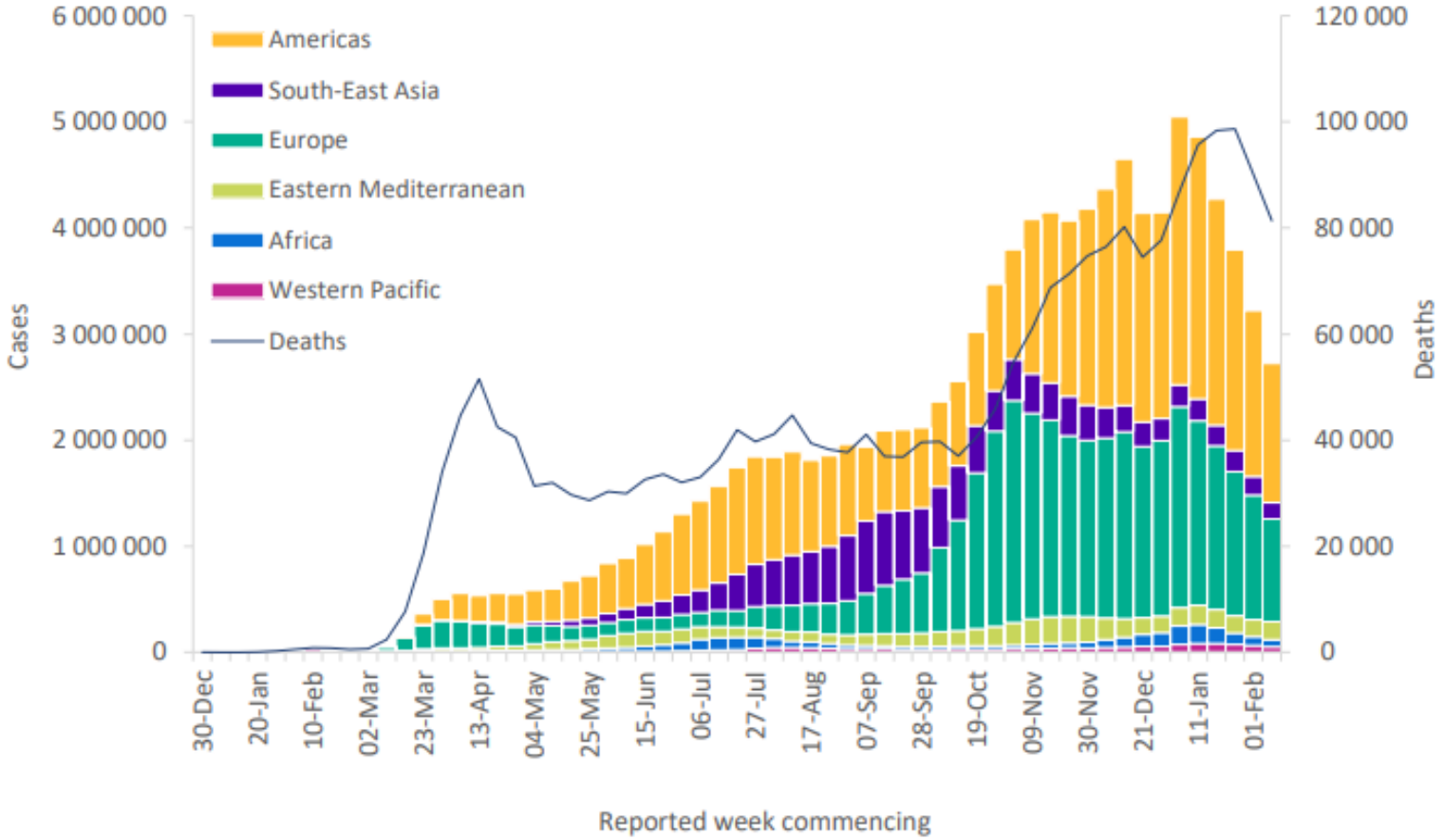
Network Analysis (INFOMNWA-2021)

Lecture 7: Simple and Complex Contagion

Jiamin Ou

The spread of COVID in human network

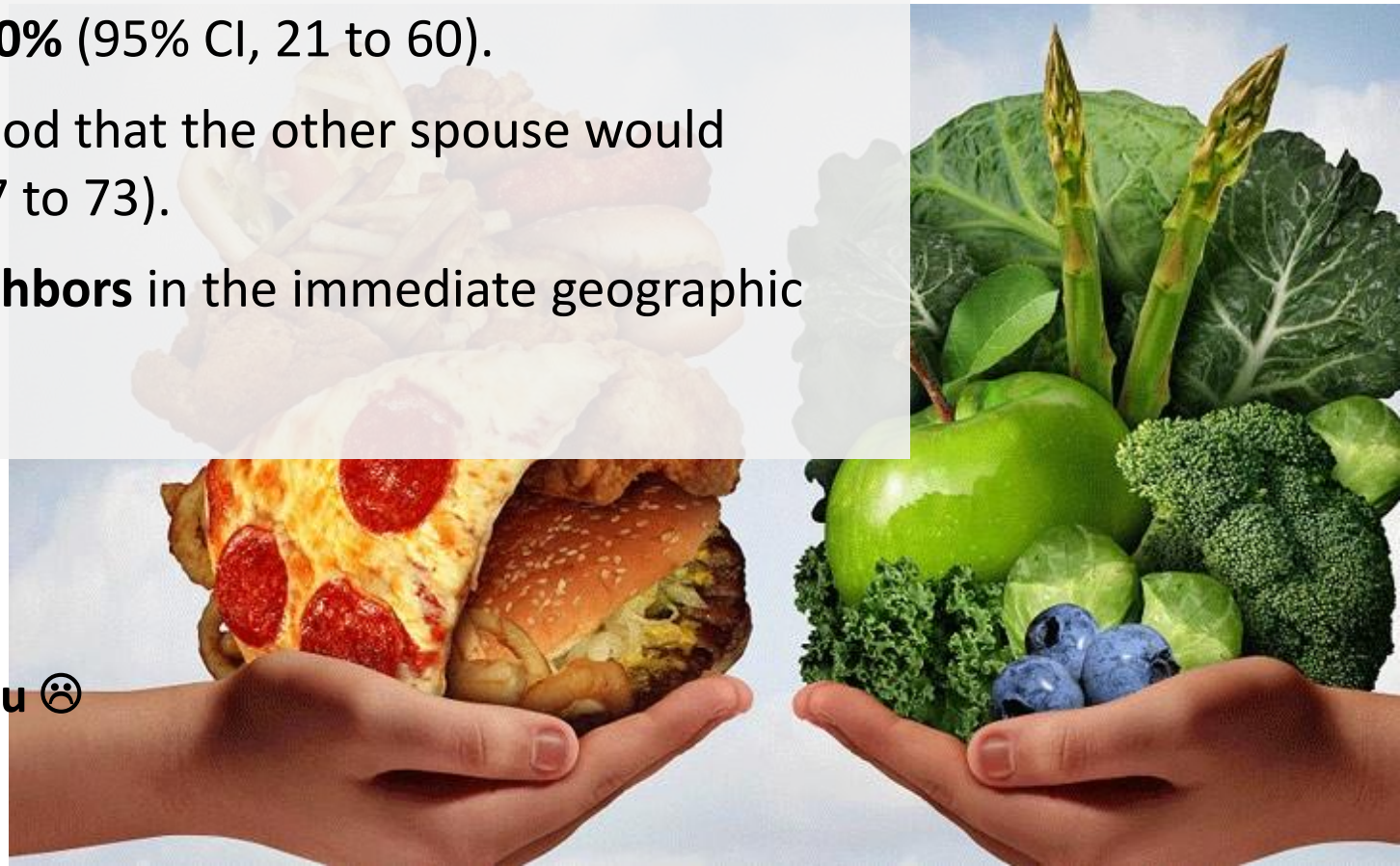
Figure 1: COVID-19 cases reported weekly by WHO Region, and global deaths, as of 14 February 2021**



COVID 19: From patient 0 in Dec 2019 to 122 million cases till now

The spread of obesity in social network of 12,067 people from 1971 to 2003 (“Framingham Heart Study”)

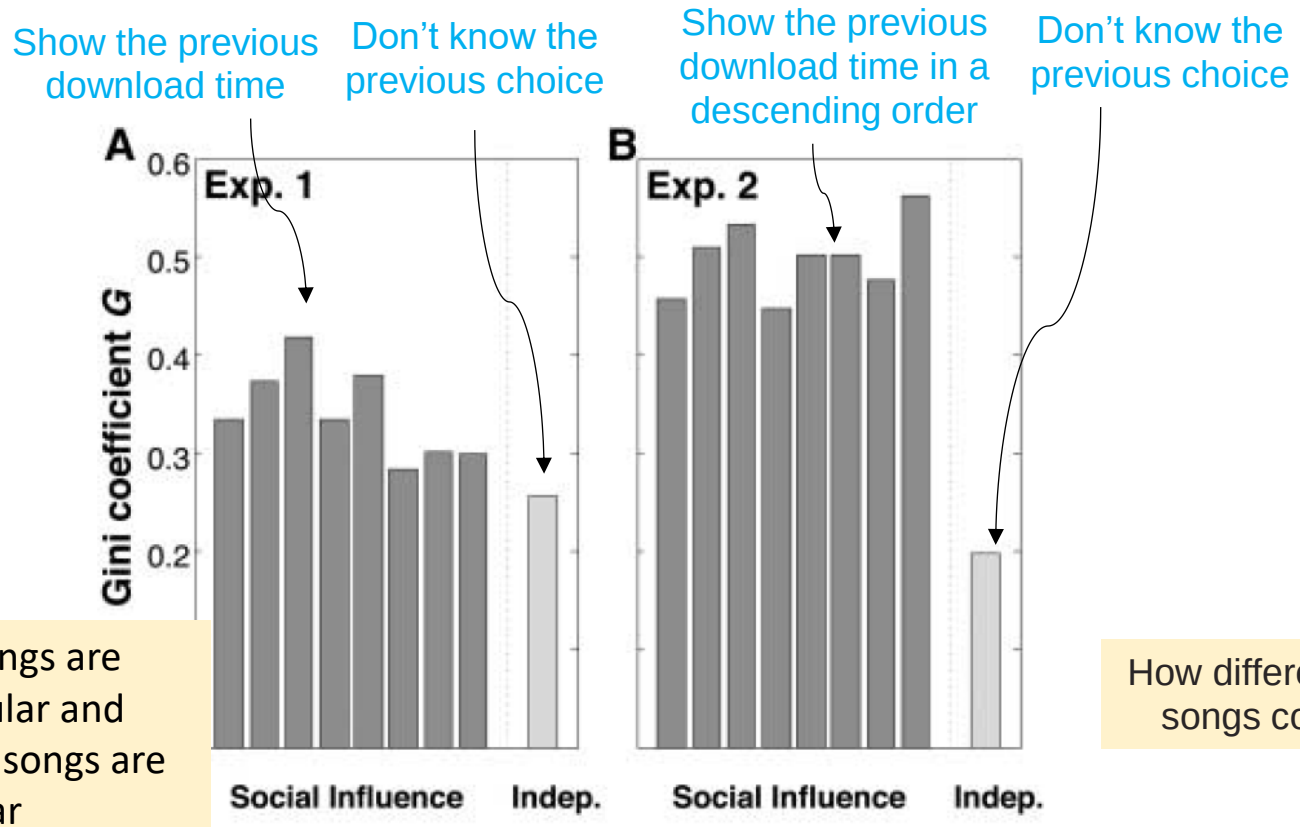
- A person’s chance of becoming obese increased by **57%** (95% confidence interval [CI], 6 to 123) if he or she had a **friend** who became obese.
- Among pairs of adult siblings, if **one sibling** became obese, the chance that the other would become obese increased by **40%** (95% CI, 21 to 60).
- If one **spouse** became obese, the likelihood that the other spouse would become obese increased by **37%** (95% CI, 7 to 73).
- These effects were **not seen among neighbors** in the immediate geographic location.



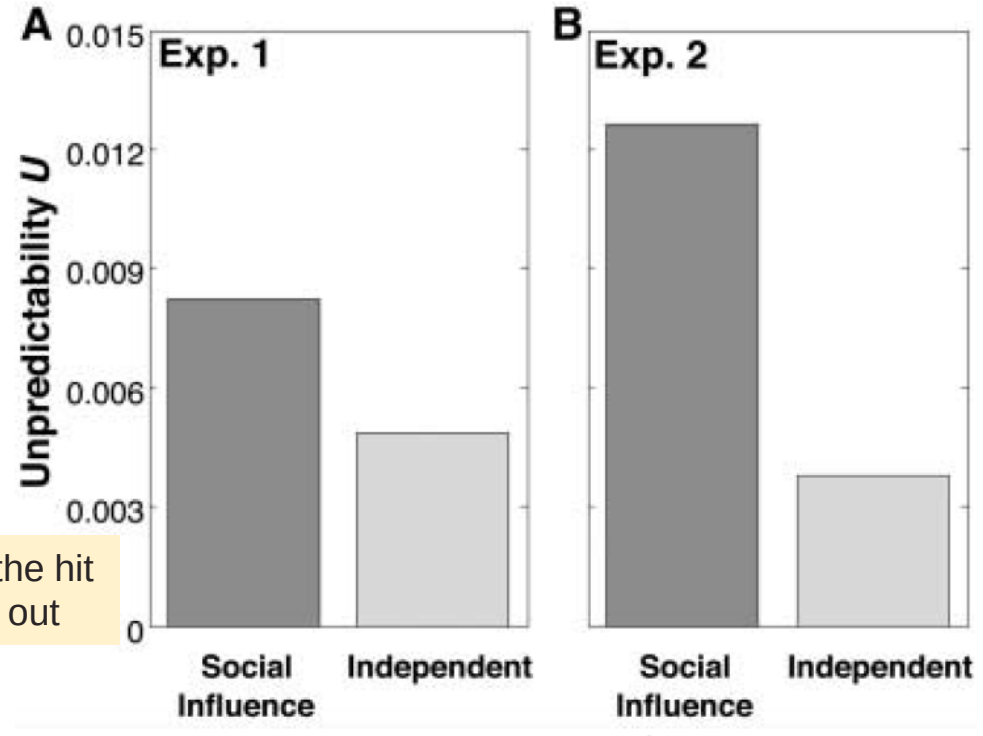
When your closed ones gain weight, so will you ☹

Hit songs are hard to predict because we are not as rational as you may think

- An artificial "music market" in which 14,341 participants.
- Success was also only partly determined by quality: The best songs rarely did poorly, and the worst rarely did well, but any other result was possible.



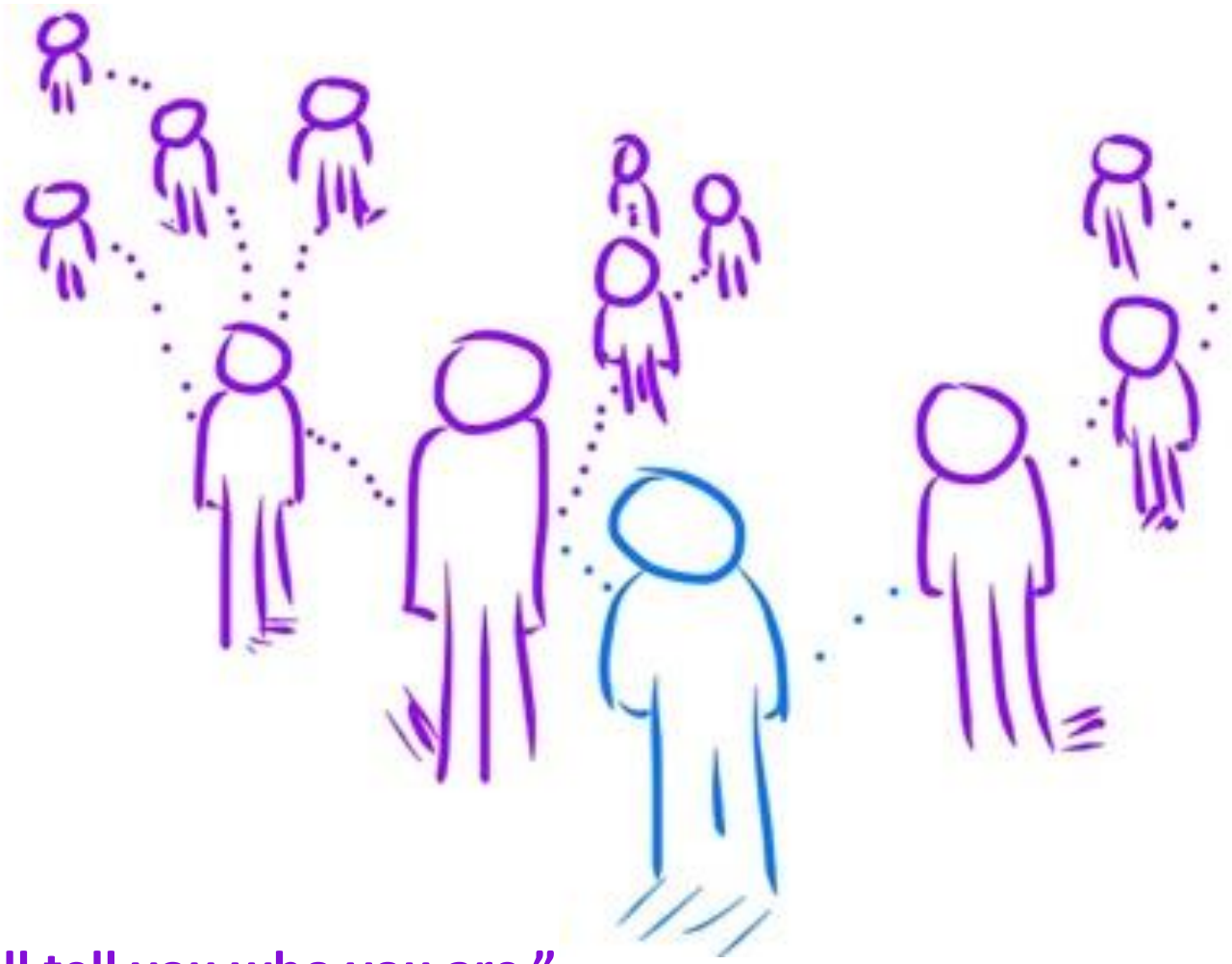
popular songs are more popular and unpopular songs are less popular



How different the hit songs come out

Matthew J. Salganik, Peter Sheridan Dodds, Duncan J. Watts. Experimental Study of Inequality and Unpredictability in an Artificial Cultural Market. Science, 2006: 311, Issue 5762.

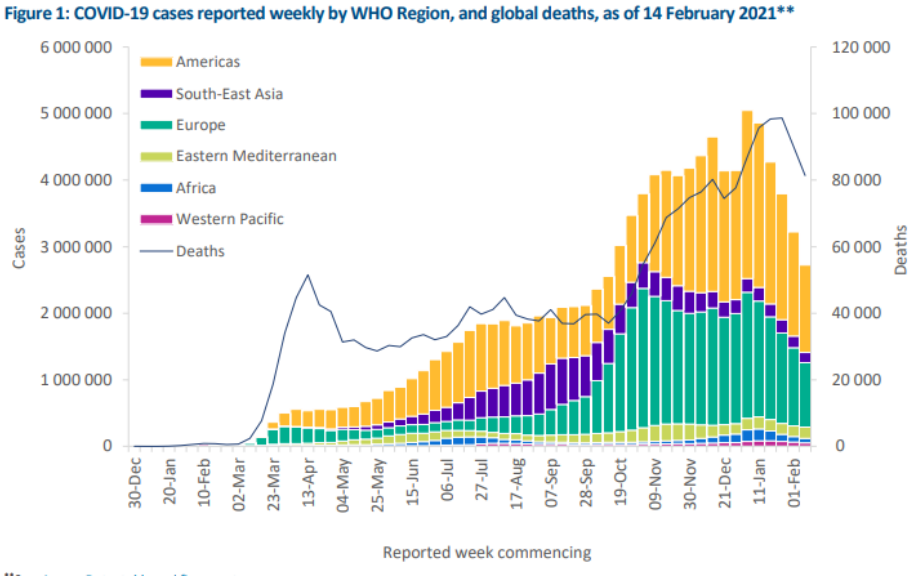
We are highly social creatures that make belief/behaviour/health contagious…



“Tell me who your friends are and I’ll tell you who you are.”

