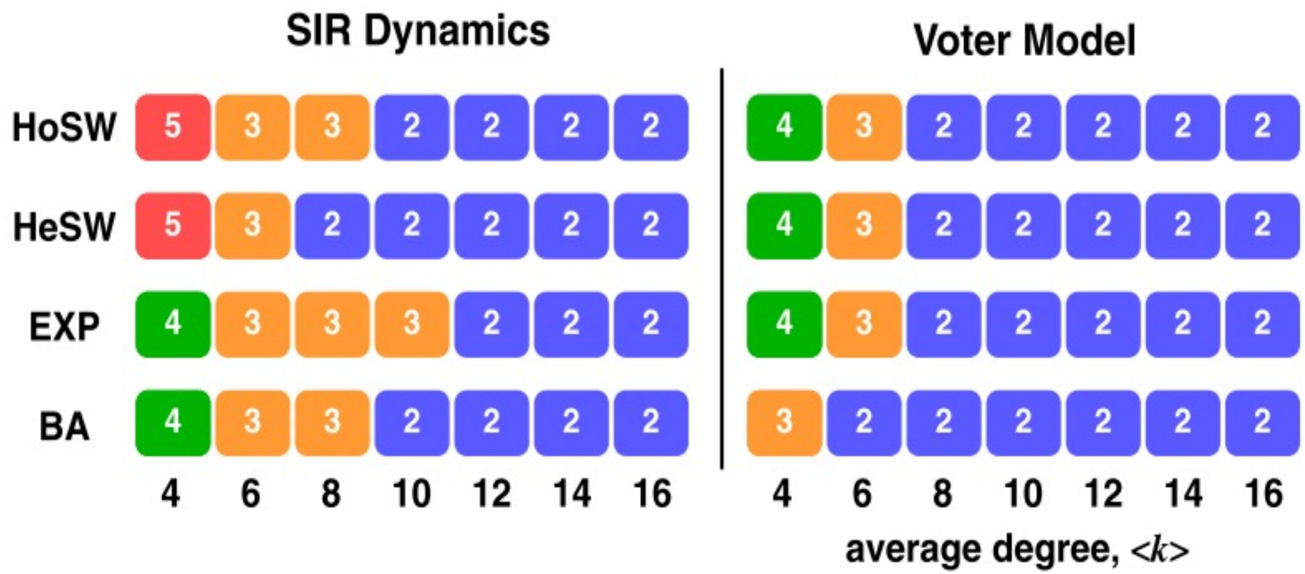




Pinheiro, Santos, Santos, Pacheco,
Phys Rev Lett 112, 098702 (2014)

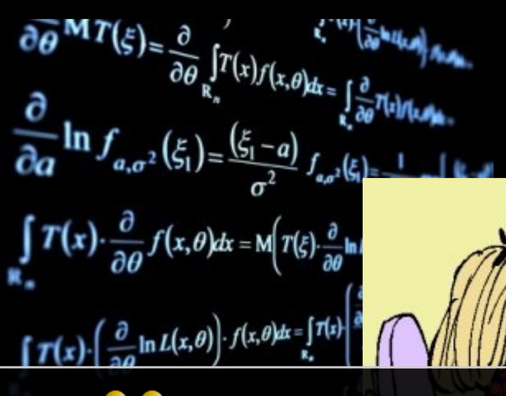
The power of large-scale simulations of multi-agent systems

