Universiteit Utrecht

summerschool UTRECHT

# Diffusion in Networks

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Jiamin Ou

Summer School: Network Science
Day 5, Morning Session
2023

# Introducing ourselves

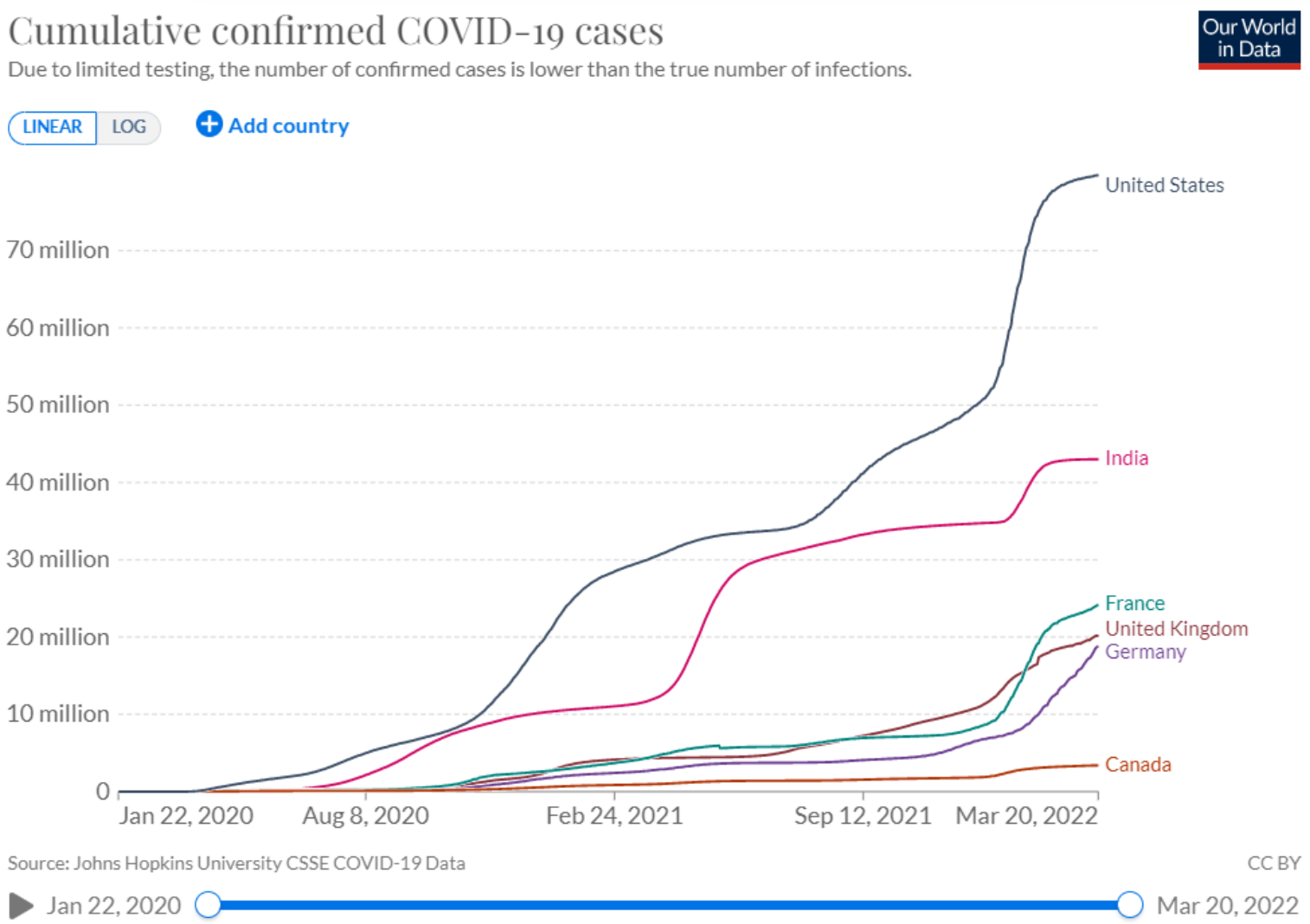
- Vincent Buskens: prof. of sociology; interested in effects of social networks on behavior: cooperation, trust etc.