But why some new ideas/news can go viral quickly in the network? While some social innovations that can benefit society often fail to diffuse?

Spread of COVID **VS** **Spread of hygiene, mask-wearing behaviour**



Let’s try to answer:

Do virus, information, social change spread in the same way as in social networks?

What kind of social networks are best suited for diffusion?

(What kind of specific features in network structure control diffusion, and how these features can be used to influence the process of social change?)

Can we predict the success or failure of a diffusion?

Today's program

- Simple contagion

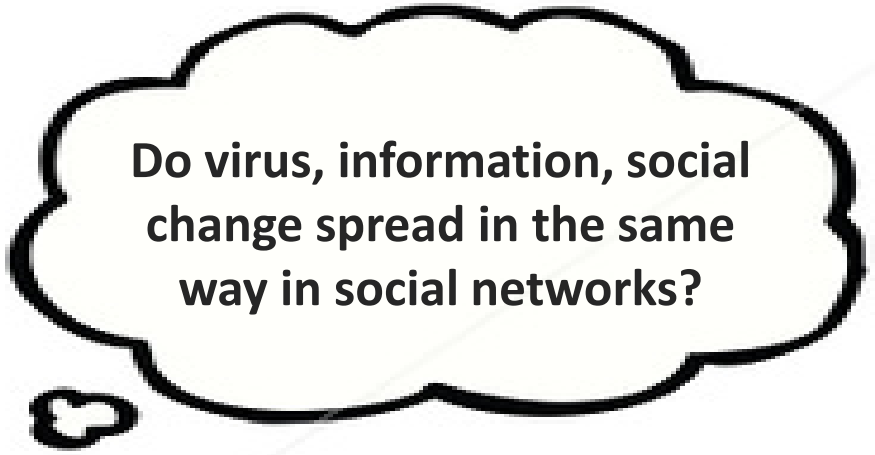
  Mechanism and the strength of 'weak ties'
- Complex contagion

  Mechanism and the strength of 'strong ties'
- Can we predict the success or failure of diffusion?

  Network topology matters!

  Inhomogeneity of people
- Application of social contagion

  Online experiment in Facebook;
  Diffusion of hashtag in Twitter



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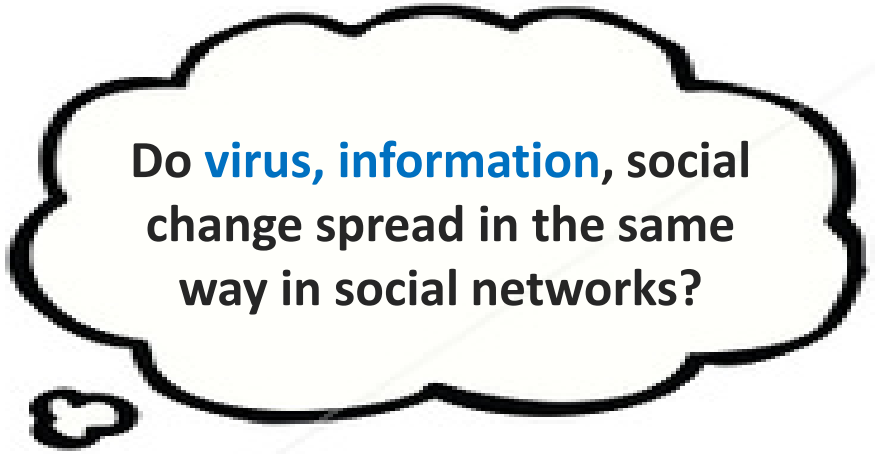


Simple contagion

- Single contact sufficient for transmission

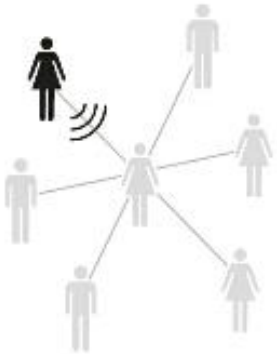
("One infected person can transmit the virus to many other, who can in turn spread it to many other")

- Examples

Epidemic

Easily convincing rumors (one can costlessly repeat a story to many other)

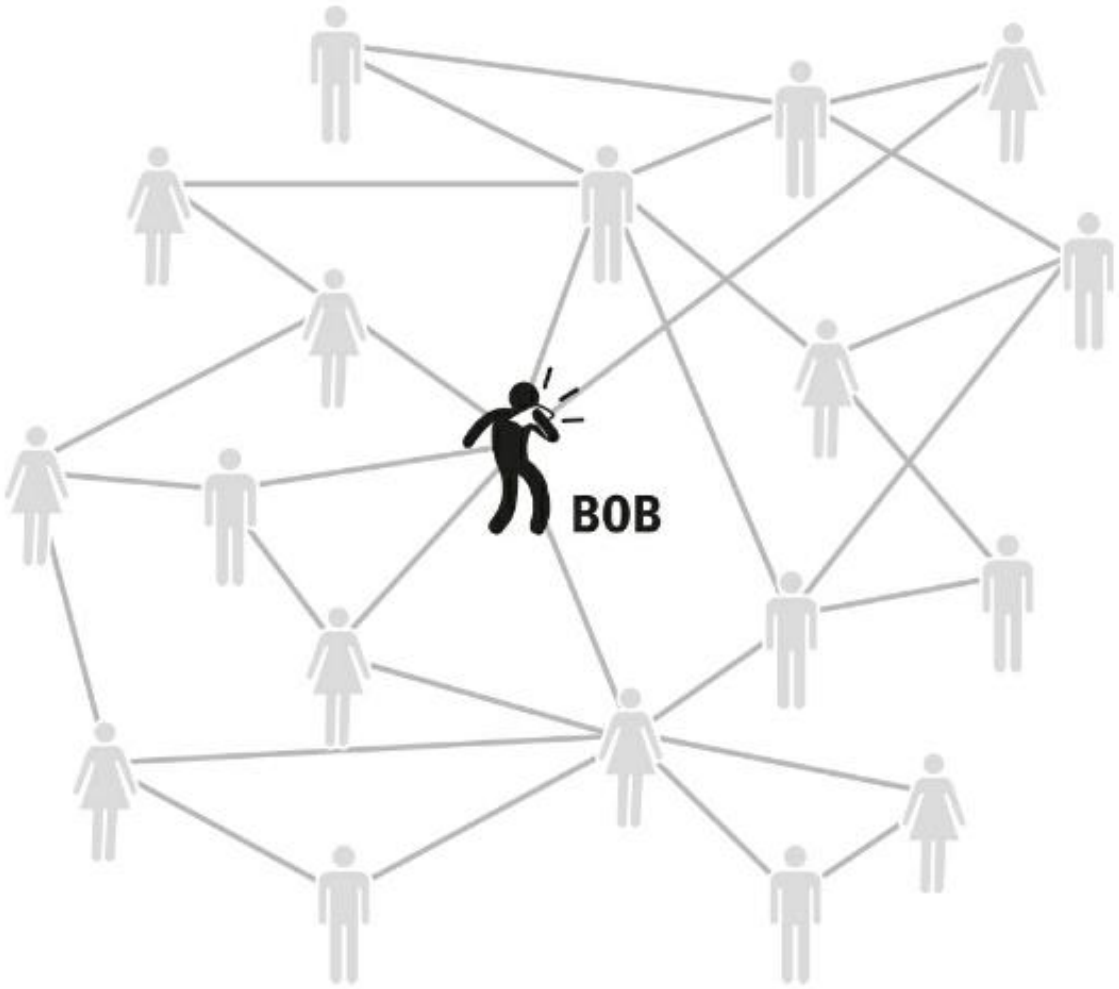
Job information



Diffusion in social network under simple contagion

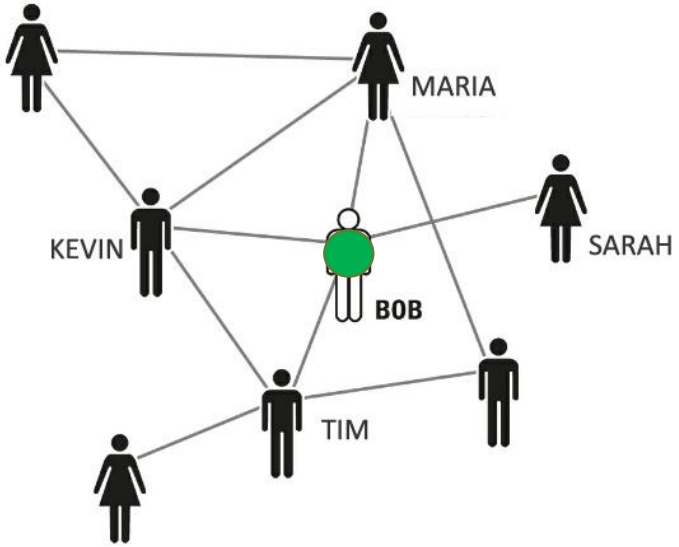
Two states of people: Either a person is **unactivated**, in which case they are “susceptible” to a contagion, or they become **activated** through social contact, in which case they are “infected” and can transmit the contagion to others.

Bob is ‘patient 0’ and can pass the virus/information with probability *ß*

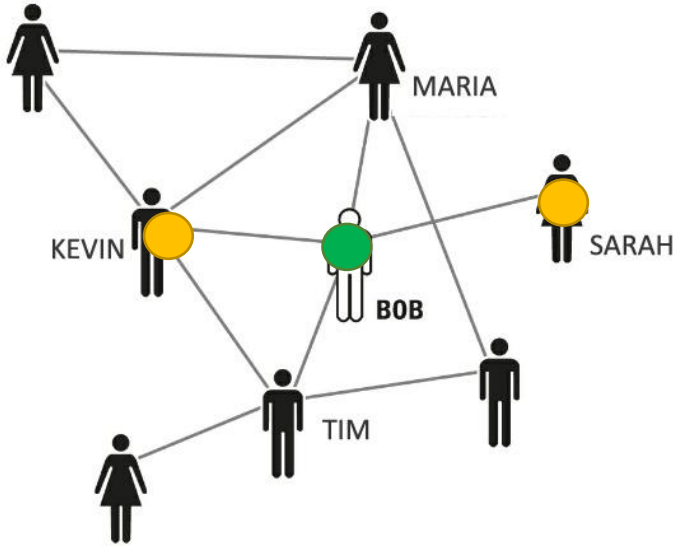


ß=50%

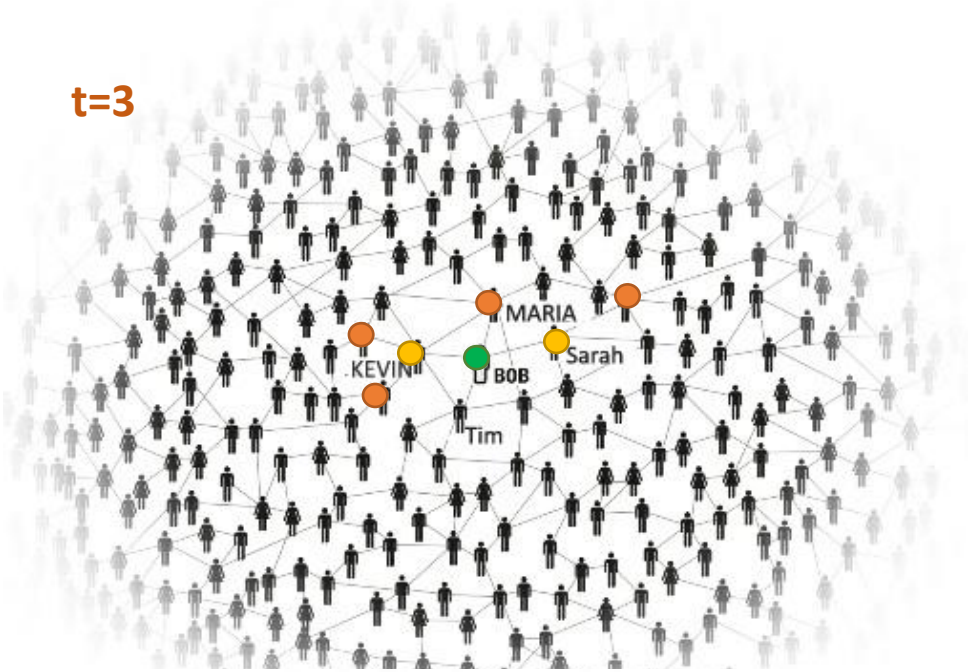
t=1



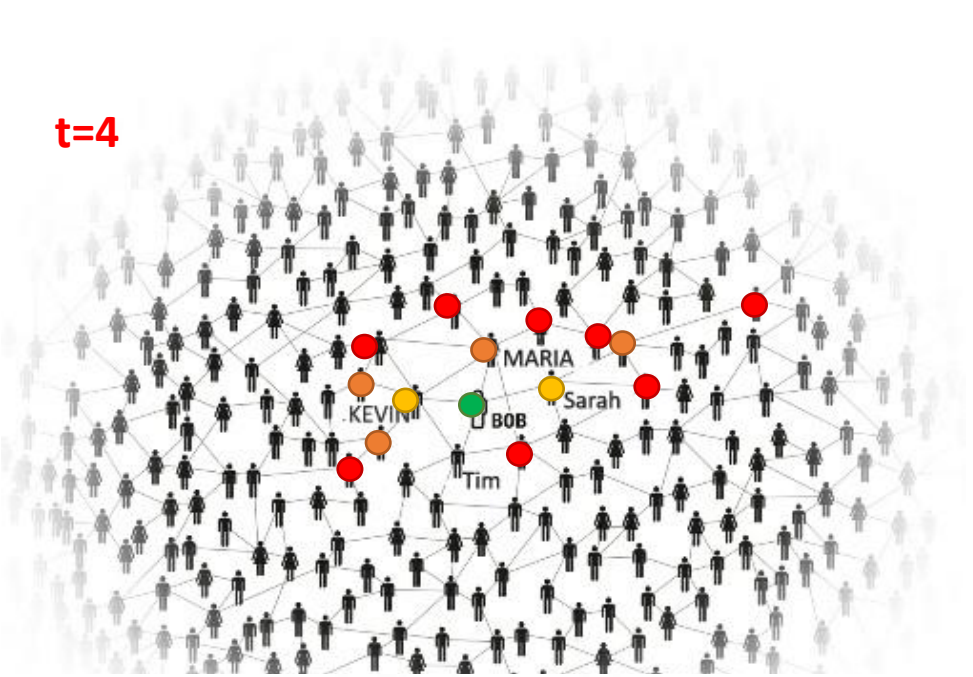
t=2



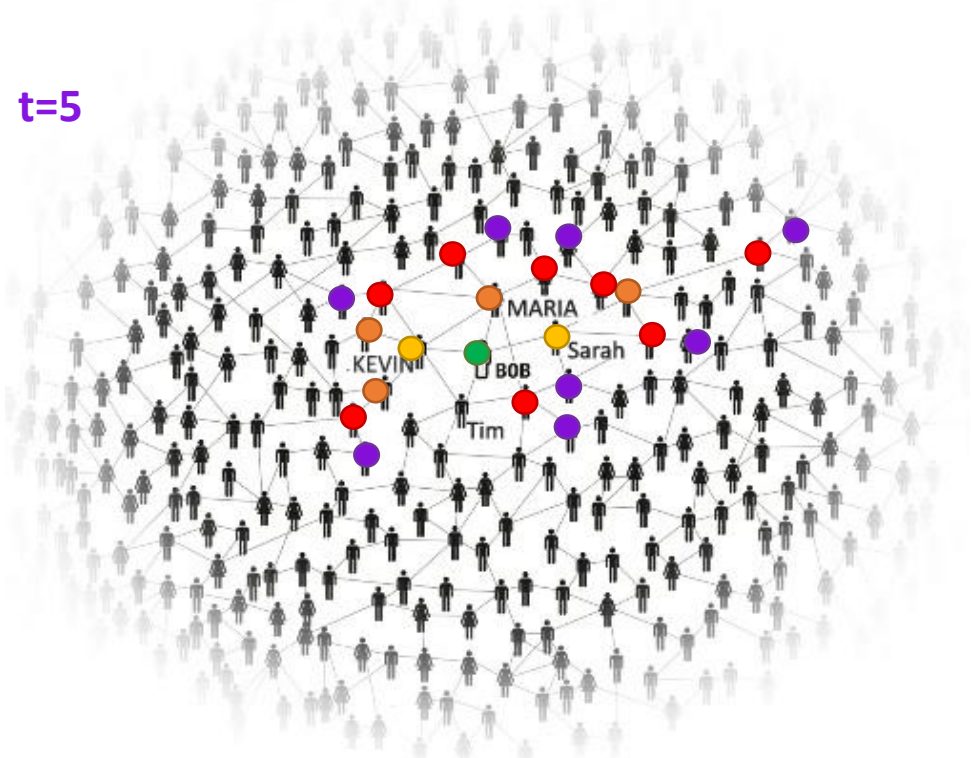
t=3


MARIA
Sarah
KEVIN
BOB
Tim

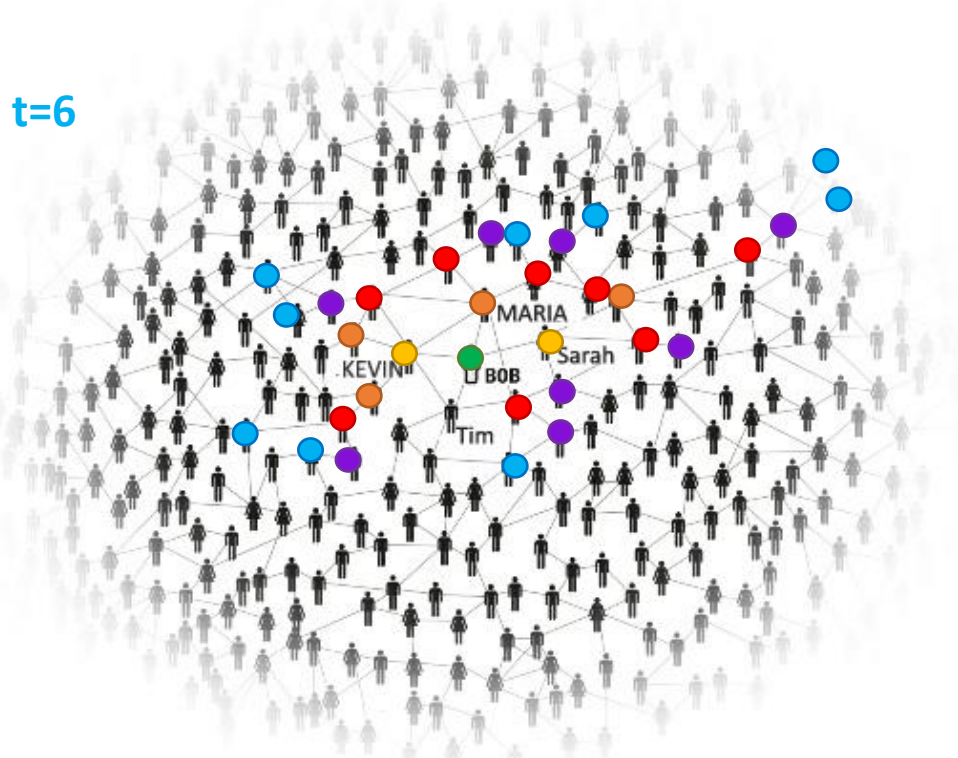
t=4


MARIA
Sarah
KEVIN
BOB
Tim

t=5


MARIA
Sarah
KEVIN
BOB
Tim

t=6


MARIA
Sarah
KEVIN
BOB
Tim

Under simple contagion, what kind of specific features in network structure control the diffusion ?