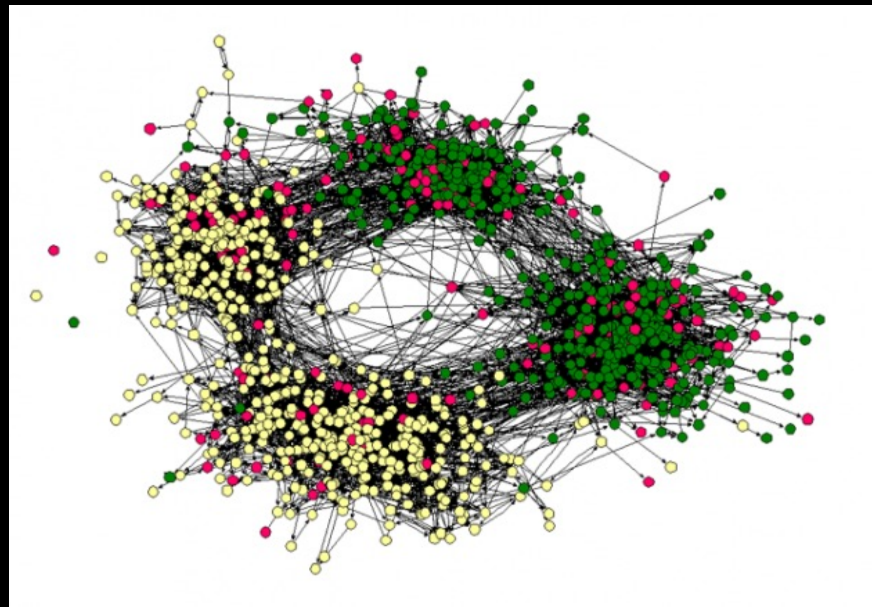


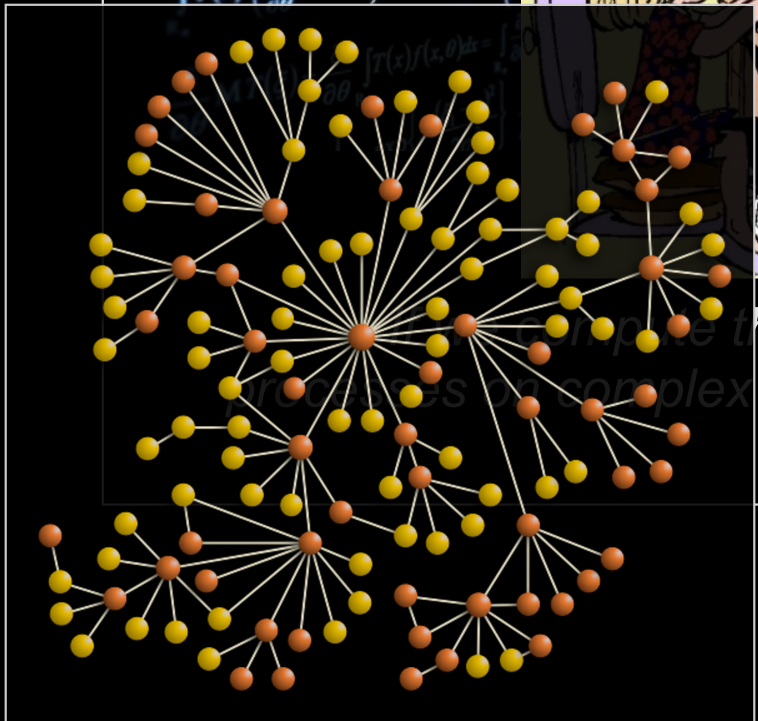


Pinheiro, Santos, Santos, Pacheco, Phys Rev Lett 112, 098702 (2014)

The power of large-scale simulations of multi-agent systems





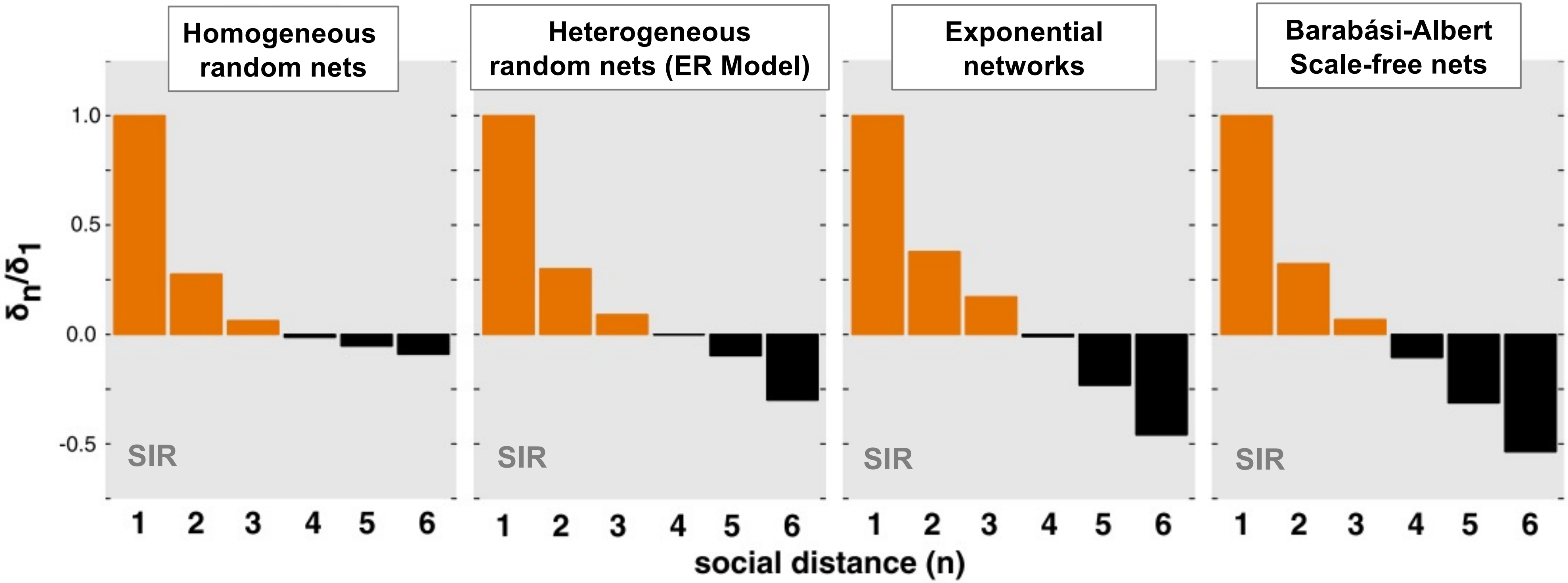


... compute the correlations emerging from different dynamical processes on complex networks, we get critical correlations of 2-3, as in empirical results…

Are we just an outcome of our social network?

NO!!
The impact of our decisions goes well beyond what we had thought!!

Pinheiro, Santos, Santos, Pacheco, Phys Rev Lett 2014.

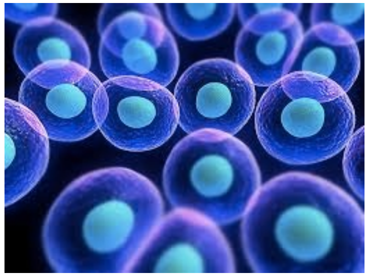


Challenge: Would you obtain the same profile in the case of a complex contagion?

DEI
DEPARTAMENTO
DE ENGENHARIA INFORMÁTICA
TÉCNICO LISBOA

What's next?

Decision-making, cooperation and evolutionary dynamics





from cells, to societies

The complexity of social behavior

•Diffusion of memes, ideas or innovations often follows a similar trend as disease spreading.

• Often opinions are adopted from the assessment of aggregates and not from a single contact.

• Moreover, spread of information, adoption of new trends, habits, opinions, etc., may be intentional acts, unlike disease spreading. Some behaviors, trends and ideas may bring more benefits than others…

Contrary to disease spreading, there's much more around than "contact processes"