- Jiamin Ou: assistant professor, interested in dynamics of sustainable behavior, energy/emission models

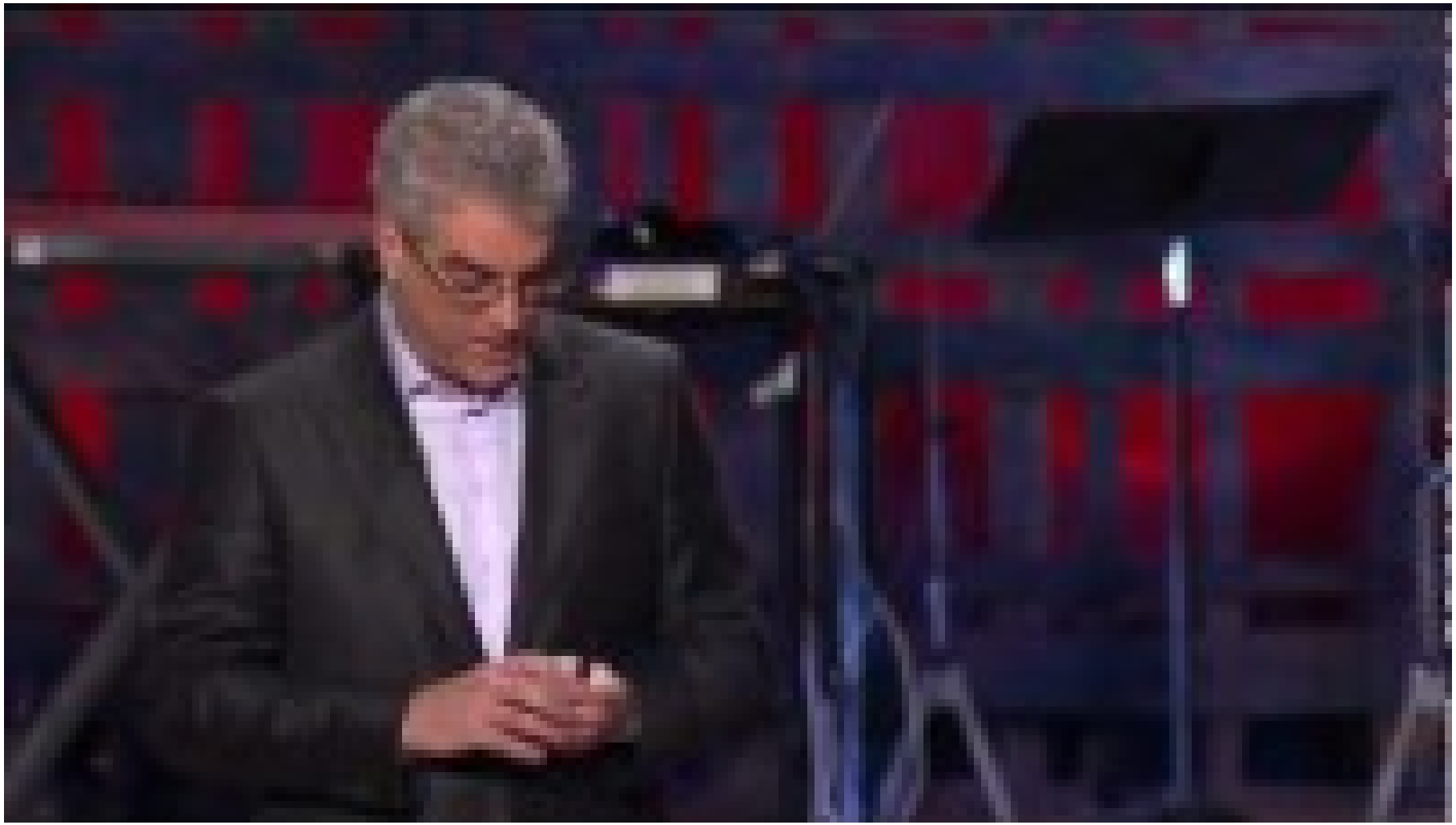
# Simple contagion

## The spread of COVID in a human network

- **COVID 19**: From patient 0 in Dec 2019 to 470 million cases till now



# Nicholas Christakis realizing the importance of networks



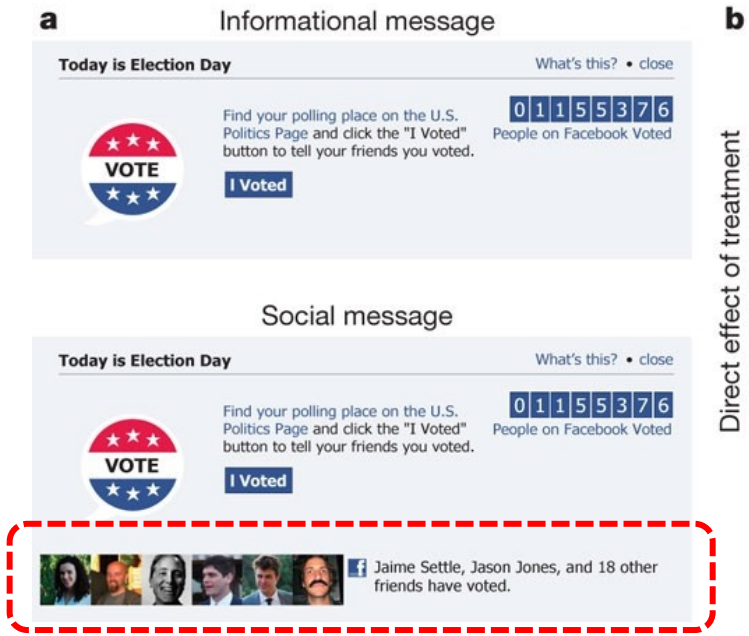
# The spread of obesity in social network of 12,067 people from 1971 to 2003 (“Framingham Heart Study”)

- A person’s chance of being obese increased by **57%** (95% confidence interval [CI], 6 to 123) if he or she has a **friend** who is obese.
- 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 neighbours** in the immediate geographic location.
- Persons of the **same sex** had relatively **greater influence** on each other as compared with those of the opposite sex.