“The strength of weak ties”, Mark Granovetter, 1973

Most people got their current jobs through acquaintances rather than close friends

Most people got their current jobs through acquaintances rather than close friends

- **Sample:**

A random sample of recent professional, technical and managerial job changers living in a Boston suburb, 1973

- **Procedure & Result:**

How often they saw the contact who communicated job offers to them:

Often (> twice a week), 16.7%

Occasionally (more than once a year but less than twice a week), 55.6%

Rarely (once a year or less), 27.8%


Forbes

Aug 17, 2016, 11:24am EDT

To Get A Job, Use Your Weak Ties

Next Avenue Contributor

Next Avenue Contributor Group

Retirement

The PBS website for grown-ups who want to keep growing

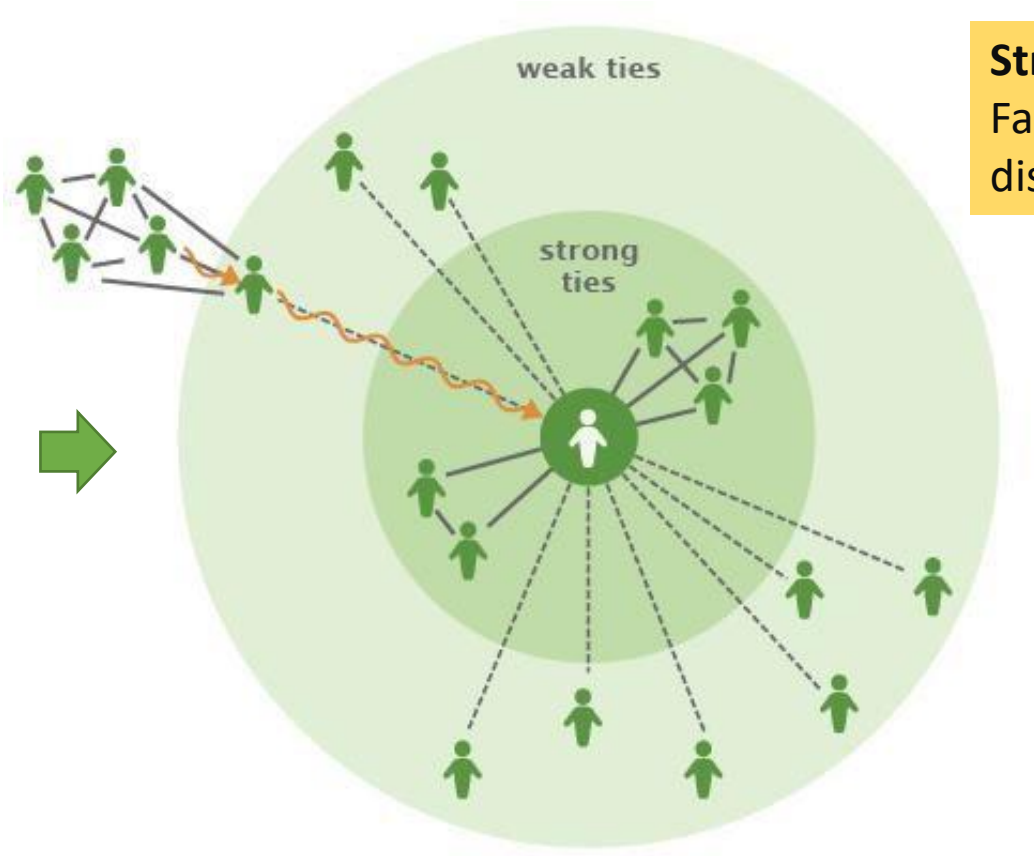
People that you don't meet often provide more efficient access to new information

Mark. S. Granovetter, 1973. "The Strength of Weak Ties", Americal Journal of Sociology, 78 (6), 1360-1380.

Weak and strong ties

Frequency of Contact

Emotional intensity and support



Strong ties
Family, partner, close friends (Core discussion network)

Weak ties
Distant friends, neighbors, colleagues

Interact less frequently, less invested in relationship

How about your friends on LinkedIn, Facebook and Twitter?

Is LinkedIn making you more successful?

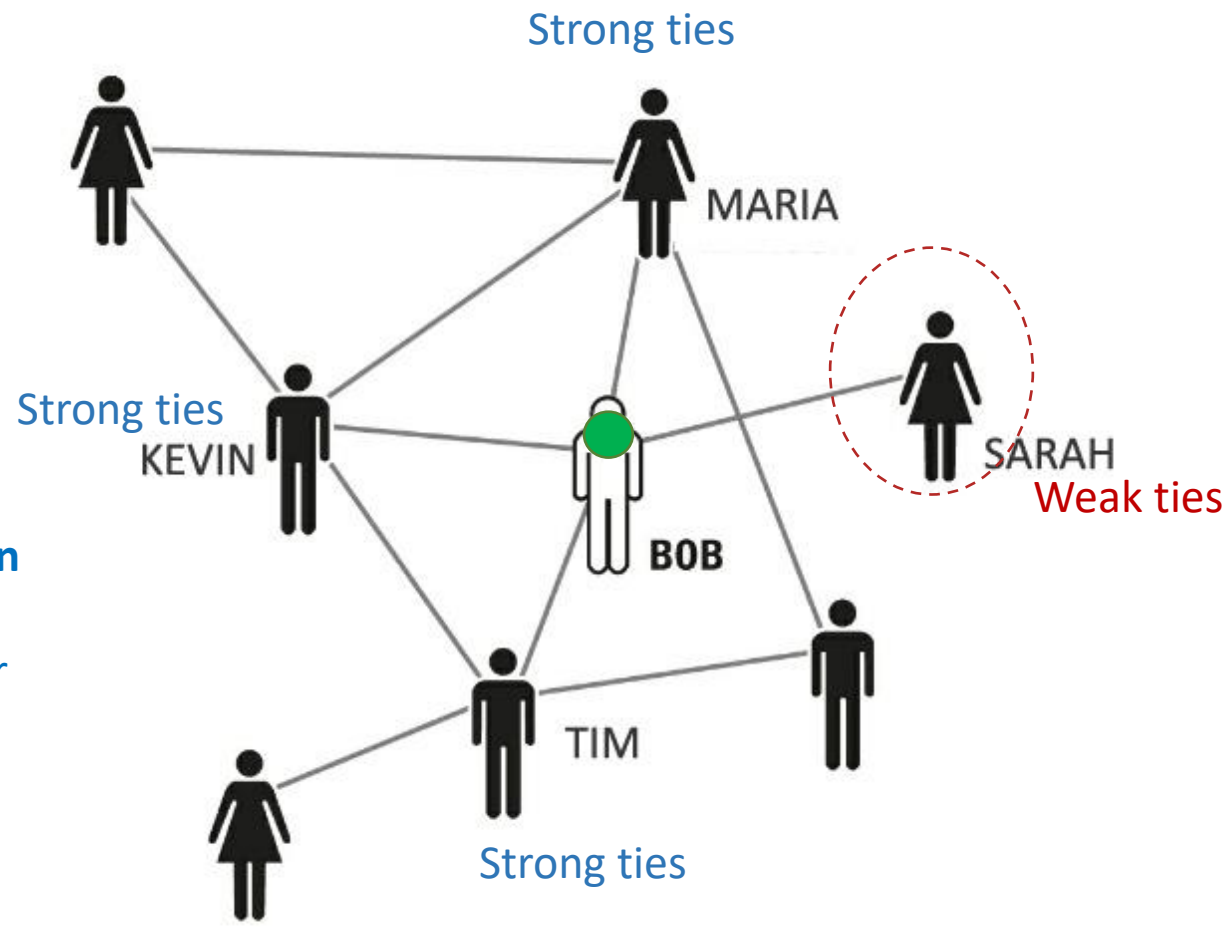
- Mission of LinkedIn “connect the world’s professionals to make them more productive and successful.”
- Major social ties in LinkedIn: acquaintances or former colleagues
- Informational benefits from the usage of LinkedIn, Twitter, Facebook among a representative sample of Dutch online users
- Using LinkedIn significantly increased informational benefits. Using Twitter also resulted in a significant increase in informational benefits.
- Using Facebook resulted in significantly lower informational benefits.

Sonja Utz, 2016. Is LinkedIn making you more successful? The informational benefits derived from public social media. New media & society, Vol. 18(11) 2685 –2702

But why weak ties can accelerate information diffusion?

Among all the people connected to Bob, who is the weak tie?

A person's strong ties tend to be located within "closed triangles" in the network
(your closed friends will know your family and some of your friends as well)



Now Bob needs to hire a new programmer and wants to use his “word of mouth” network to spread the news of job opening (e.g., ß=1 as the previous example)

1st round: Bob

2nd round: Bob→Kevin, Maria, Tim, Sarah

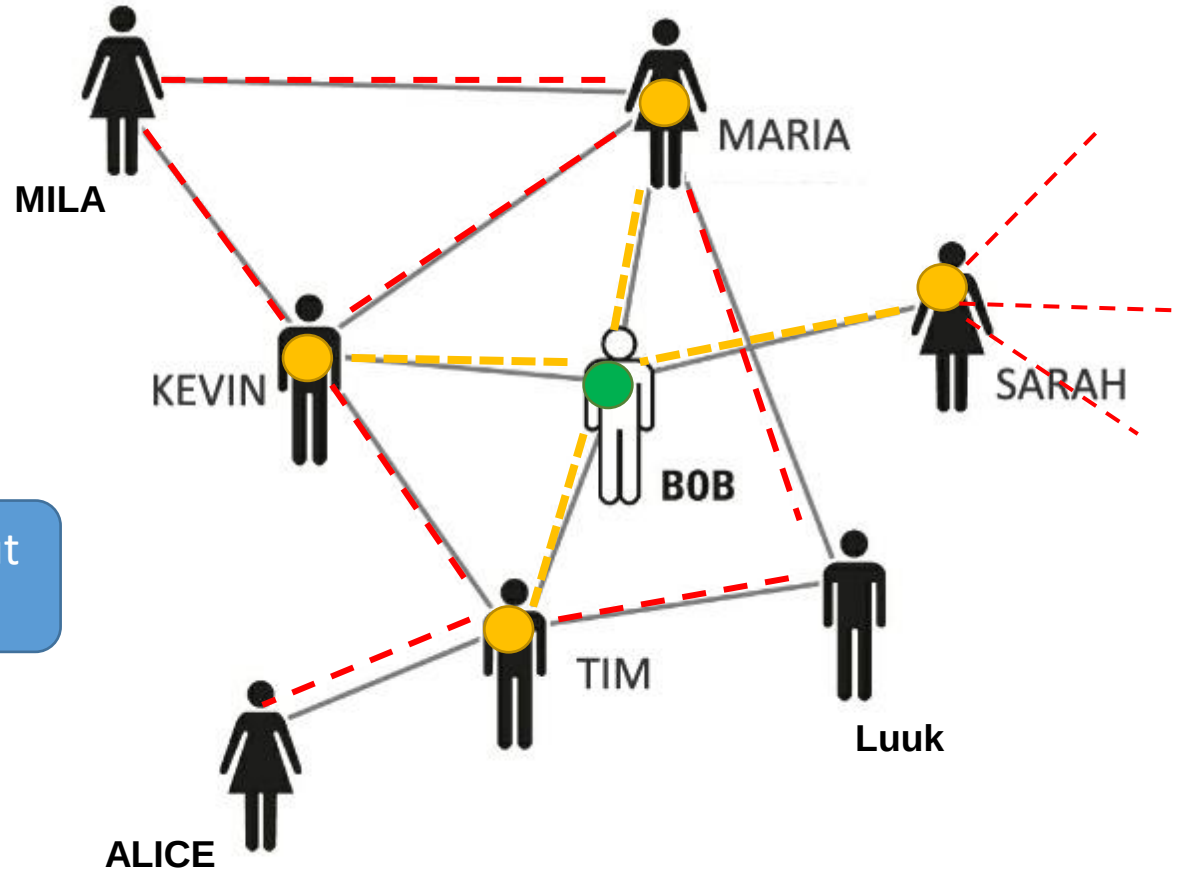
3rd round:

Kevin→ Mila, Maria

Maria→ Kevin, Mila, Luuk

Tim→ Kevin, Luuk, Alice

Sarah → to her other contacts



I’ve heard about it already!

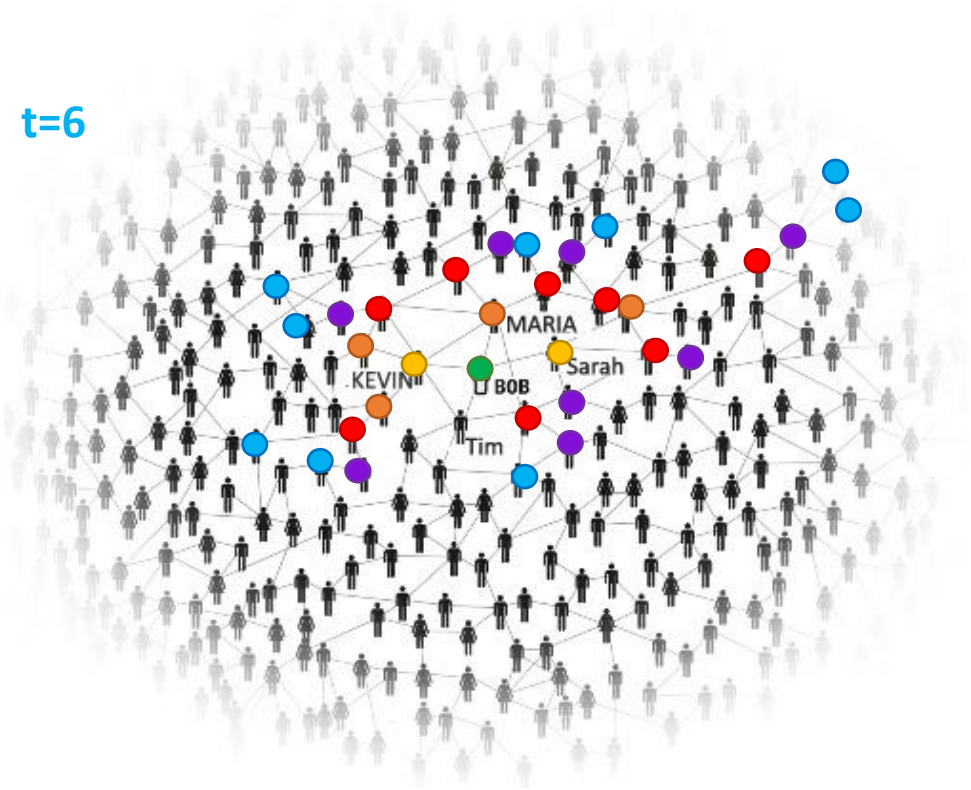
A lot of redundant information within the close community of Bob, which is not efficient.

Weak ties act as bridges of real-world communities

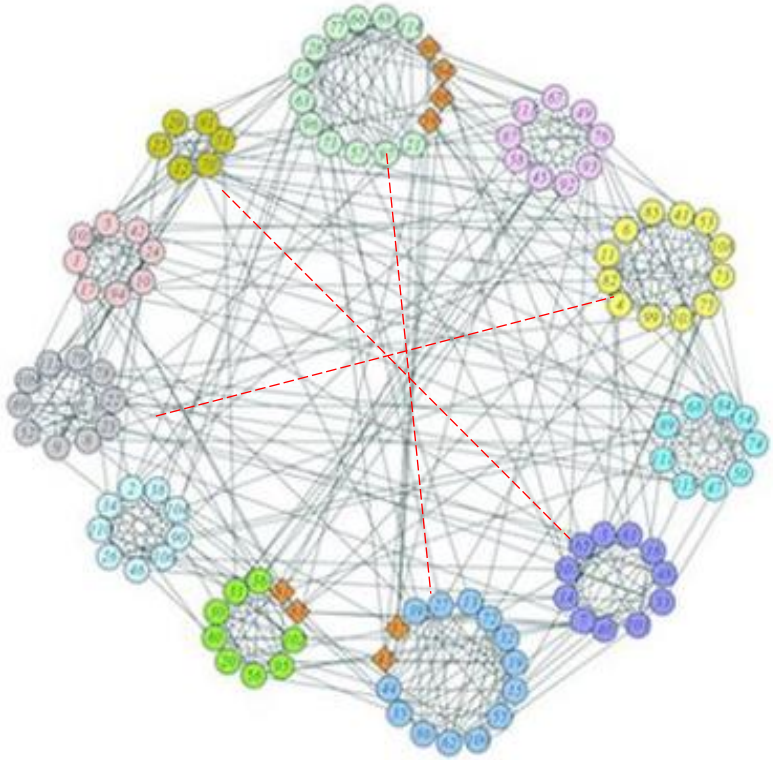
Social functions of weak (long) ties:

To reach communities that are further away in terms of ***geographic and social distances, information and beliefs***;

Binding a large and diverse network together



Bob's community: similar in geographic location, social status, information and beliefs



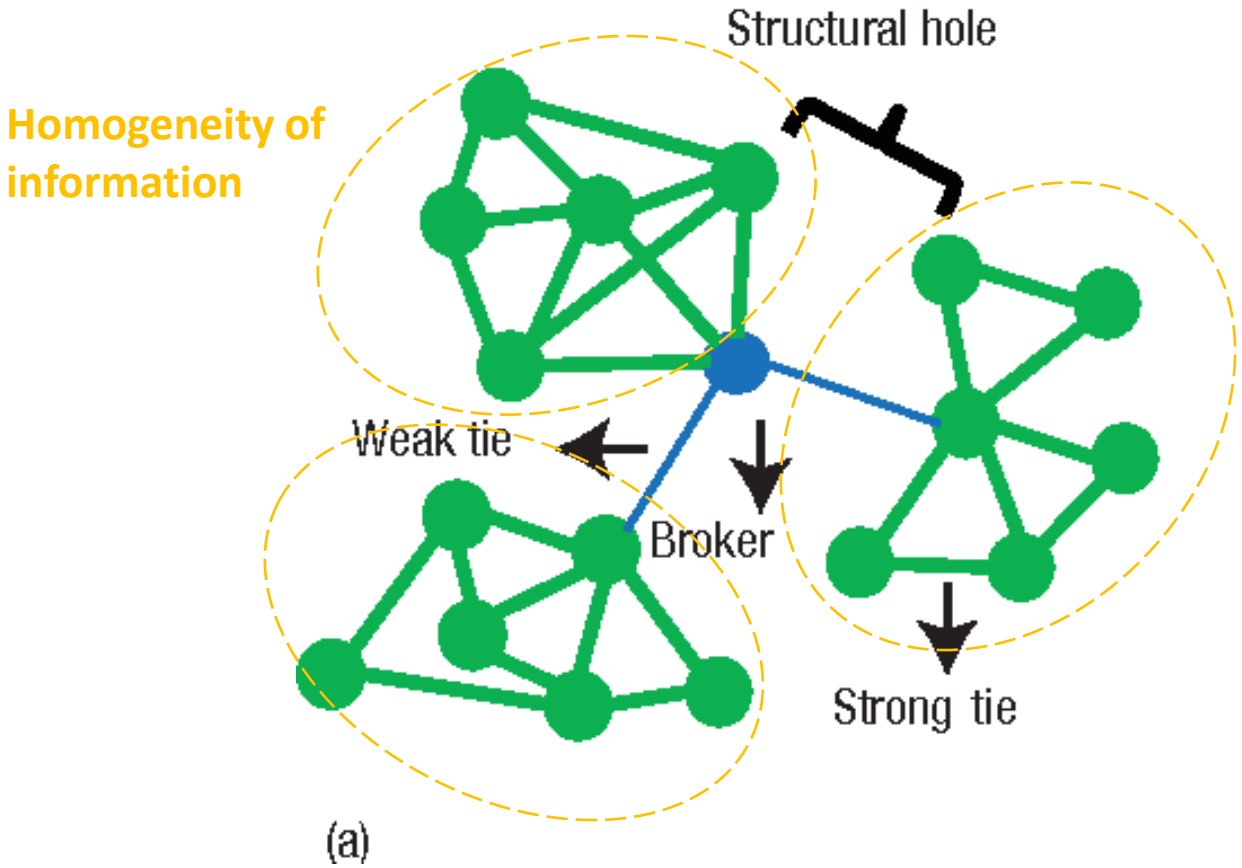
Sarah's community: :similar in geographic location, social status, information and beliefs

Where weak tie is missing: Structure holes

Where weak tie is missing: **Structure holes**

The more structure holes, the more diffusion is controlled by the few 'brokers' (highest betweenness) in the network

The values of brokers are higher (e.g., higher wage); but not a good thing for diffusion efficiency of the whole network



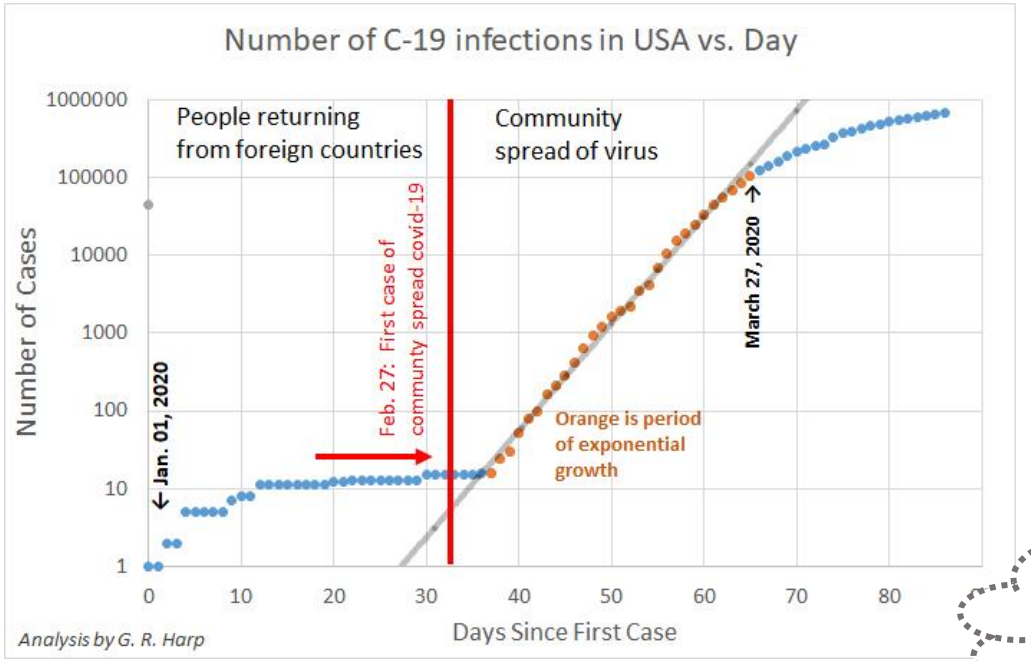
Weak ties now are abundant in offline and online networks

The abundance of weak ties in offline and online social networks

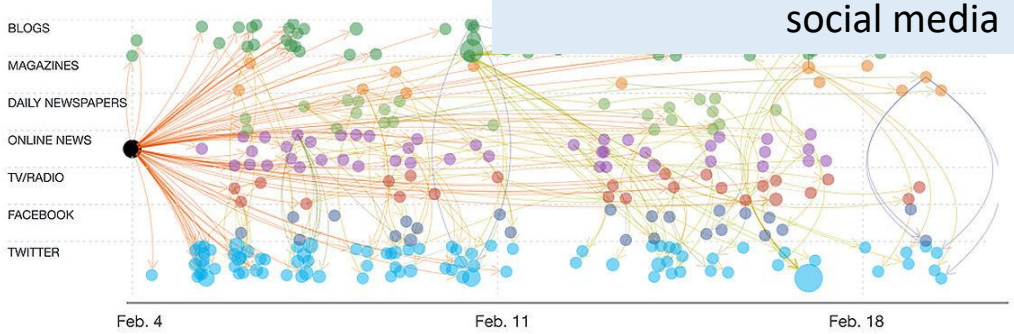
Spread of rumour/false news

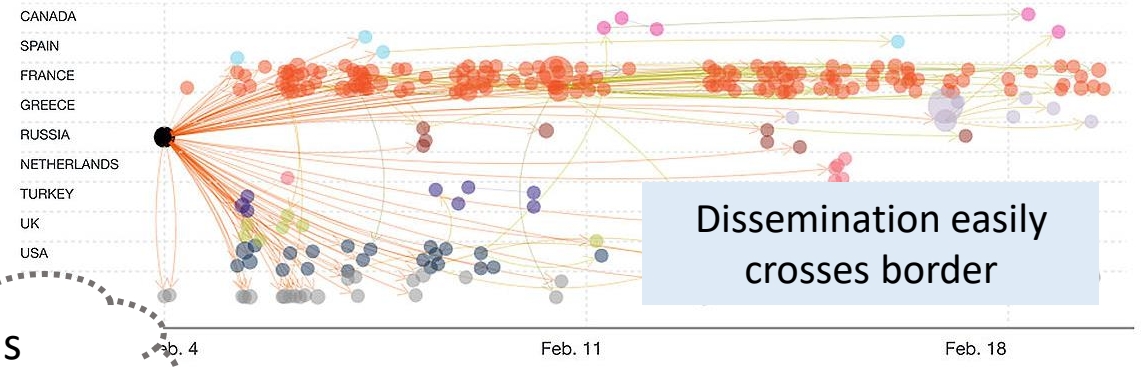
Rumors about Macron's possible homosexuality, 2017

Spread of COVID and other communicable diseases



Dissemination through different online social media





Dissemination easily crosses border

Bad news travels fast and far

From https://www.unicepta.com/impulse-news/how-do-fake-news-spread.html

When will the strength of weak ties fail?
(are there other mechanisms driving diffusion?)

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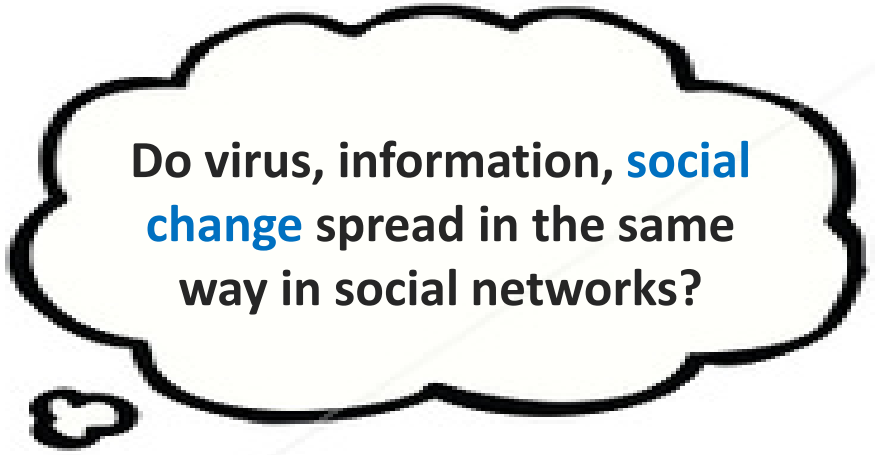
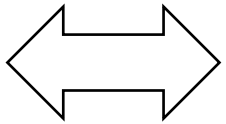


Some social contagions skip over weak ties, and spread through clustered networks

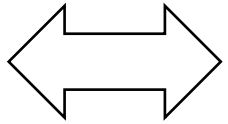
When behaviour is risky, costly or fights against your habits

Most people **heard about their current jobs** through acquaintances rather than close friends



Memberships of civil rights activists : Despite the fact that weak ties offered an obvious advantage for rapidly increasing the movement's exposure, memberships **grew primarily through recruitment networks composed of strong ties**. ('Freedom Summer, Doug McAdam and Ronnelle Paulsen') in 1964

Rumor easily spreads through spatial borders

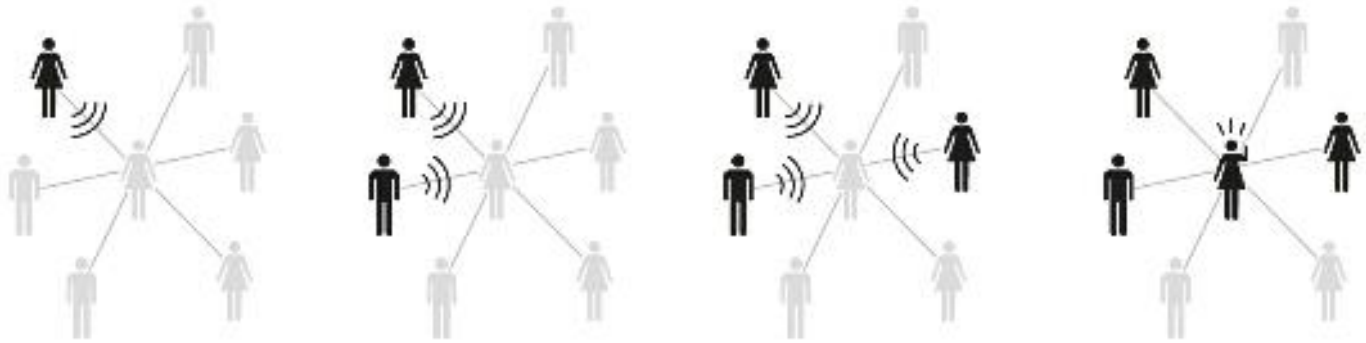


Innovation of health behaviour: Instead of sparse network with weak ties, **dense neighbourhood networks and cohesive social settings** are the most likely places for the rapid spread.(Lisa Berkman and Ichiro Kawachi, 2011)

"Behaviors spread like virus" **VS** Many social movements break out from a small, localized group to become widespread phenomena

Complex contagion

- Multiple (and credible) sources are required for transmission



Examples

- Change of diet
- Get the latest model of Iphone
- High-risk social movements
- Other behaviours that require social reinforcement

Recall for simple contagion:

Bob is now considering to join a street protest

1st round: Bob

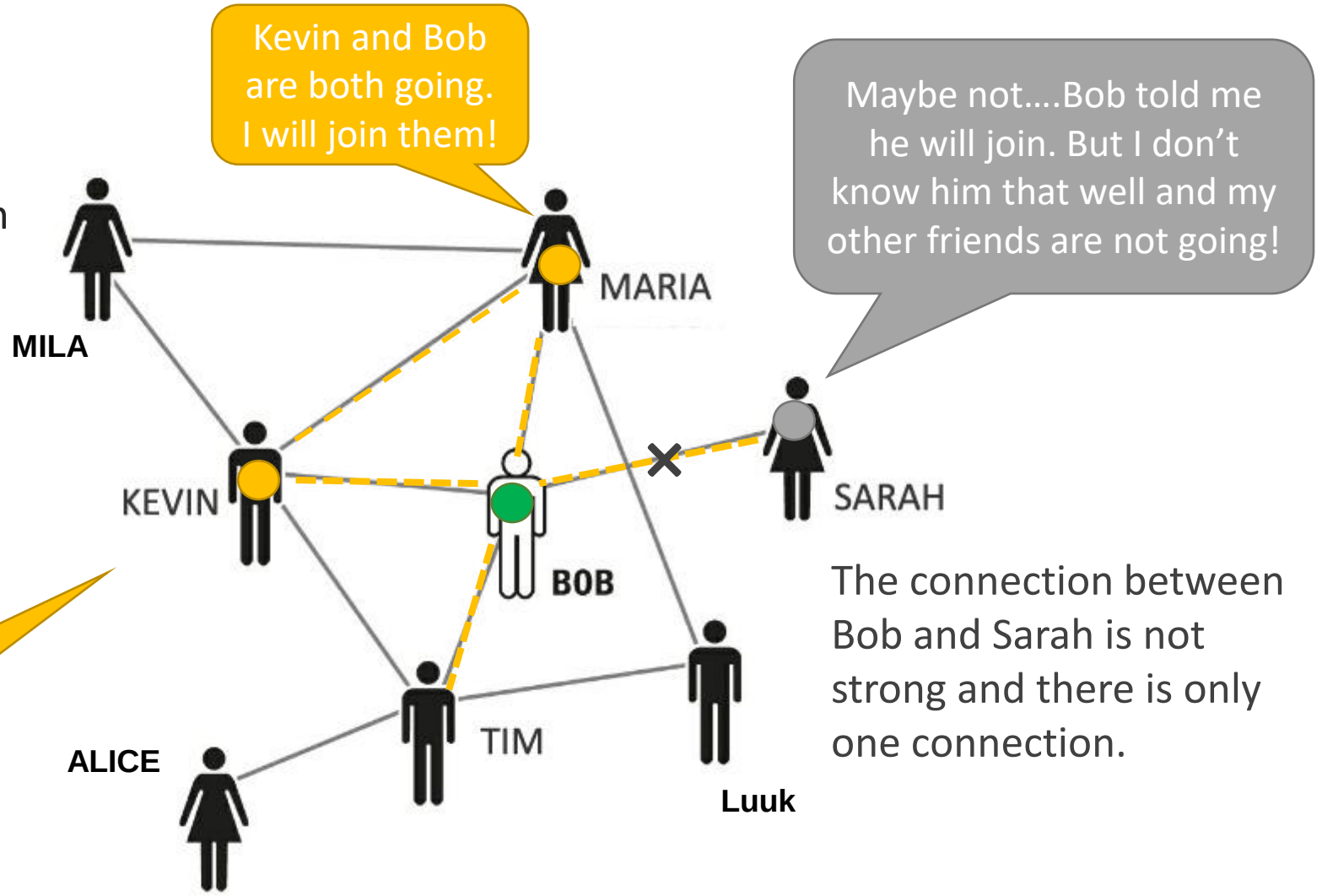
2nd round: Bob→ Kevin, Maria, Tim, Sarah

3rd round:

Kevin→ Mila, Maria

Maria→ Kevin, Mila, Luuk

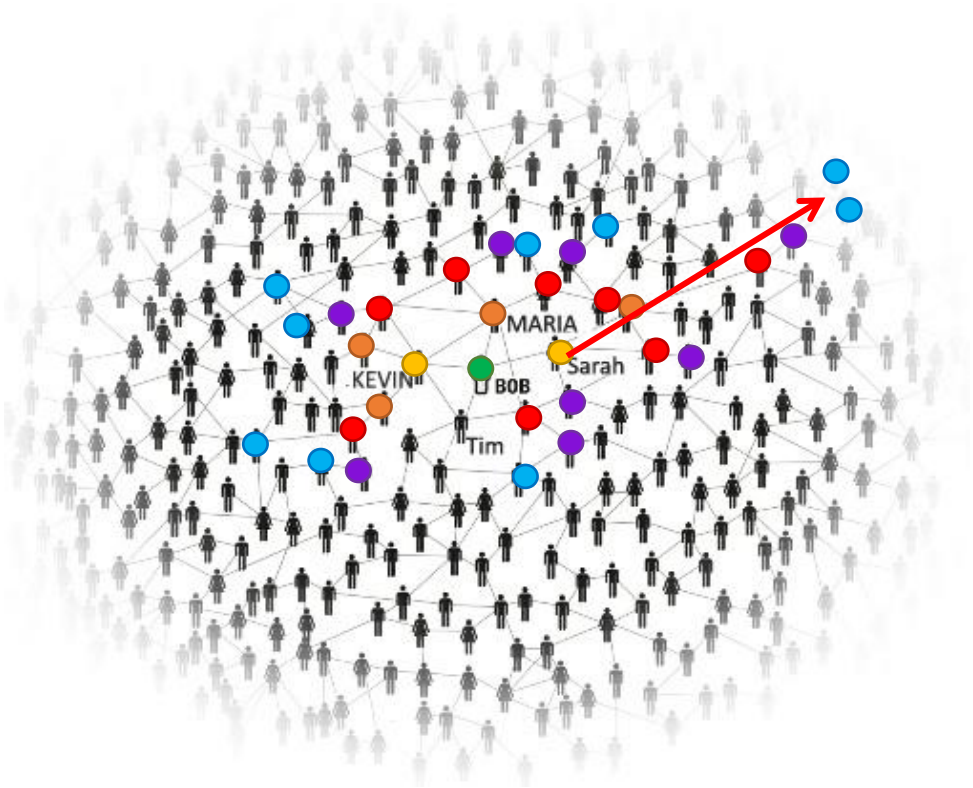
Tim→ Kevin, Luuk, Alice



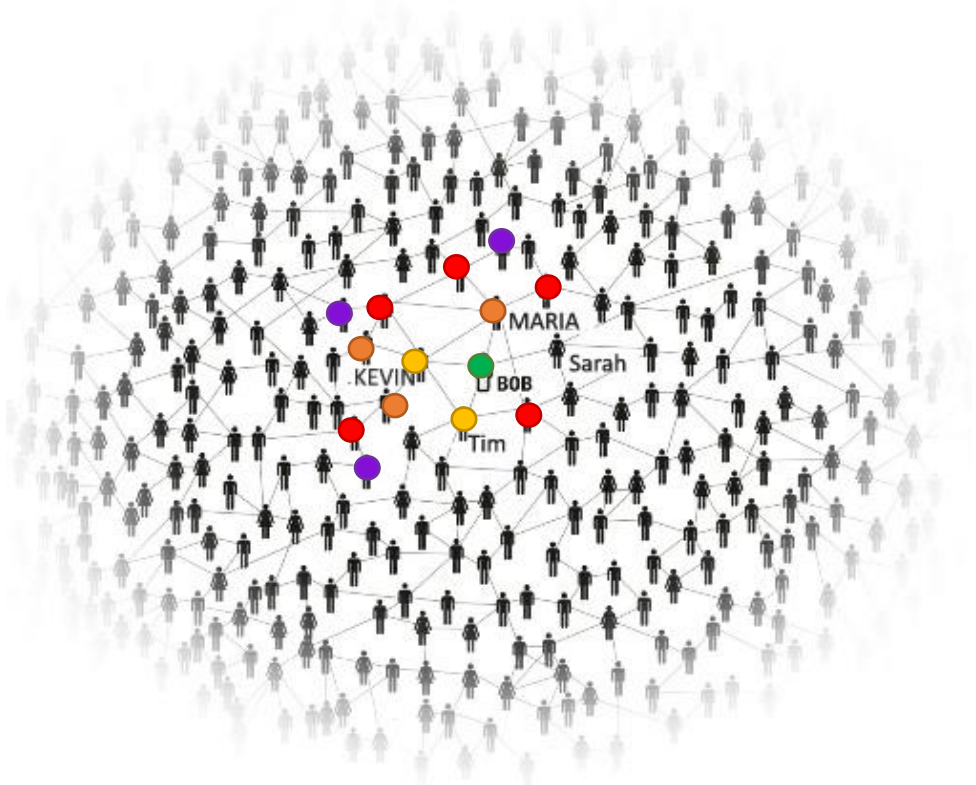
The connection between Bob and Sarah is not strong and there is only one connection.