When your close ones gain weight, so will you ☹

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

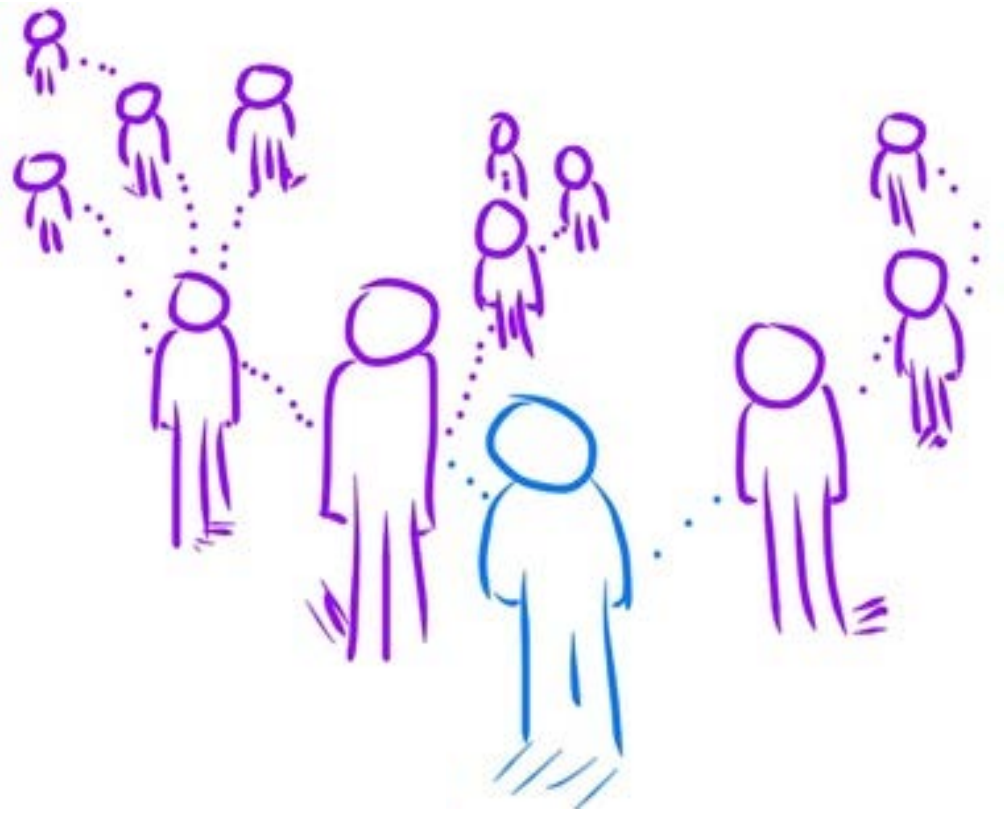
A controlled experiment for US Facebook users during the 2010 US congressional elections





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

# We are highly social creatures that make belief/behavior/health condition contagious…



"Tell me who your friends are and I'll tell you who you are."

Many mechanism at work that cause similarities between connected people

- Contagion

- Selection

- Common context / third variables

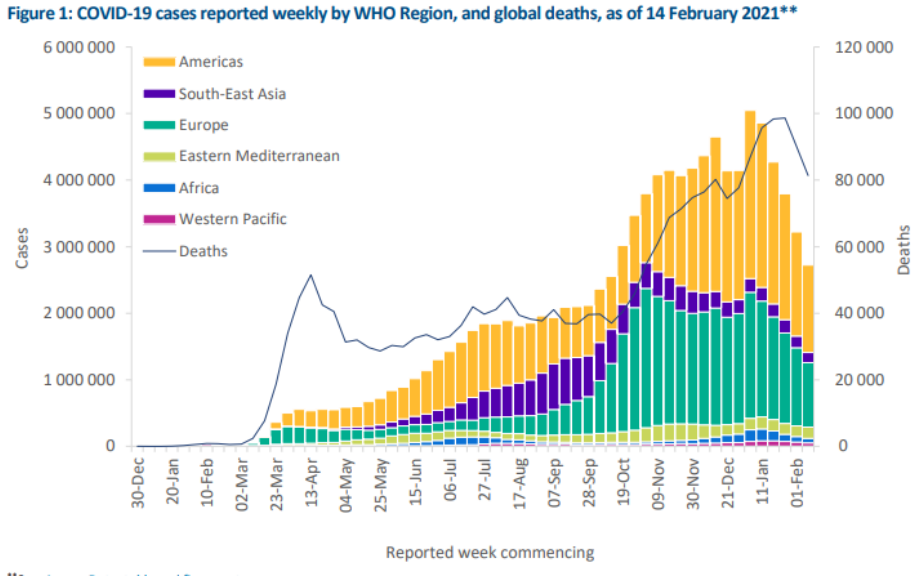
- Social dynamics

We will focus on the contagion mechanism today

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 find out:

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

- Can we depict the contagion process in numerical models?