Because of redundant of strong ties, Kevin, Maria and Tim have multiple sources to confirm the credibility of the behavior and support each other

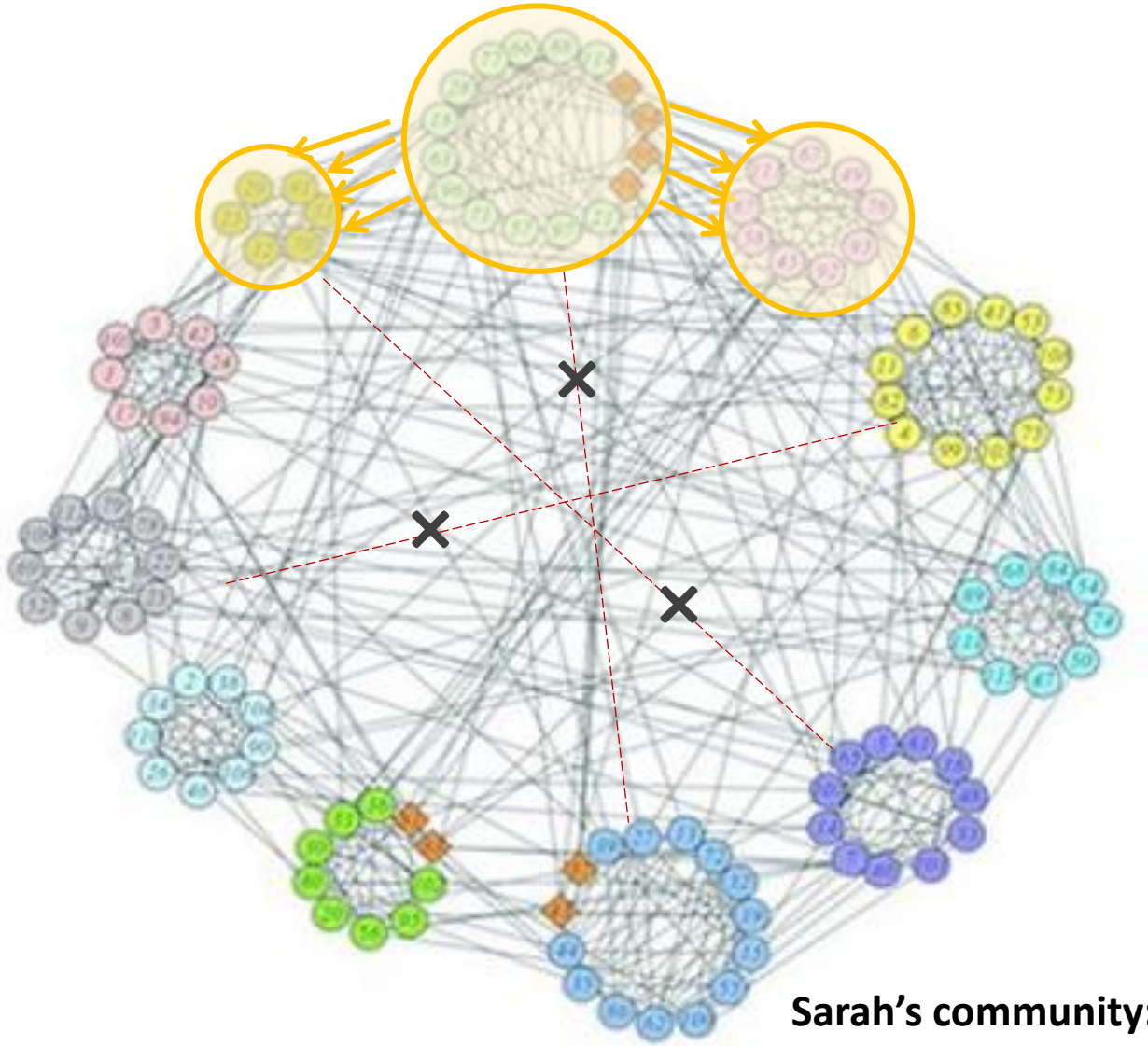
Under simple contagion, the weak tie between Bob and Sarah can pass the information into other communities that Bob have no other connections



Under complex contagion, behavior will spread through the close friends of Bob. It requires much longer time to reach distant communities (or even fail to reach…)



Bob's community: similar in geographic location. social status. information and beliefs



Sarah's community: :similar in geographic location, social status, information and beliefs

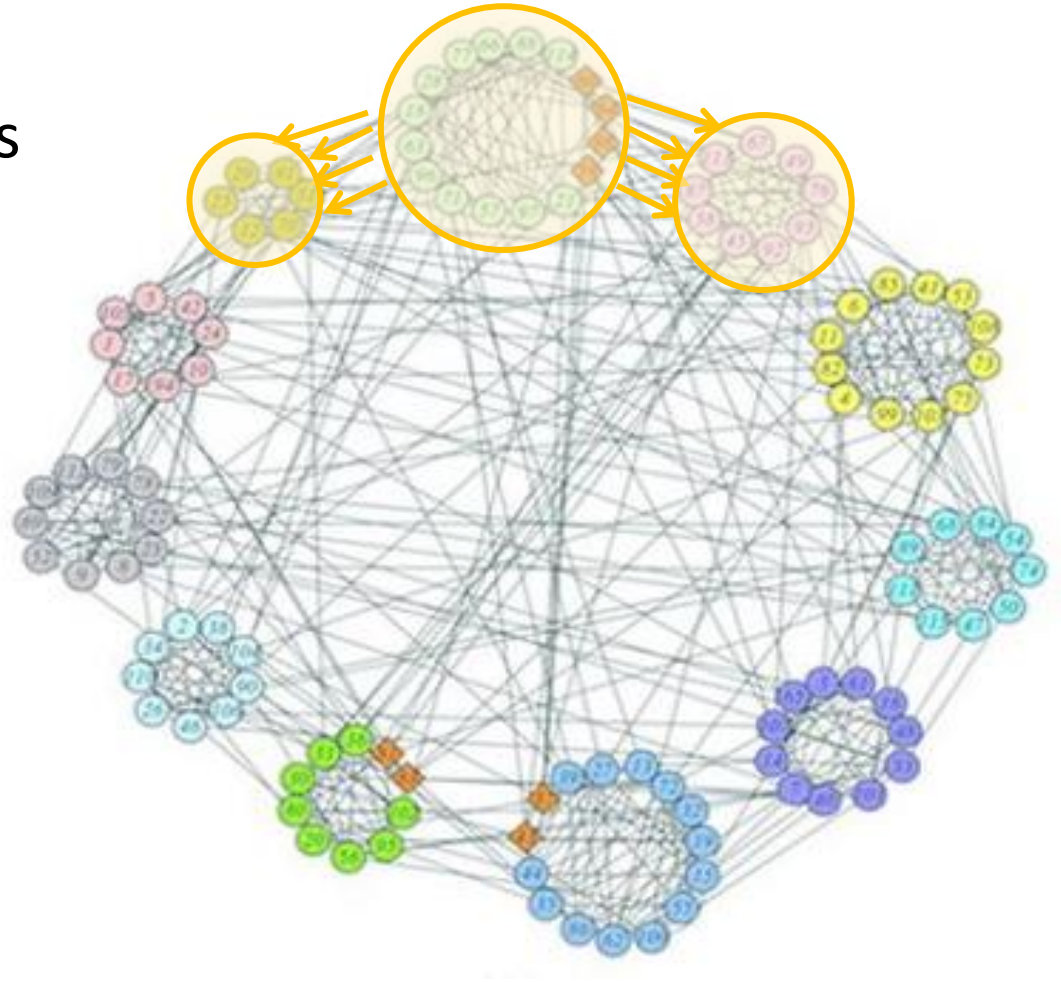
Complex Contagions and *the Weakness of Long Ties*, Centola &Macy, 2007

Complex contagions depend primarily on the width of the bridges across a network, not just their length. Wide bridges are a characteristic feature of many spatial networks, which may account in part for the widely observed tendency for social movements to diffuse spatially.

Damon Centola
https://www.damoncentola.com/

Width of a bridge decides the diffusion of complex behavior

- The width of a bridge between two communities/neighborhoods is defined as the number of overlapping ties between them.
- Works better to achieve and maintain complex behaviors
- “Account in part for the widely observed tendency for social movements to diffuse spatially.”



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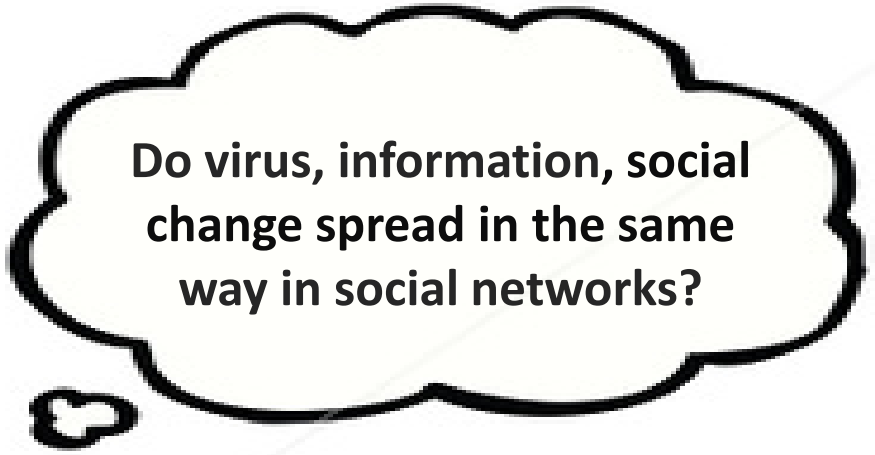
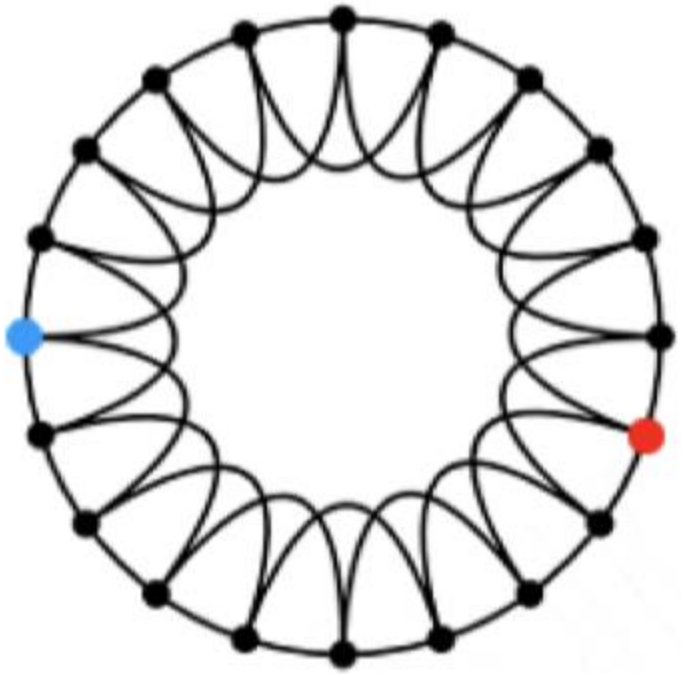
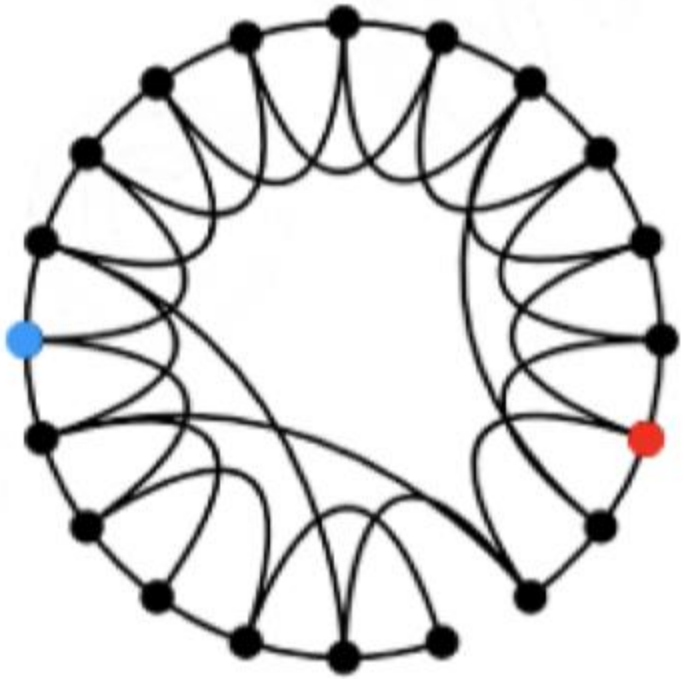


As you recall from last session: the three theoretical networks…

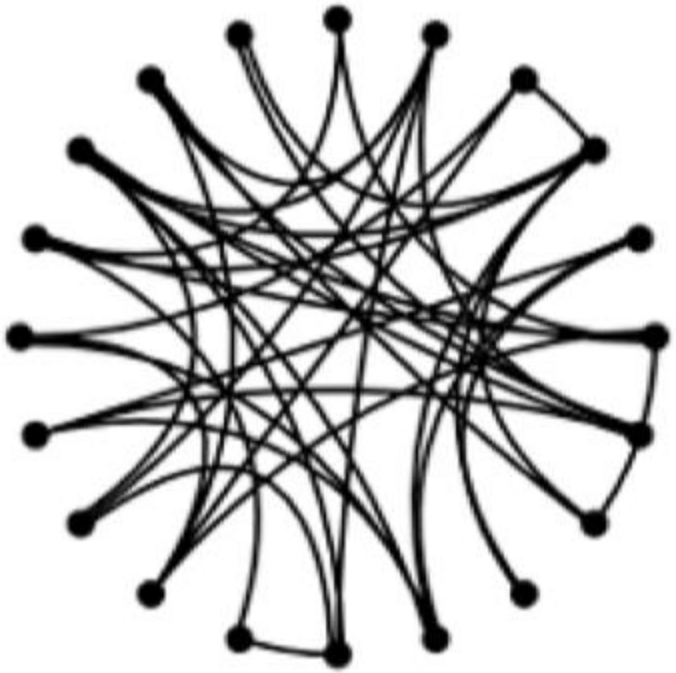
Regular/clustered Network



Small World Network



ER random Network

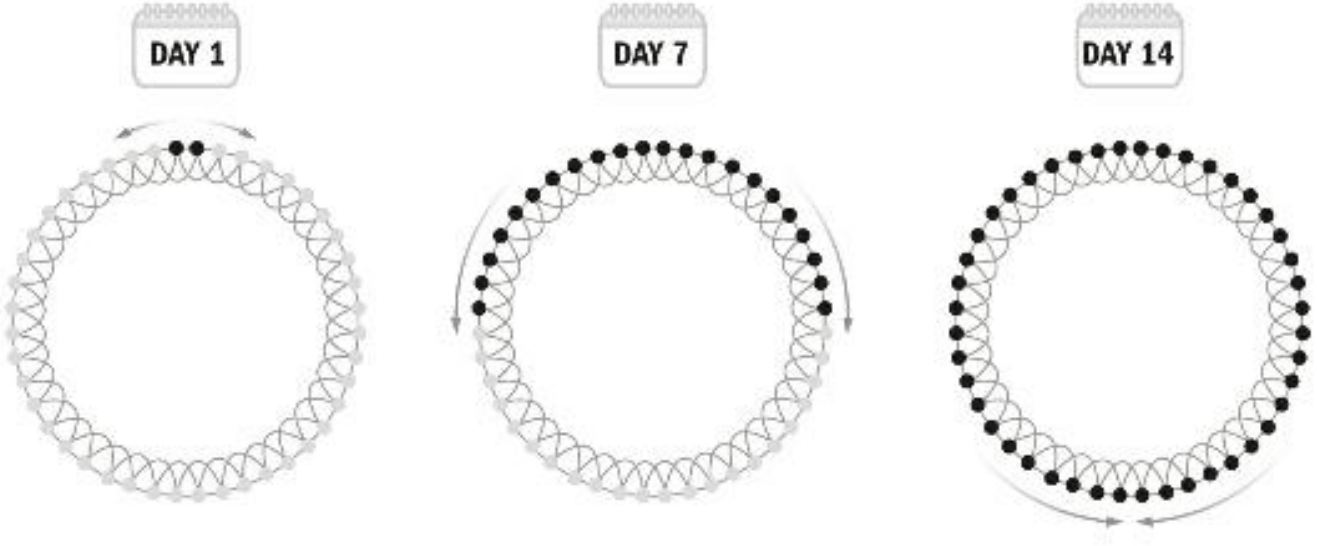


P=0 → INCREASING RANDOMNESS → P=1

High clustering High diameter	High clustering Low diameter	Low clustering Low diameter

Simple contagion

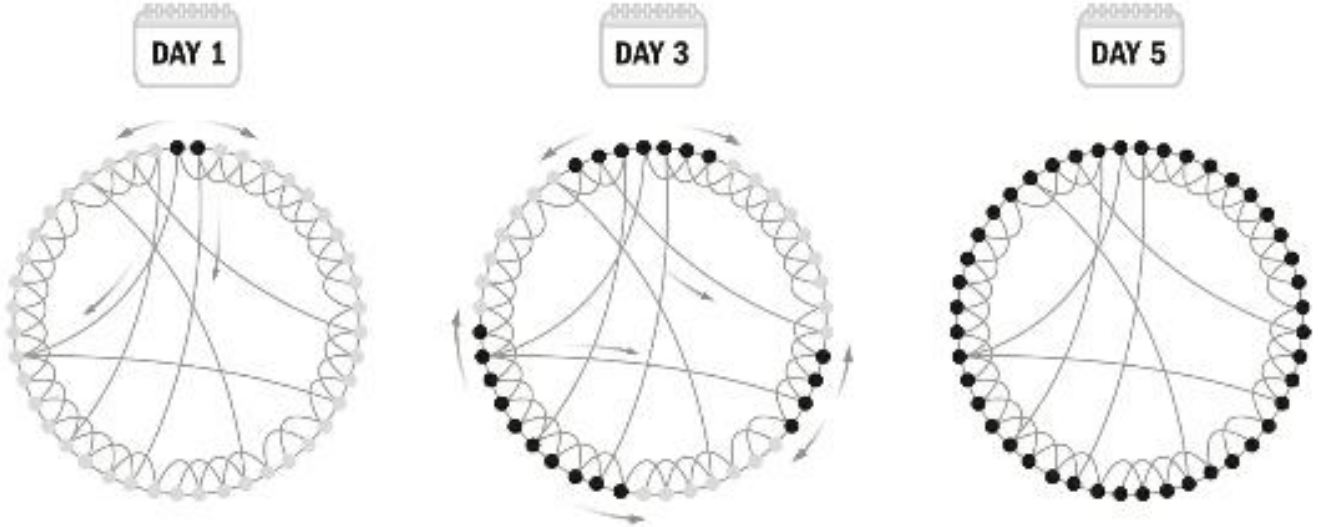
Diffusion in a clustered network (high clustering with no weak ties/ no 'short cuts')



Many people heard about the same information for more than once

By rewiring 5 edges to reduce the redundancy:

Diffusion in a small-world network (high clustering with a few weak ties)

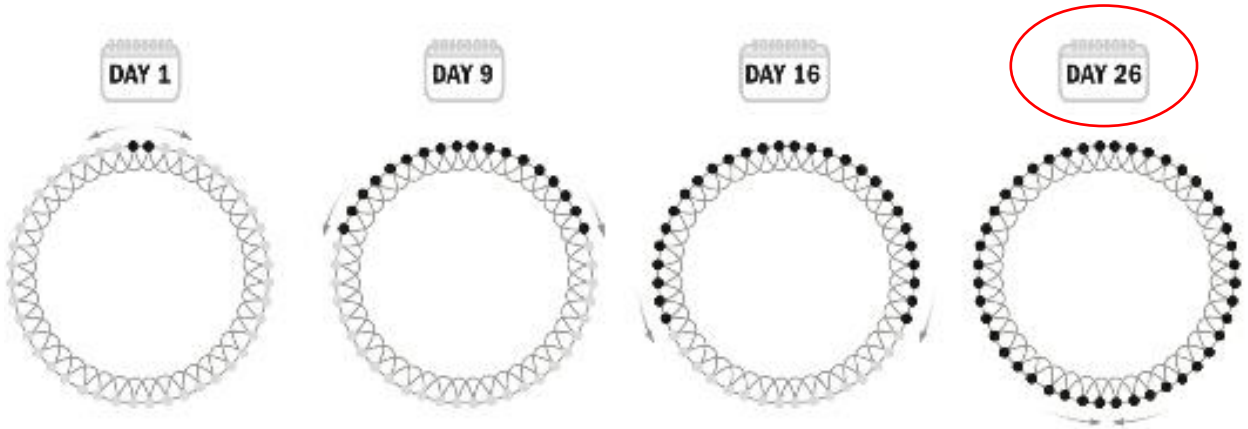


Each weak tie allows information to spread to ***an untouched region of the network.***
Simple contagion spreads faster and easier in small-world or random networks.