# Today's programe

- **Simple contagion**

  Mechanism and the strength of 'weak ties'

- **Diffusion model for simple contagion**

  Independent cascade model and other variants

- **Complex contagion**

  Mechanism and the strength of 'strong ties'

- **Diffusion model for complex contagion**

  Threshold model

# Mechanism of simple contagion

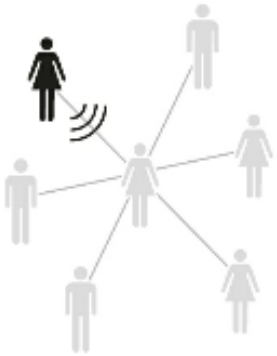
- Single contact sufficient for transmission

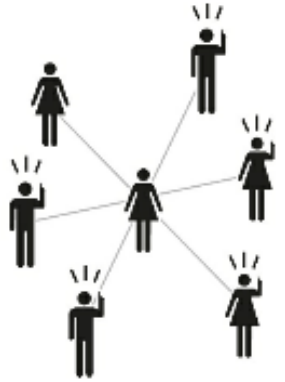
- Examples

Epidemic

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

Job information



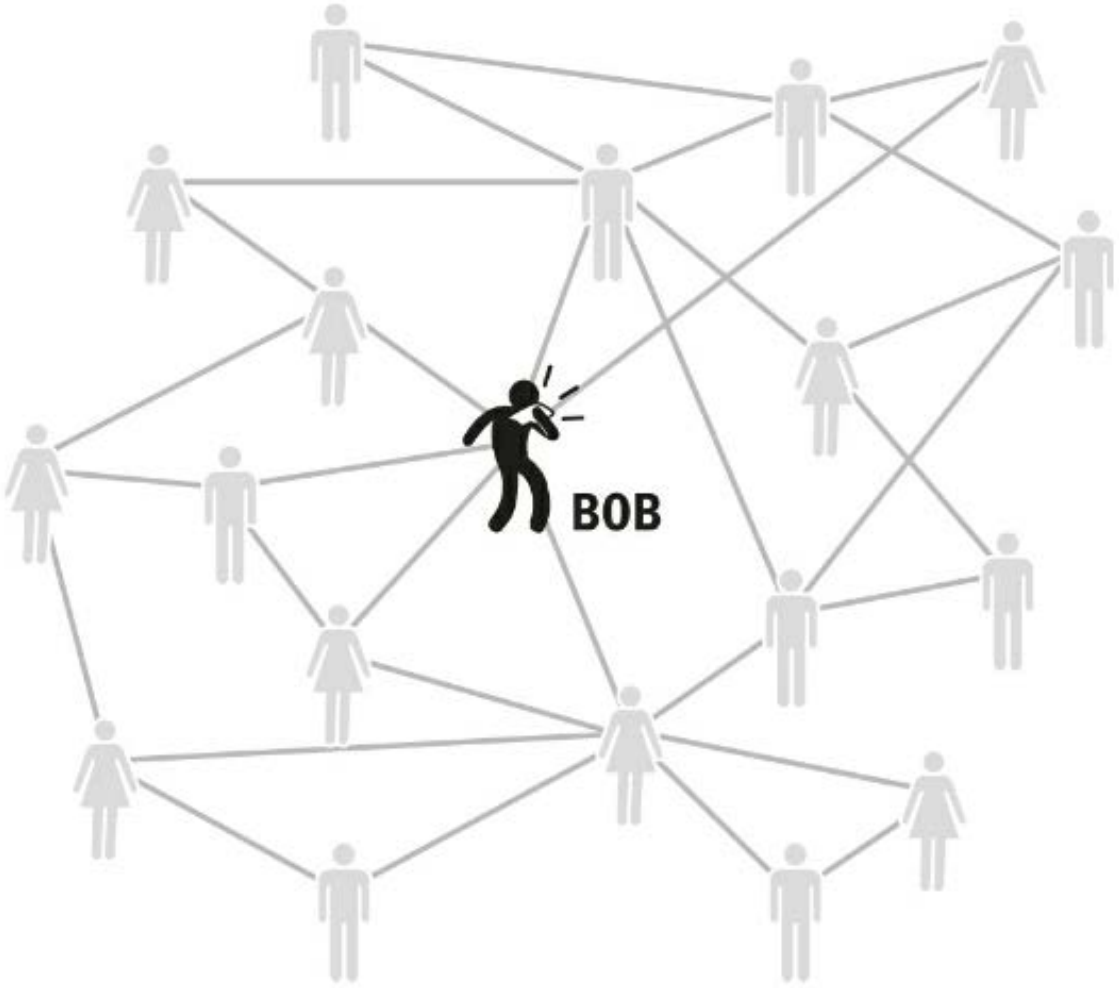


# Diffusion in social network under simple contagion

**Two states of people**:

**Inactivated**, susceptible to a contagion;
**Activated**, infected and can transmit the contagion to others

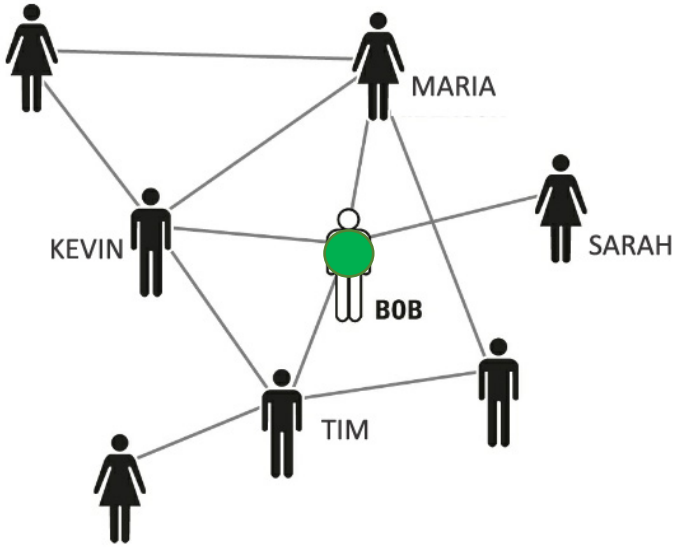
Bob is ‘patient 0’ and can pass the virus/information with probability $\beta$



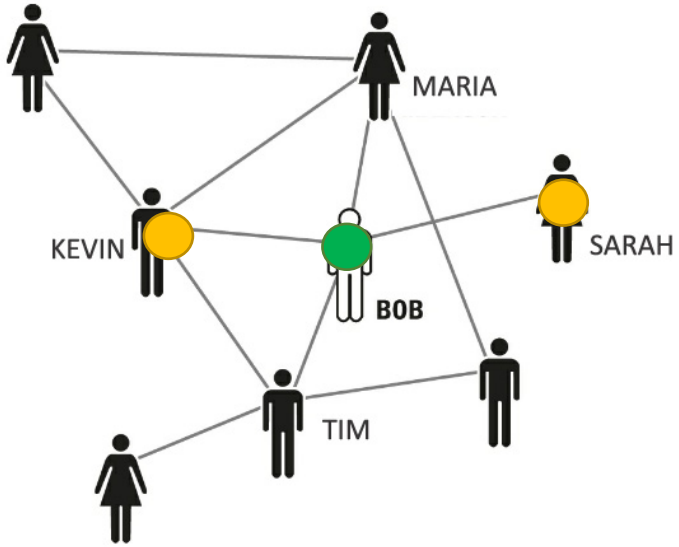
# Diffusion in social network under simple contagion

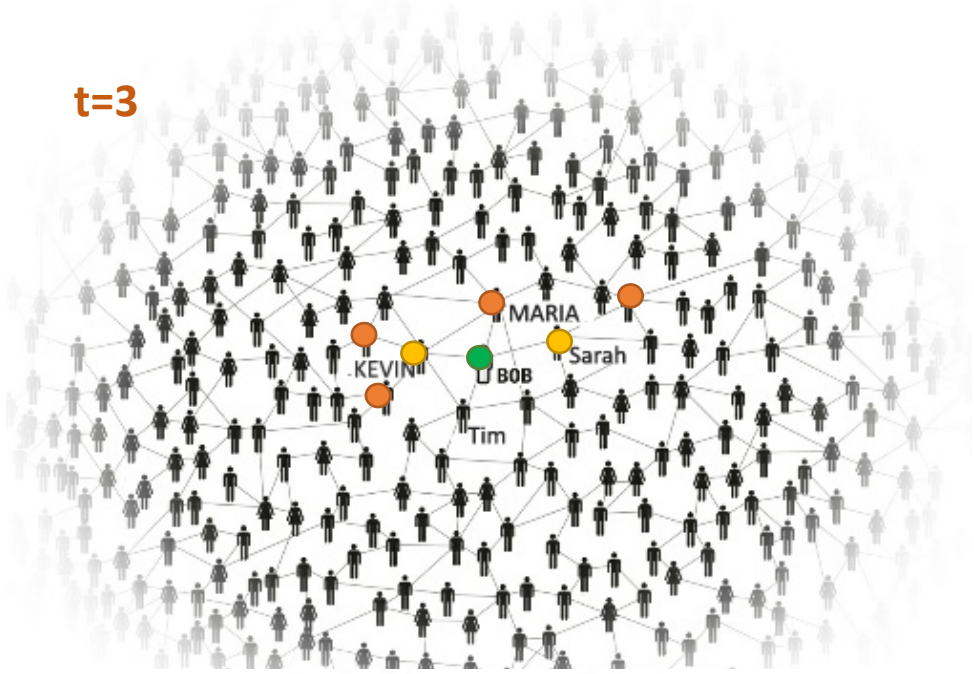
*ß=50%*

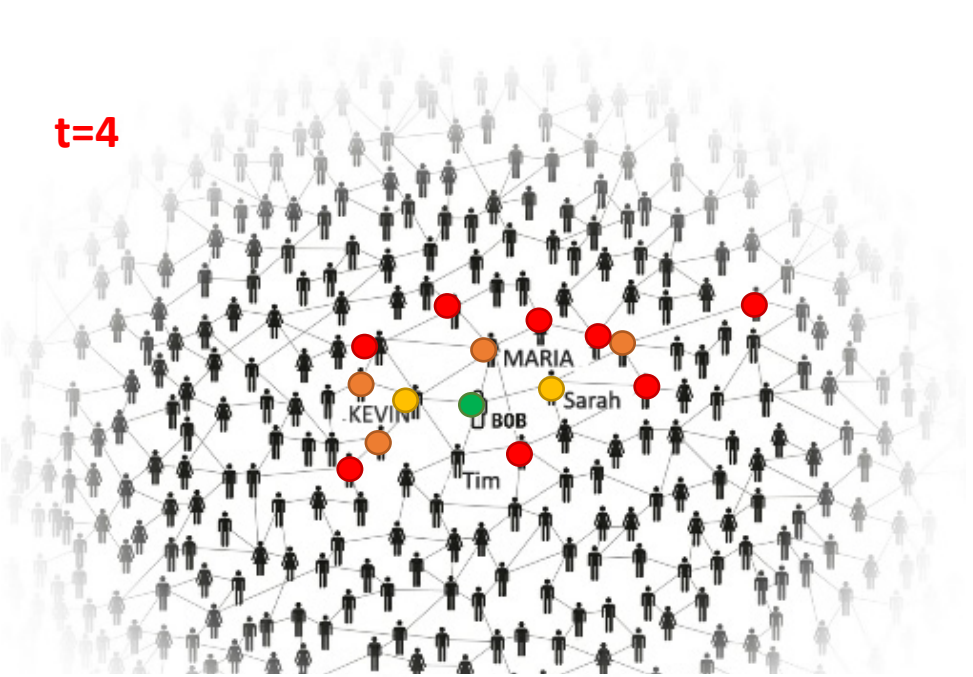
t=1

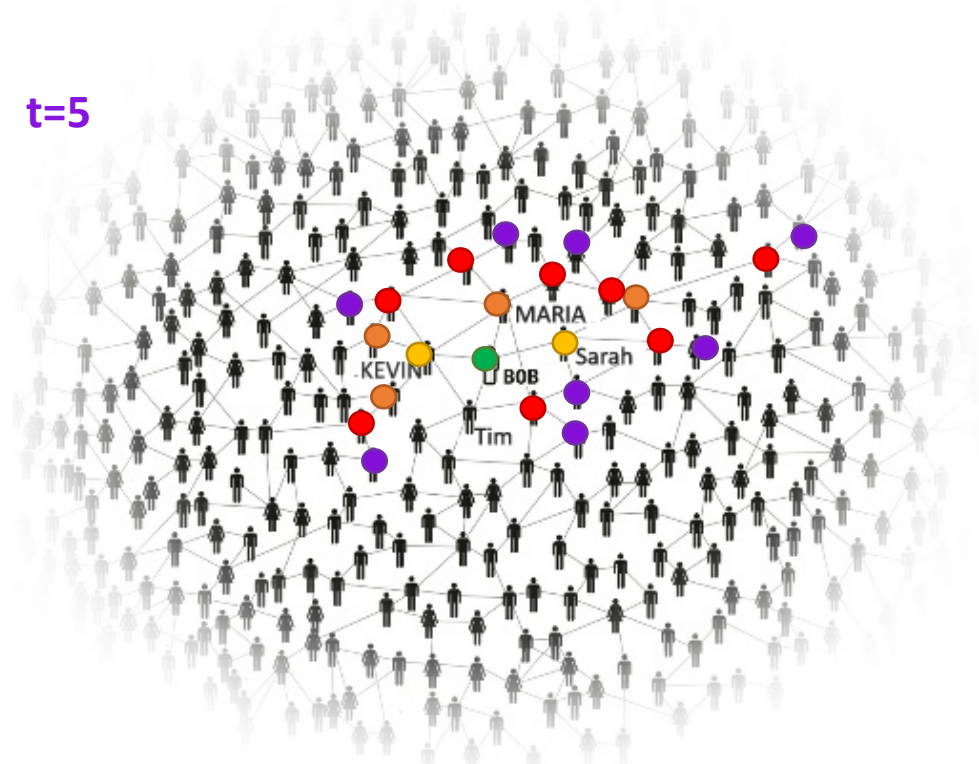


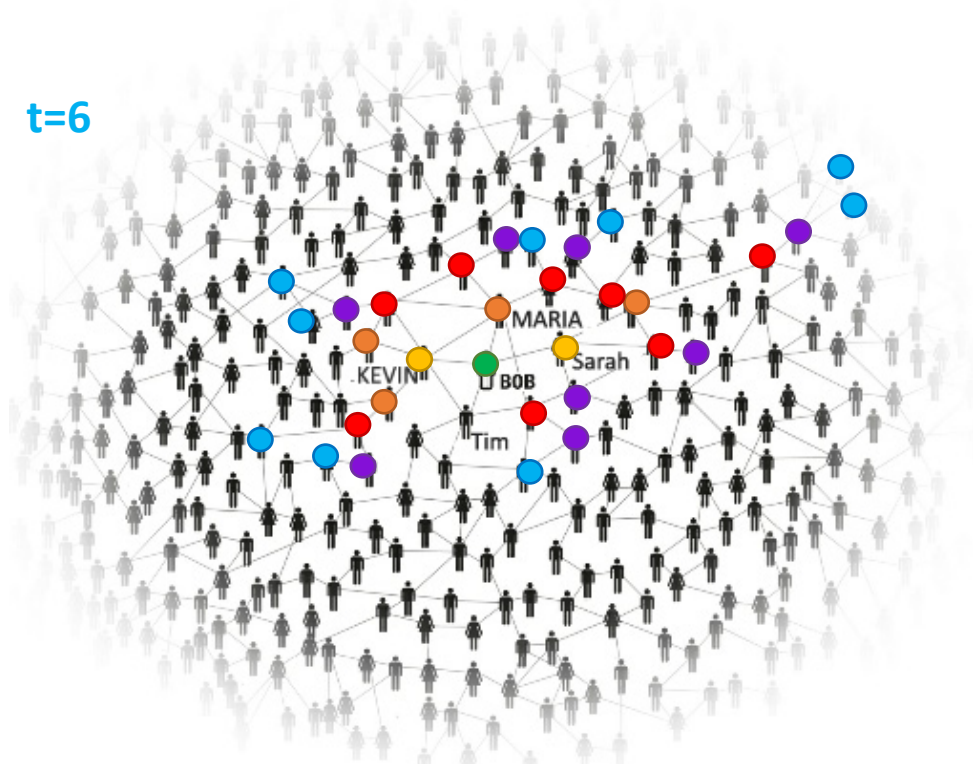

t=2




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