Centola, Damon. How Behavior Spreads: 3 (Princeton Analytical Sociology Series) (pp. 28-29).

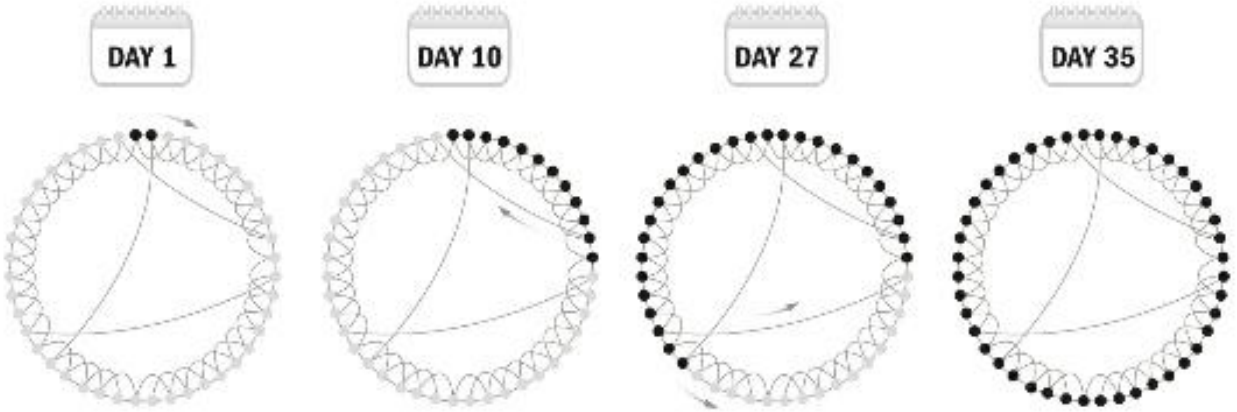
Complex contagion

Diffusion in a clustered network (high clustering with no weak ties/ no 'short cuts')

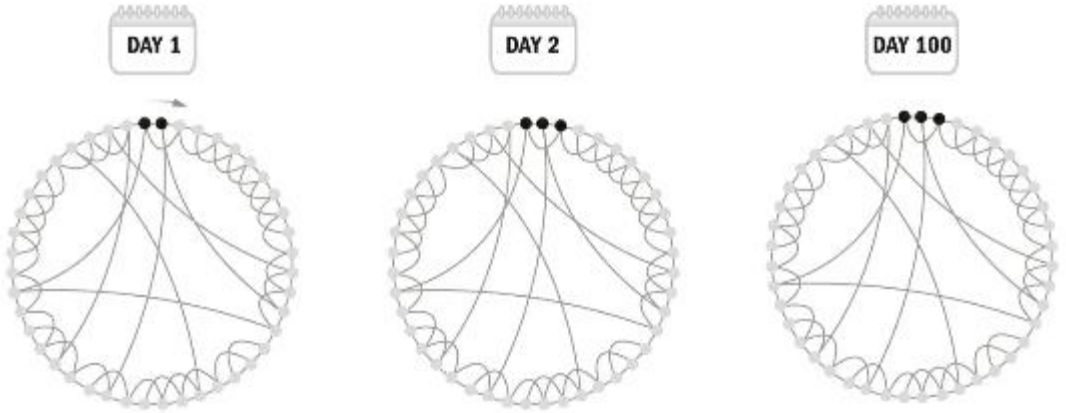


Diffusion in a small-world network (high clustering with a few weak ties)

By rewiring 3 edges to reduce the redundancy:



By rewiring 6 edges to reduce the redundancy:

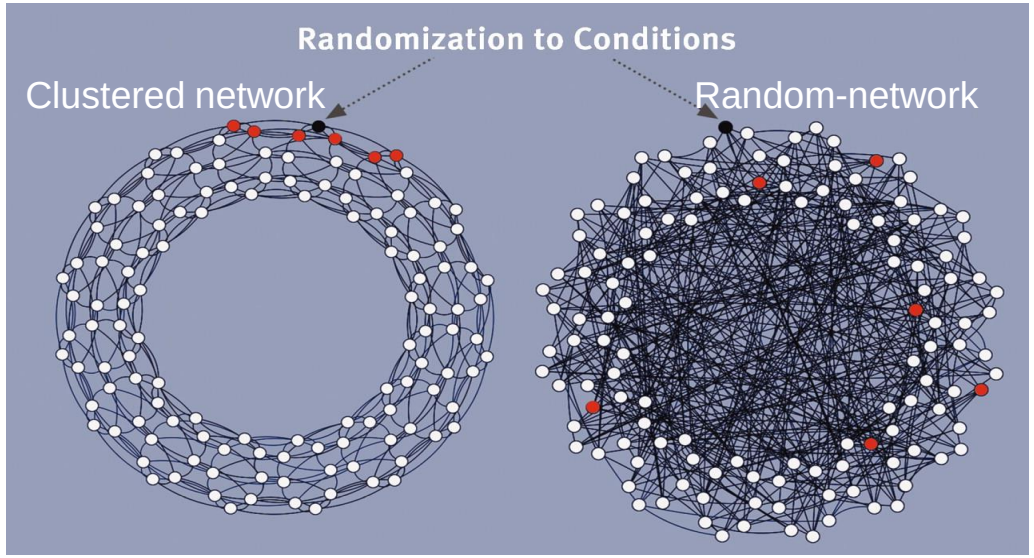


Overall number of ties remains the same;
Everyone still has four neighbors

The spread of **health behavior (complex contagion)** in an online social network experiment, Centola, 2010

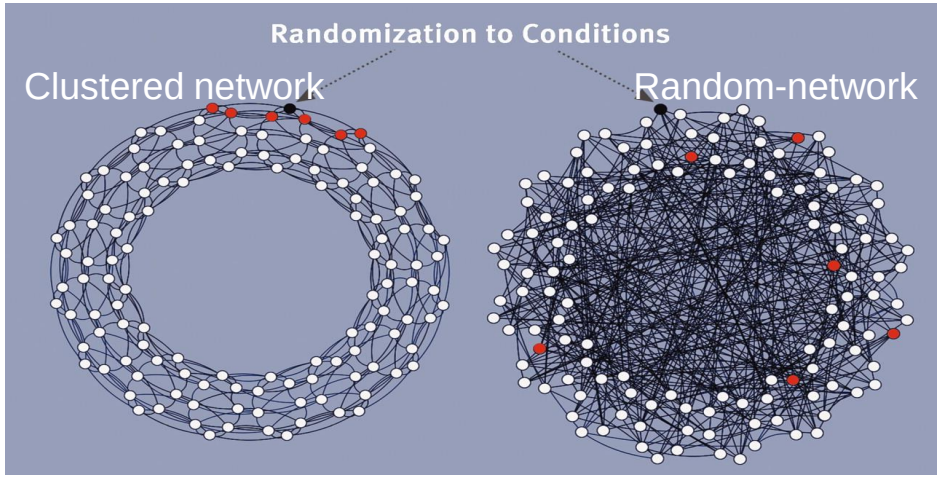
Individual adoption was much more likely when participants received social reinforcement from multiple neighbors in the social network.

The behavior spread farther and faster across clustered networks than across corresponding small world or random networks.



Randomization of participants to clustered and random networks (N = 128, Z = 6). The black node shows the focal node of a neighborhood to which an individual is being assigned, and the red nodes correspond to that individual's neighbors in the network.

Damon Centola. The Spread of Behavior in an Online Social Network Experiment. SCIENCE, 329, 2010.

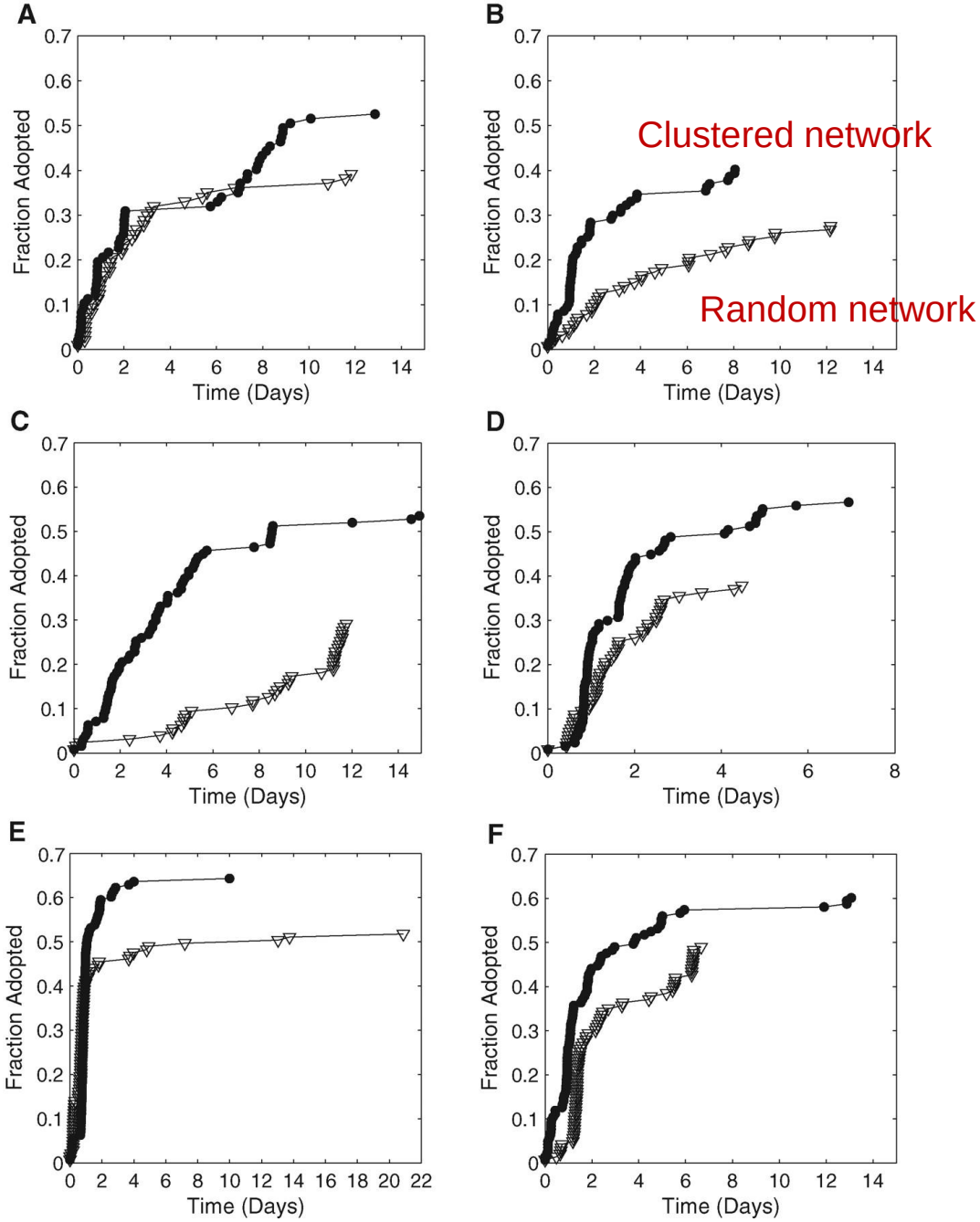


1) Select a random “seed node,” which sent signals to its network neighbors encouraging them to register for a health forum Web site

2) Every time a participant registered, messages were sent to her health buddies inviting them to adopt.

3) If a participant had multiple health buddies who adopted the behavior, then she would receive multiple signals, one from each neighbor. The more neighbors who adopted, the more reinforcing signals a participant received.

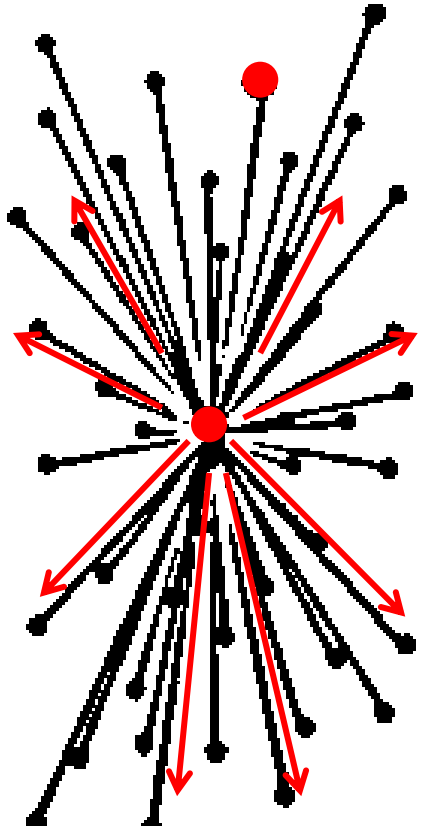
Damon Centola. The Spread of Behavior in an Online Social Network Experiment. SCIENCE, 329, 2010.



Six independent trials of the study are shown, including (A) N = 98, Z = 6, (B to D) N = 128, Z = 6, and (E and F) N = 144, Z = 8

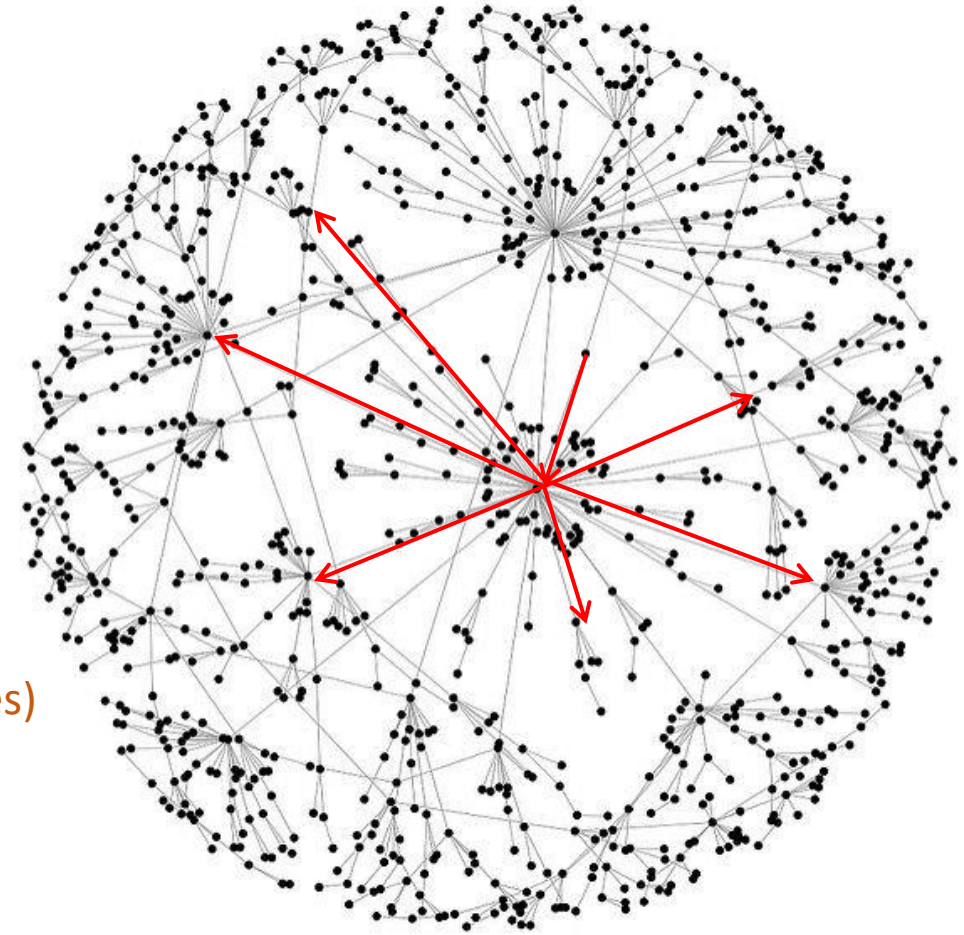
Different roles of hubs in scale-free network under simple and complex contagion

Simple contagion



Hubs will quickly spread the information out.

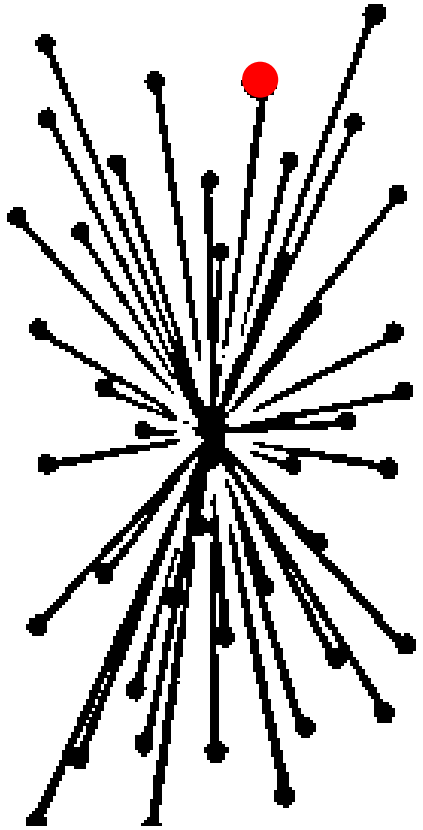
“memes” (short, viral messages)



Different roles of hubs in scale-free network under simple and complex contagion

Complex contagion

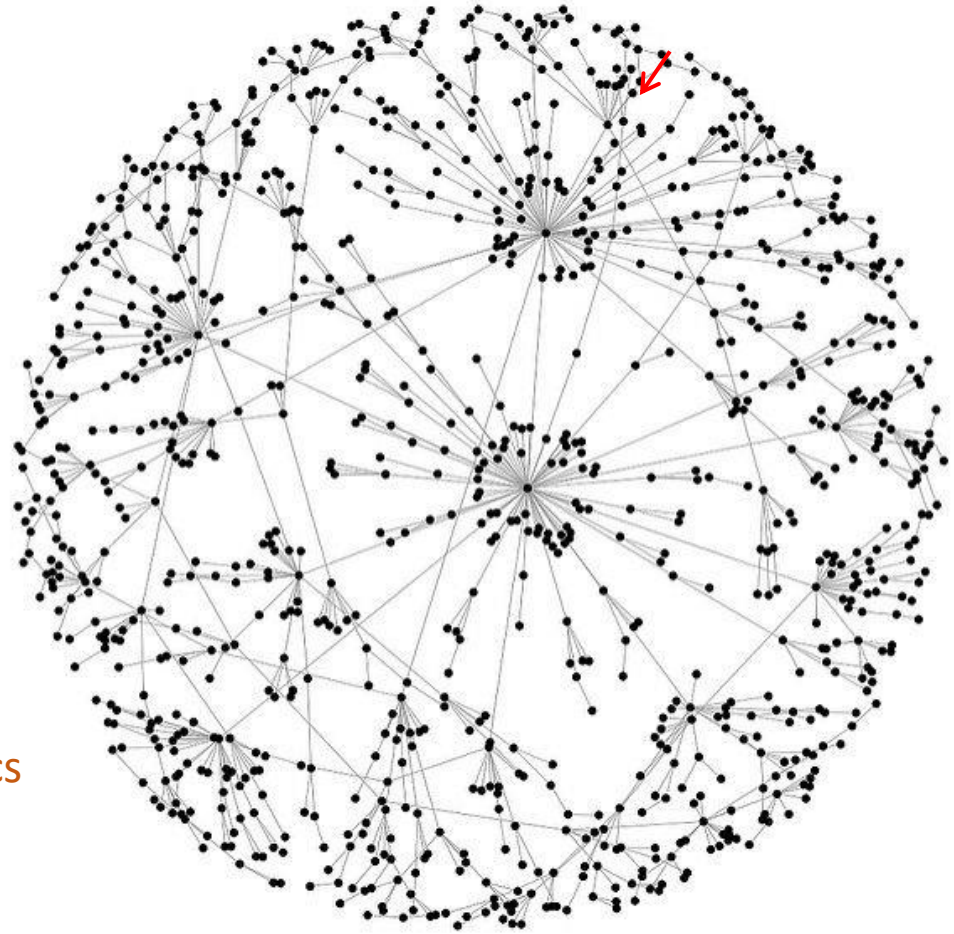
Absolute threshold: >2 friends adopt
Fractional threshold: >30% or 50%



When behavior is risky (e.g., one will adopt when 30% or 50% of friends adopt), the hubs will wait and see until they see more successful proofs in the network.

Hashtags on politically controversial topics

Diffusion starts from peripheral actor (e.g., “grass-root” activities. Influencer will not endorse until they see it is quite popular in some communities)



Today's program

- Simple contagion

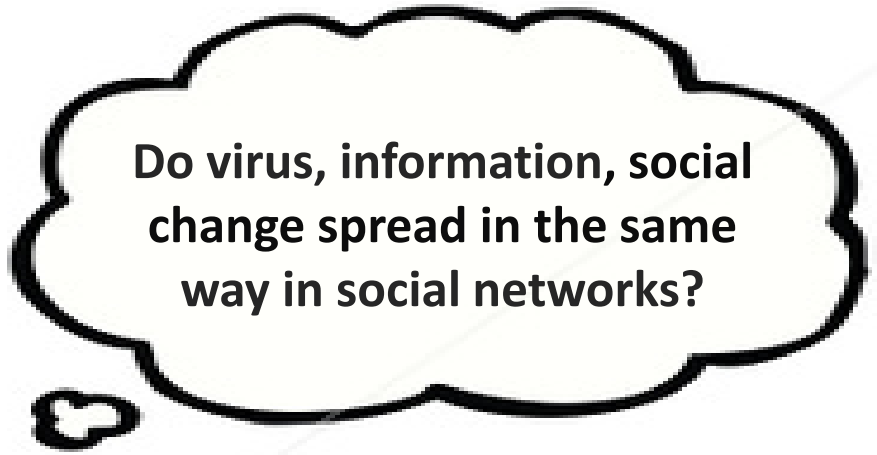
  Mechanism and the strength of 'weak ties'
- Complex contagion

  Mechanism and the strength of 'strong ties'
- Can we predict the success or failure of diffusion?

  Network topology matters!

  Inhomogeneity of people
- Application of social contagion

  Online experiment in Facebook;
  Diffusion of hashtag in Twitter



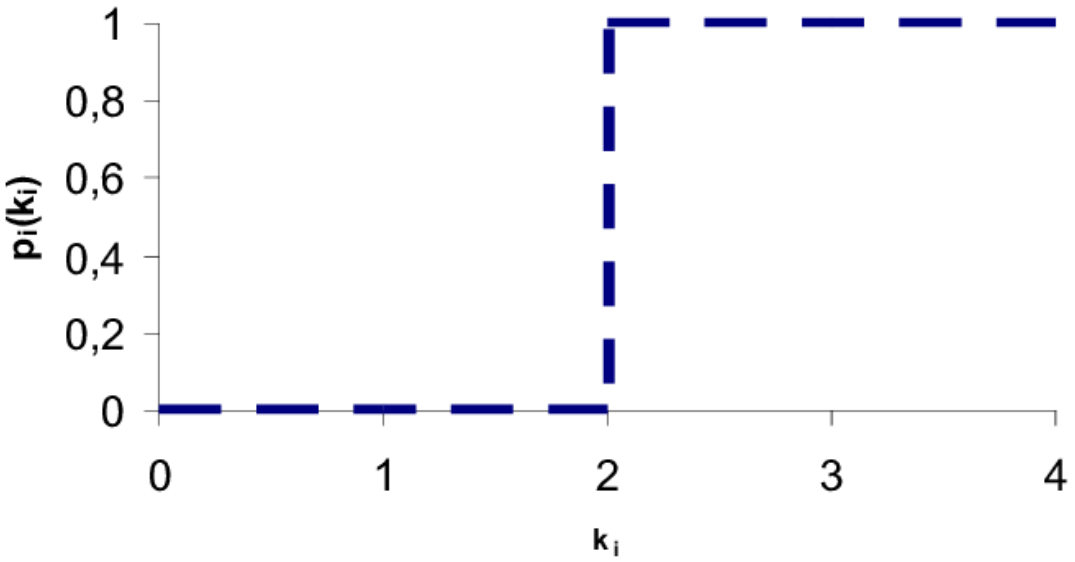
What's behind complex contagion?

Threshold: To adopt a novel behavior, an individual needs to be convinced by an absolute number or a fraction of his/her social contacts

Interacting agents whose decisions are determined by the actions of their neighbors (***binary decisions with externalities***)

Acceptance probability *p* is a function of the absolute number (or relative ratio) of adopted peoples in *k*'s neighbors

$$p(k_i) = \begin{cases} 0 \mid k_i < T \\ 1 \mid k_i \geq T \end{cases}$$



Threshold model for Collective Behavior: Riot (Mark Granovetter, 1978)

Imagine 100 people garthering near the Capitol, a potential riot situation.

Suppose their riot thresholds as follows: one individual with threshold 0, one with threshold 1, one with threshold 2 ..... (a uniform distribution of thresholds)

What will happen? (a “domino” effect)

A uniform distribution of thresholds
(or thresholds are all very low)

Remove the individual with threshold 1 and
replace with someone with threshold 2

Cross at red light

Luuk cross against the red light

Mila: with threshold 1
Alice: with threshold 2
Kevin: with threshold 3

Mila: cross
Alice: cross
Kevin: cross

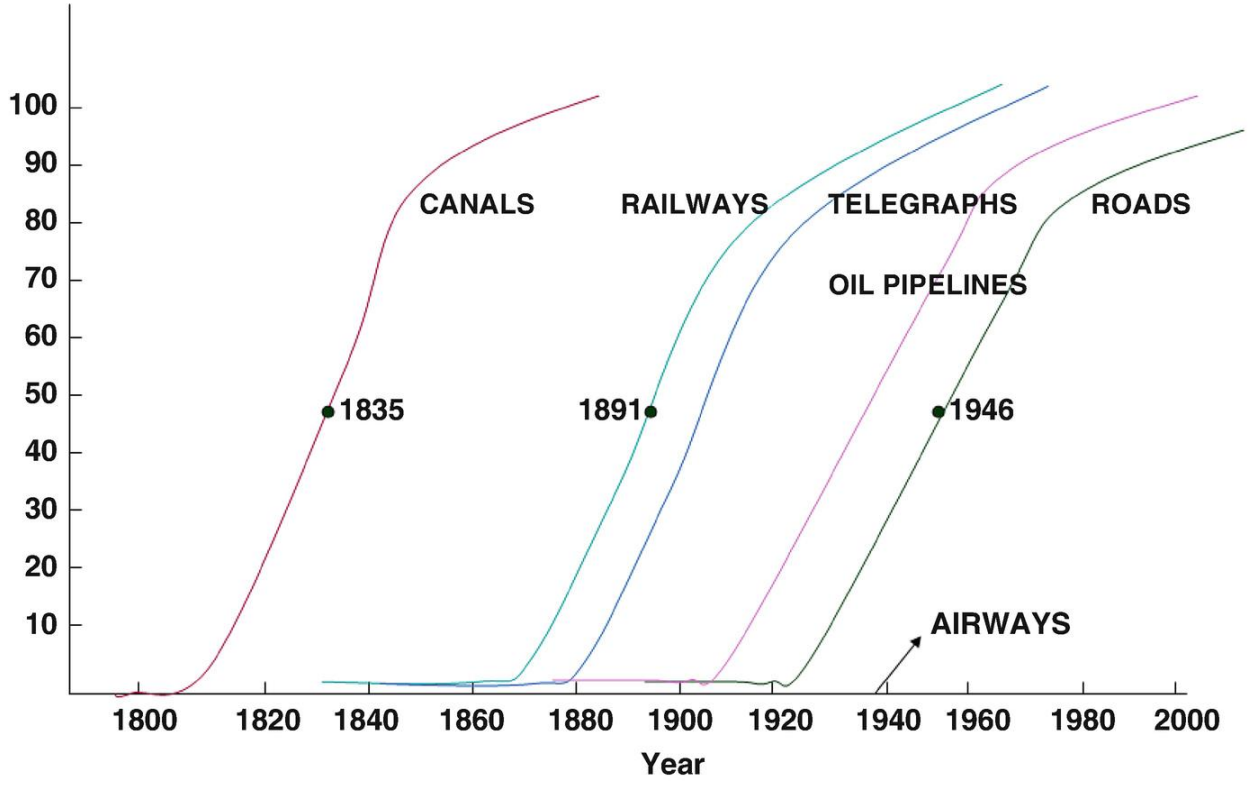
Alice: with threshold 2
Kevin: with threshold 3

Alice: wait
Kevin: wait

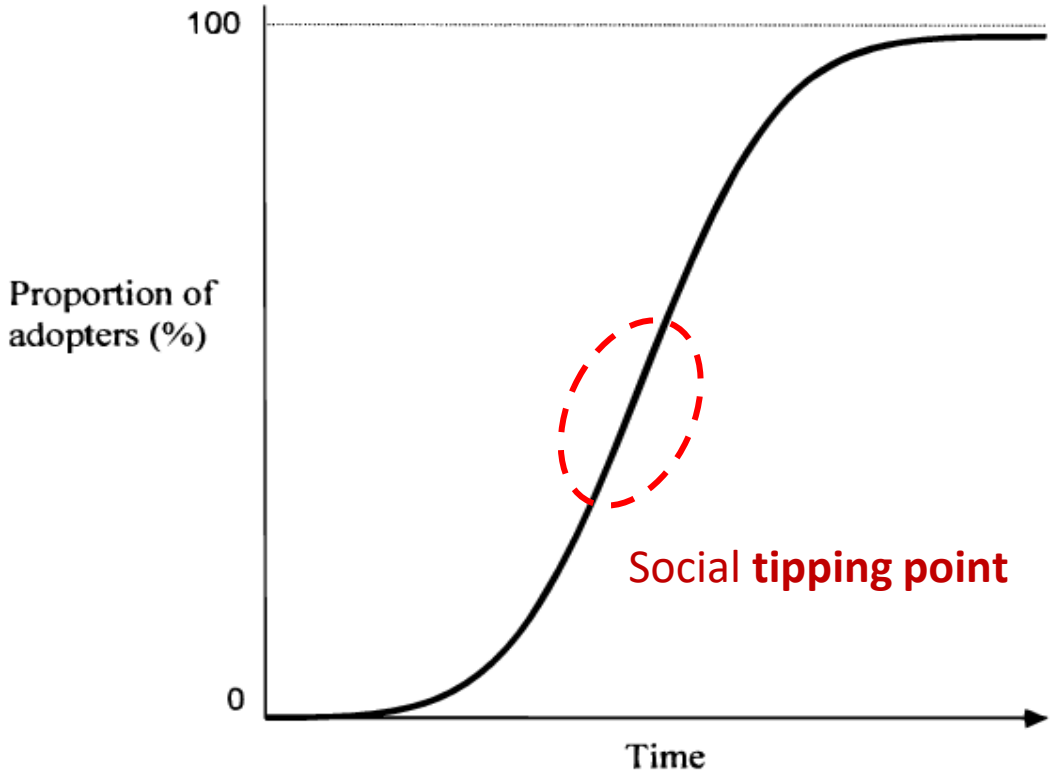
A successful diffusion curve

Cascade size: Fraction of adopters
Diffusion curve: Time vs the cascade size

The diffusion curves for some successful cases

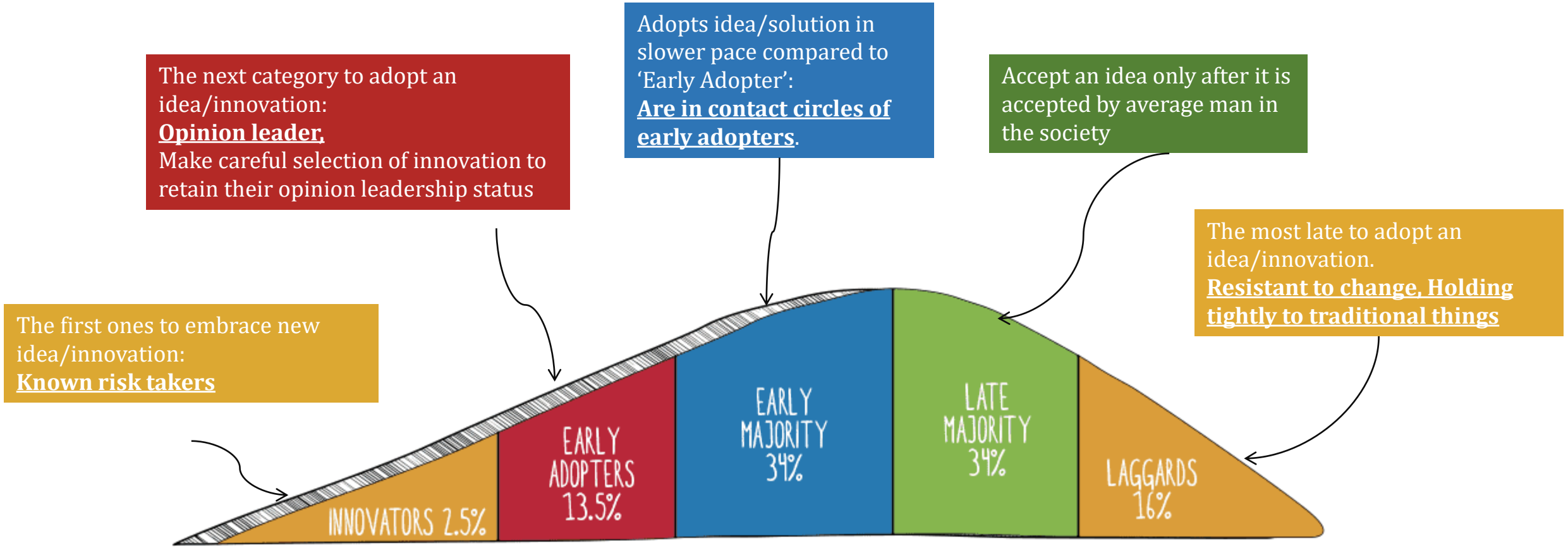


An ideal innovation diffusion curve

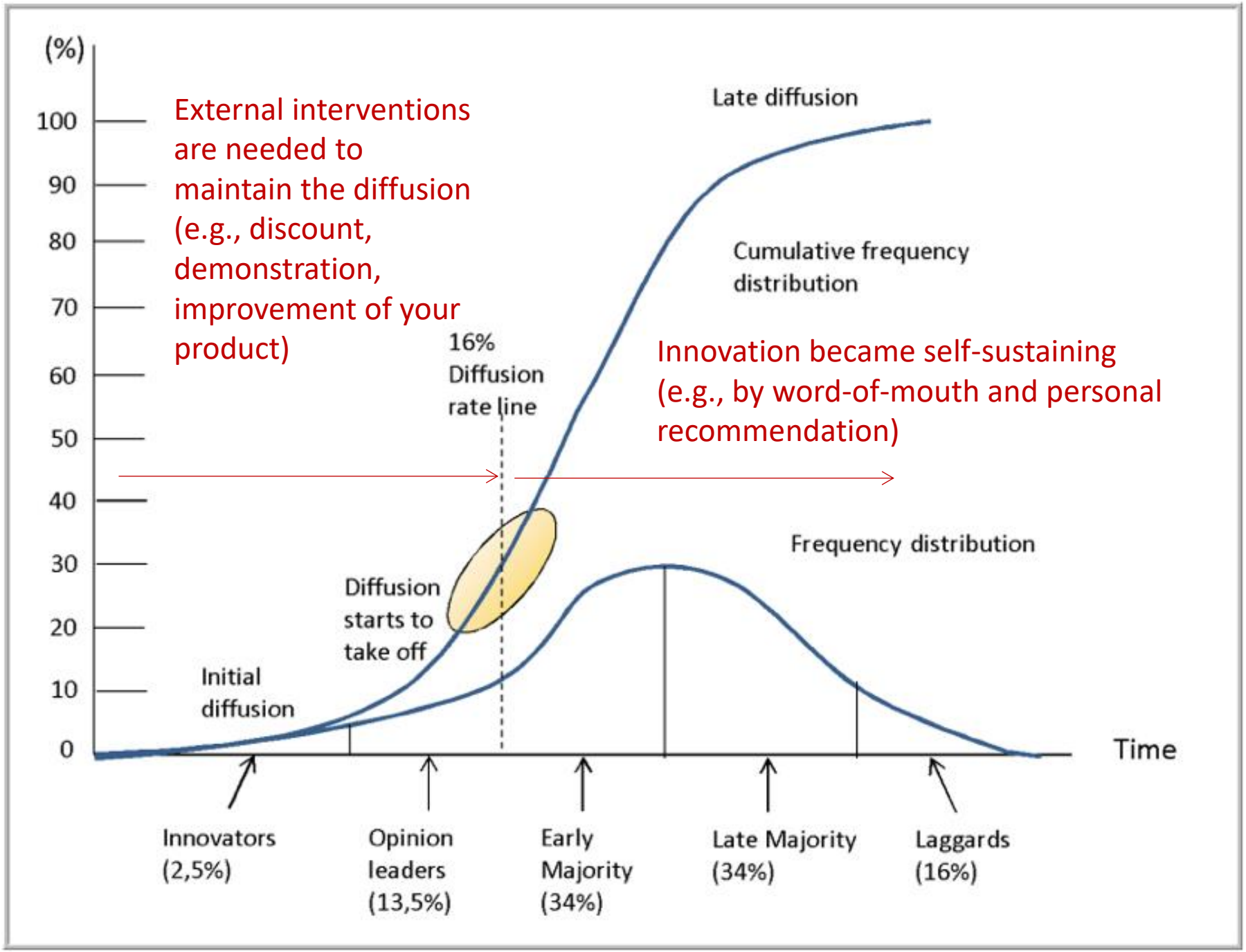


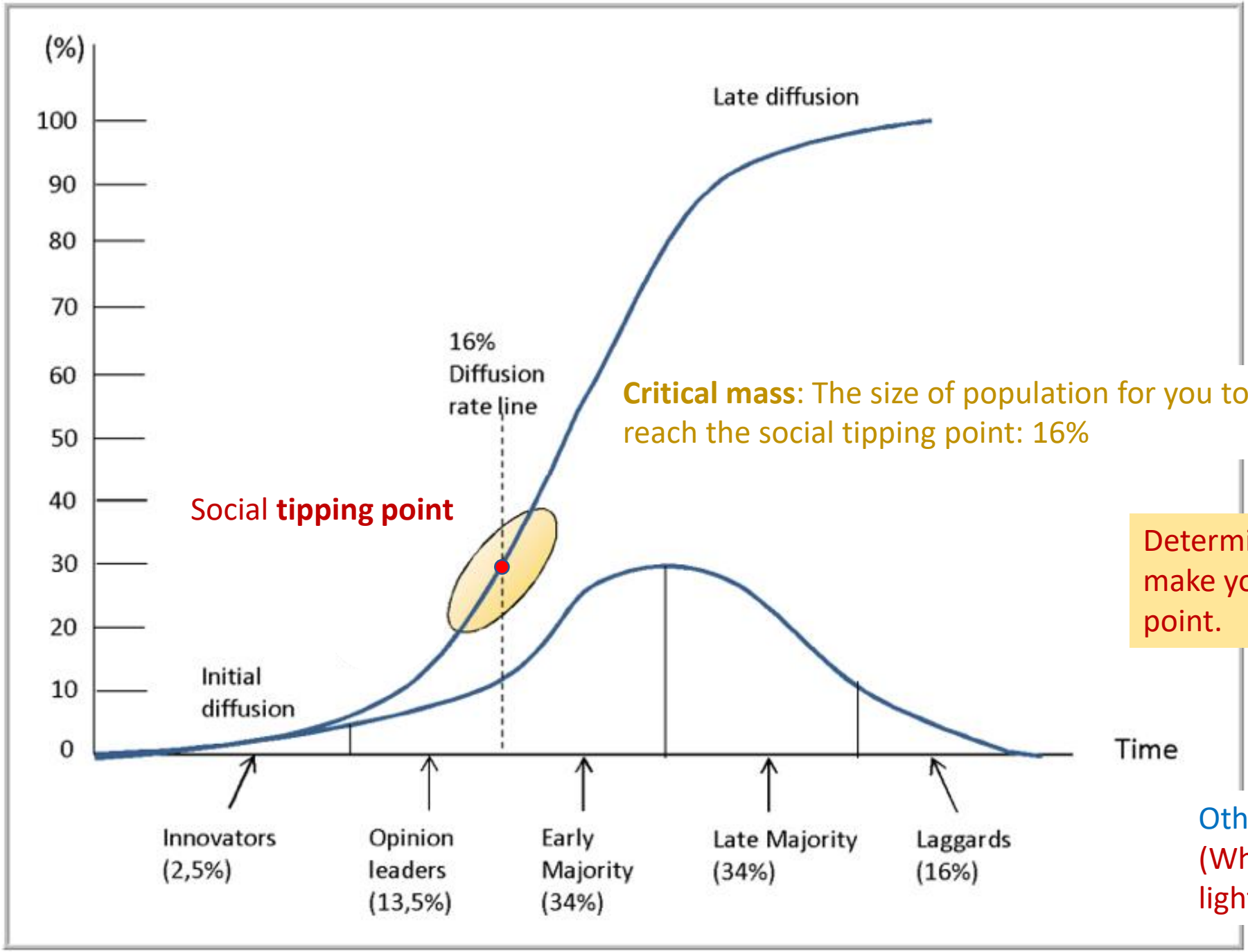
An empirical distribution of threshold of large population

If you introduce a concept or a product to a public/market, it gets accepted at different pace by different category of users.