# Today's programe

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  Mechanism and the strength of 'weak ties'

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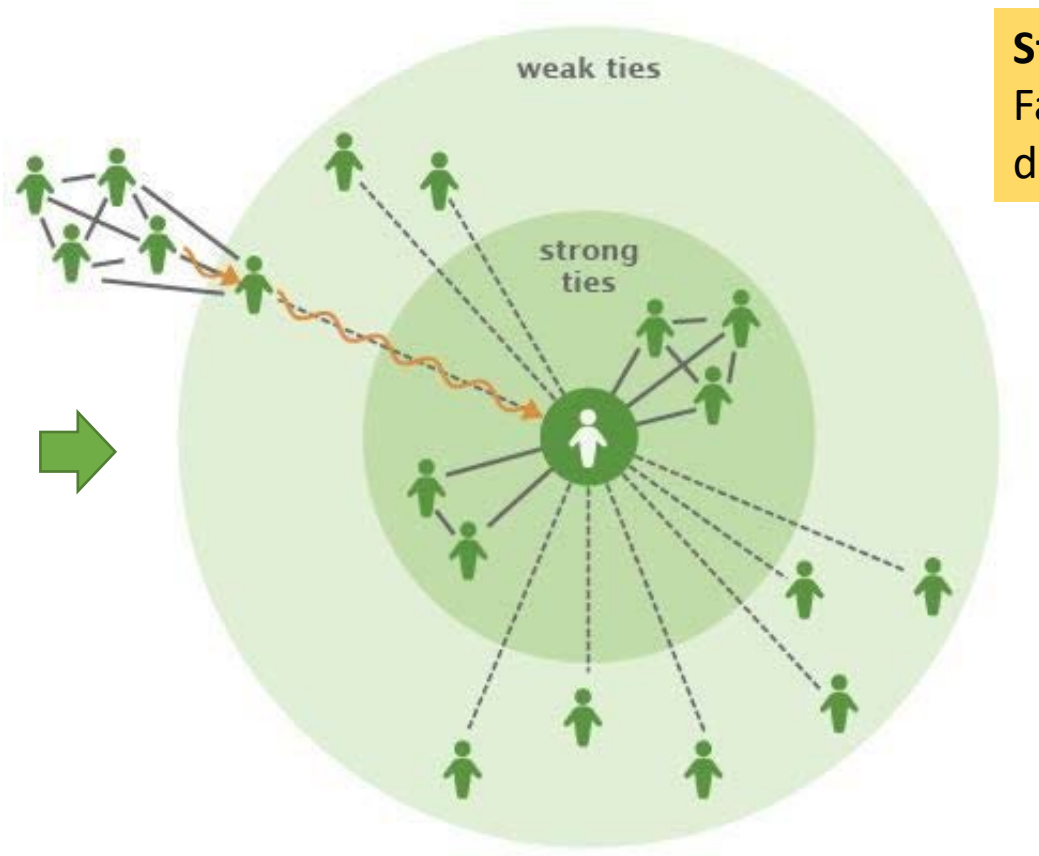
  Threshold model