Everett Rogers, Diffusion of Innovations, 1962.


(%)
100
90
80
70
60
50
40
30
20
10
0
External interventions are needed to maintain the diffusion (e.g., discount, demonstration, improvement of your product)
Late diffusion
Cumulative frequency distribution
16% Diffusion rate line
Innovation became self-sustaining (e.g., by word-of-mouth and personal recommendation)
Frequency distribution
Diffusion starts to take off
Initial diffusion
Time
Innovators (2,5%)
Opinion leaders (13,5%)
Early Majority (34%)
Late Majority (34%)
Laggards (16%)



Critical mass: The size of population for you to reach the social tipping point: 16%

Determine the 'critical mass' that can make you go pass the social tipping point.

Other studies: from 5% to 40% (Which is Mila or 1/3 in the traffic light example)

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  Mechanism and the strength of 'weak ties'
- Complex contagion

  Mechanism and the strength of 'strong ties'
- Can we predict the success or failure of diffusion?

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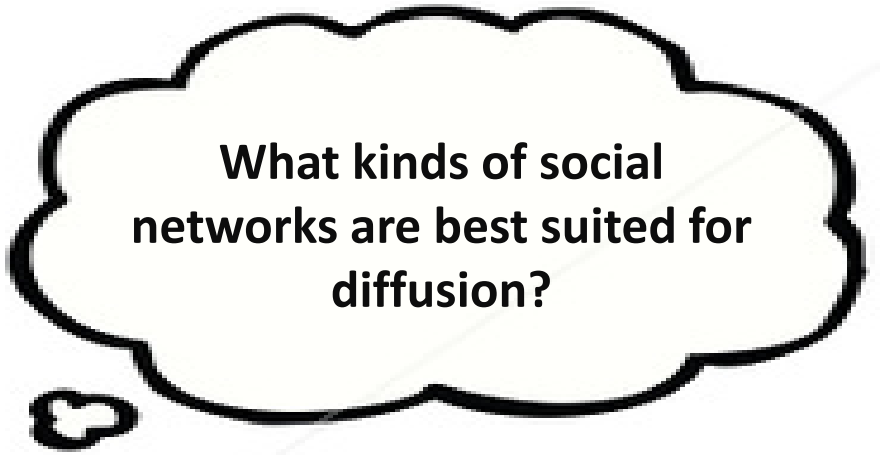
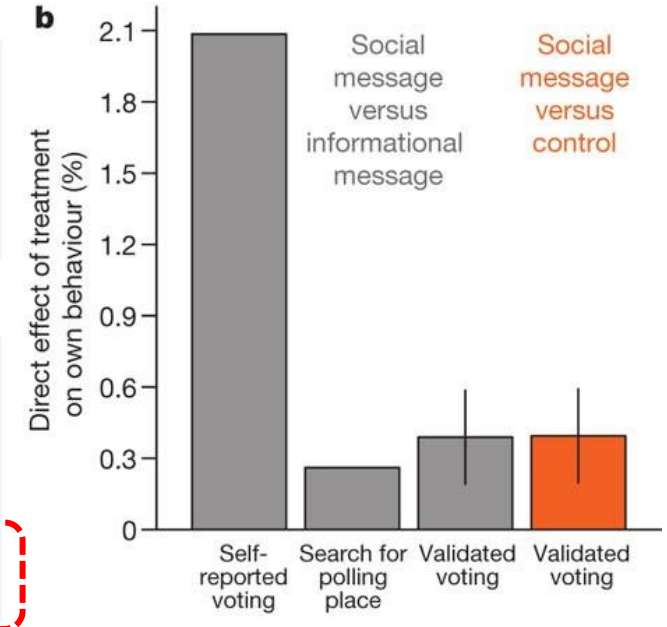
  Inhomogeneity of people
- Application of social contagion

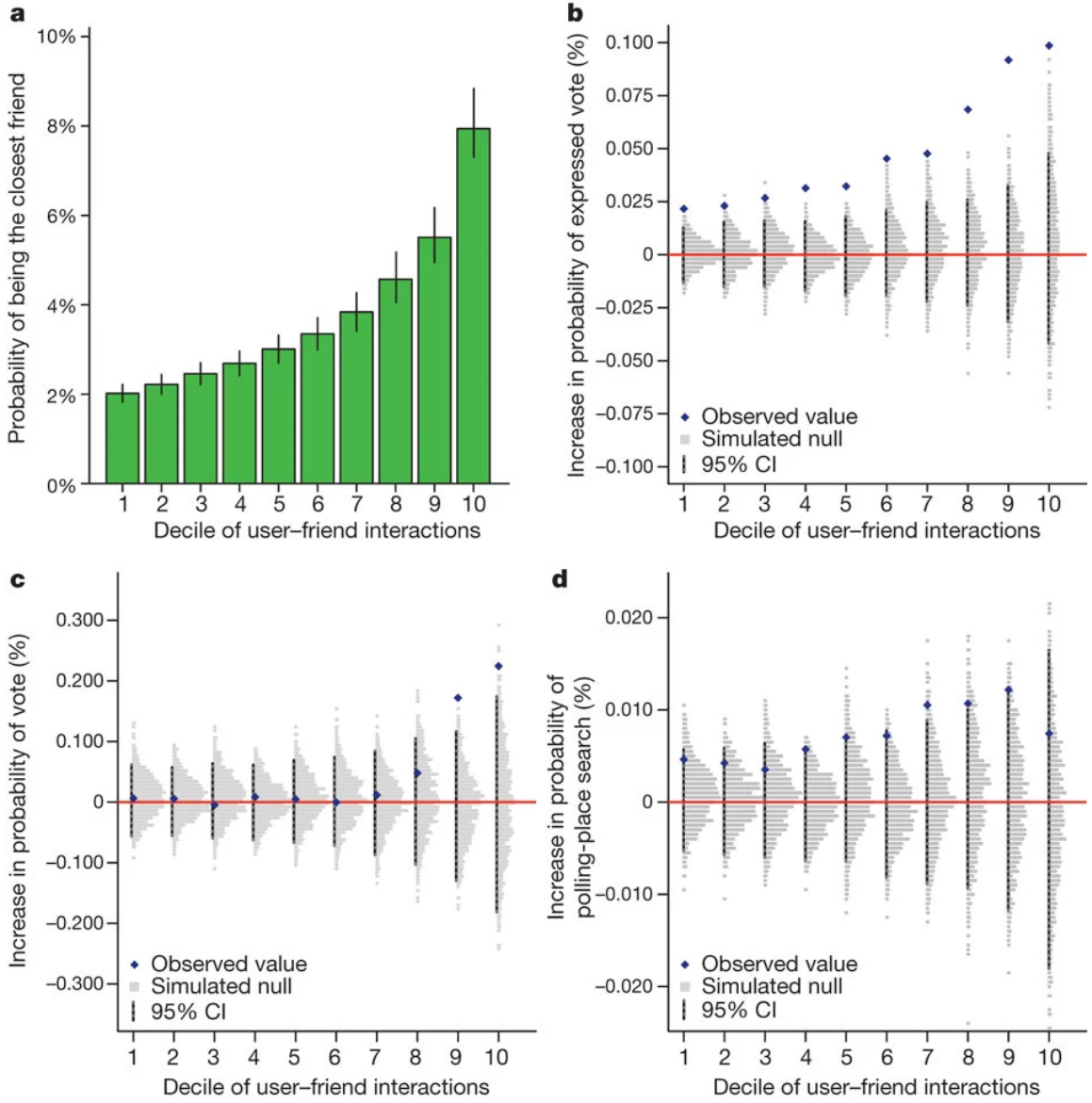
  Online experiment in Facebook;
  Diffusion of hashtag in Twitter
  Diffusion innovation that face opposition



A 61-million-person experiment of social influence in Facebook

A controlled experiment for US facebook users during the 2010 US congressional elections

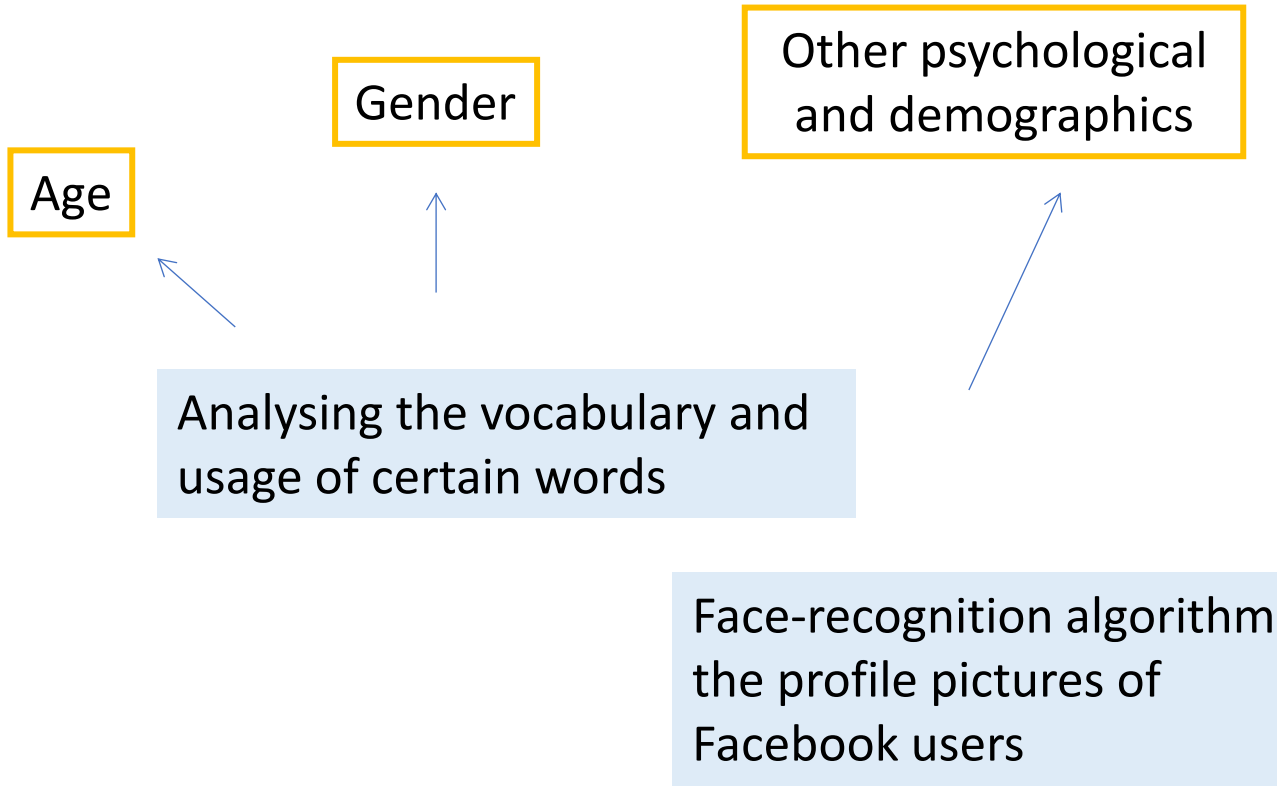




Bond, R., Fariss, C., Jones, J. *et al.* A 61-million-person experiment in social influence and political mobilization. *Nature* **489,** 295–298 (2012).

Using deep-learning algorithms to derive basic characteristics of social media users

Social network analysis using online social media data: Abundance of network data but the lack of demographic information



Ethics?

Diffusion of hashtags in Twitter

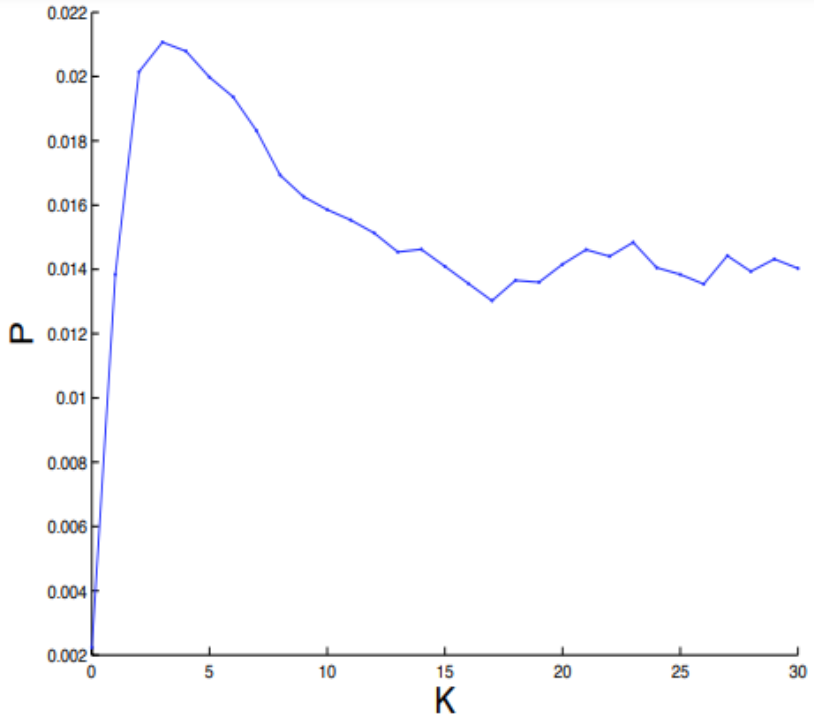


Figure 1: Average exposure curve for the top 500 hashtags. $P(K)$ is the fraction of users who adopt the hashtag directly after their k^{th} exposure to it, given that they had not yet adopted it

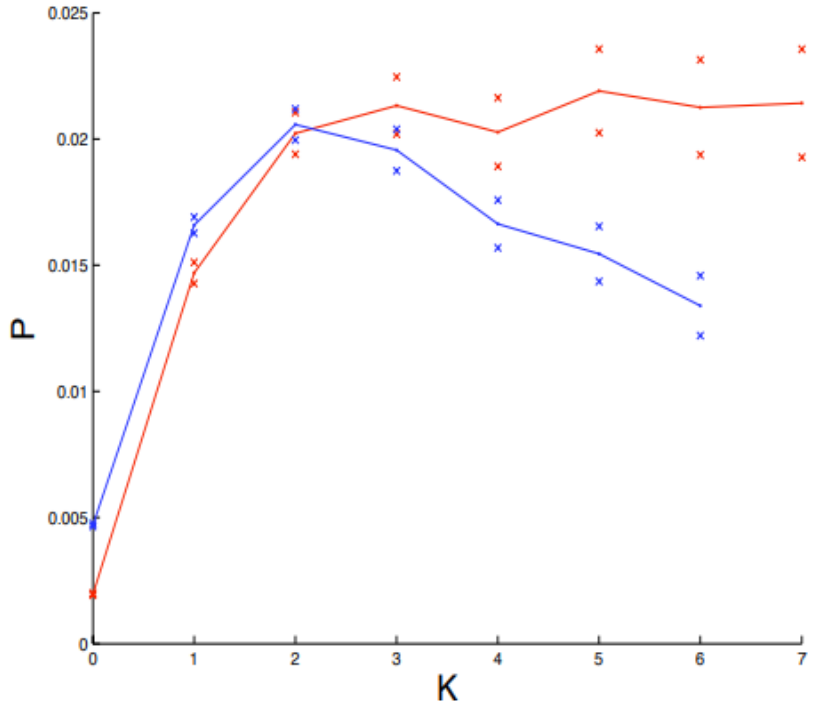
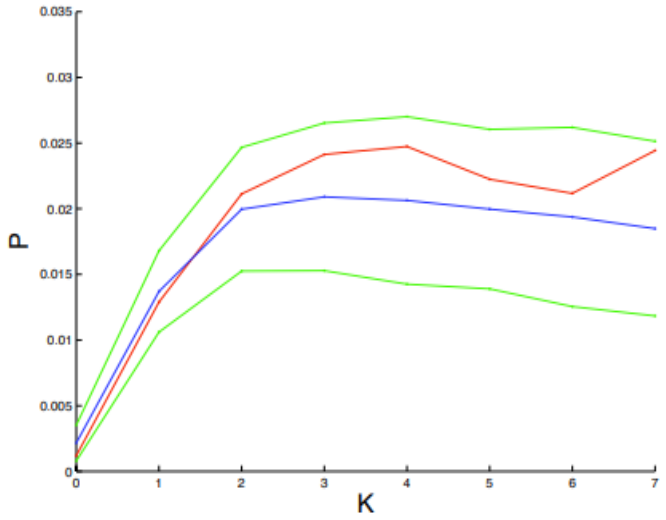
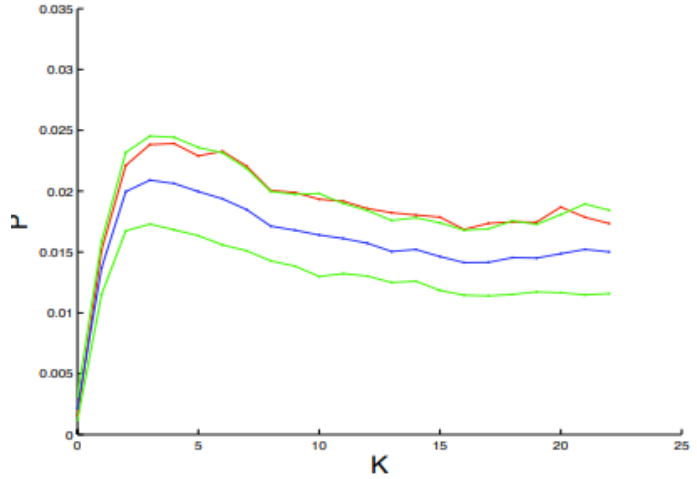


Figure 3: Sample exposure curves for hashtags #cantlivewithout (blue) and #hcr (red).

health-care reform (HCR)



(a) Celebrity



(f) Political

Romero DM, Meeder B, Kleinberg J (2011) Differences in the mechanics of information diffusion across topics: idioms, political hashtags, and complex contagion on twitter. In: Proceedings of the 20th international conference on world wide web, pp 695–704.

Recap

- Simple contagion (Virus and information)

  Single contact and the strength of ‘weak ties’
- Complex contagion (Social change)

  Multiple contact and the strength of ‘strong ties’
- Network topology & contagion

  Simple contagion: Random and small-world; and hubs of SF network

  Complex contagion: Clustered network; not the hubs of SF network
- Social tipping point and finding the ‘critical mass’

  Innovation needs to be ‘self-sustaining’ to reach the whole network
- Social contagion experiments

Questions?