# 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**

# “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.

# Is LinkedIn making you more successful?

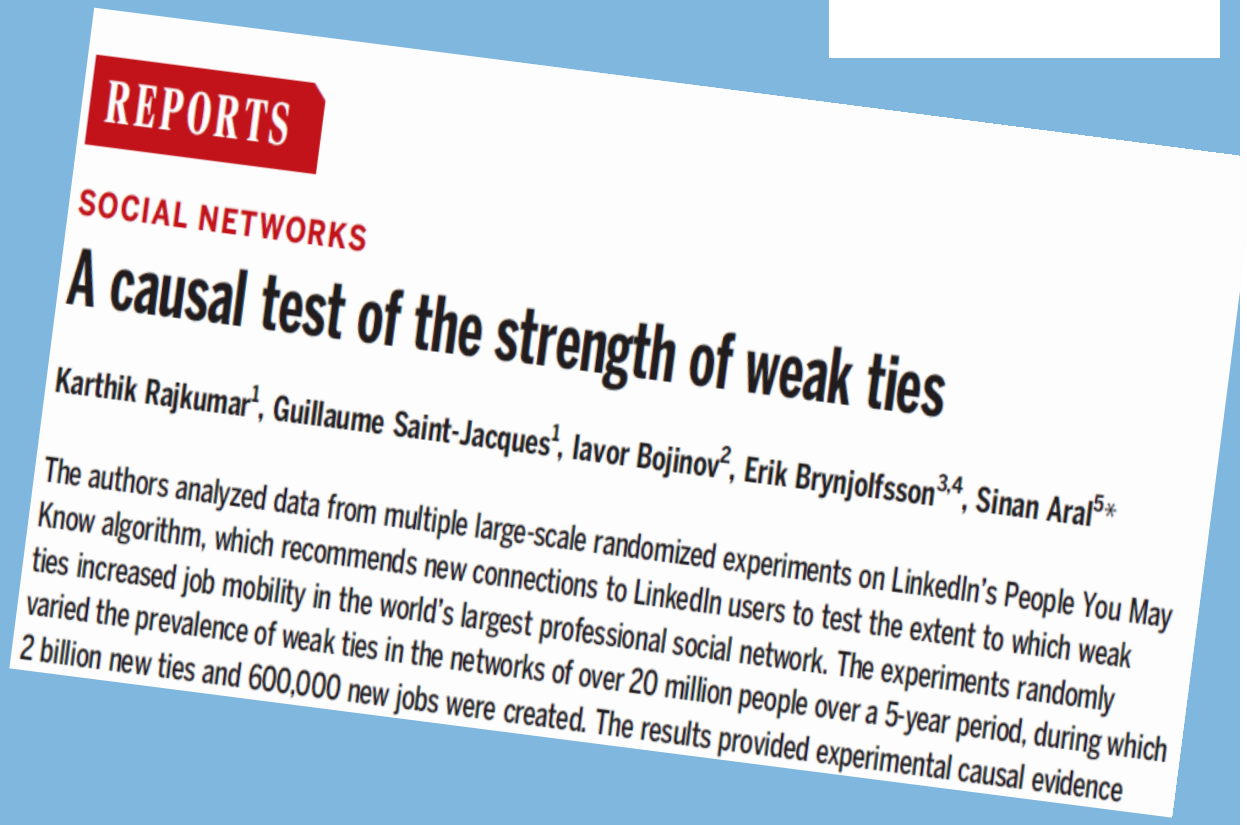
- Mission of LinkedIn “connect the world’s professionals to make them more productive and successful.”
- Major social ties in LinkedIn: acquaintances or former colleagues
- Informational benefits from the usage of LinkedIn, Twitter, Facebook among a representative sample of Dutch online users
- Using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

LinkedIn, Facebook and Twitter:
Weak or strong ties?

Sonja Utz, 2016. Is LinkedIn making you more successful? The informational benefits derived from public social media. New Media & Society, 18, 2685 –2702

# Is LinkedIn making you more successful?

- Experiment with the “People You May Know”-algorithm
- Some receive more weak tie suggestions, others more strong tie suggestions.
- Weak (and medium) ties have the strongest effects on job transmission



REPORTS

SOCIAL NETWORKS

## A causal test of the strength of weak ties

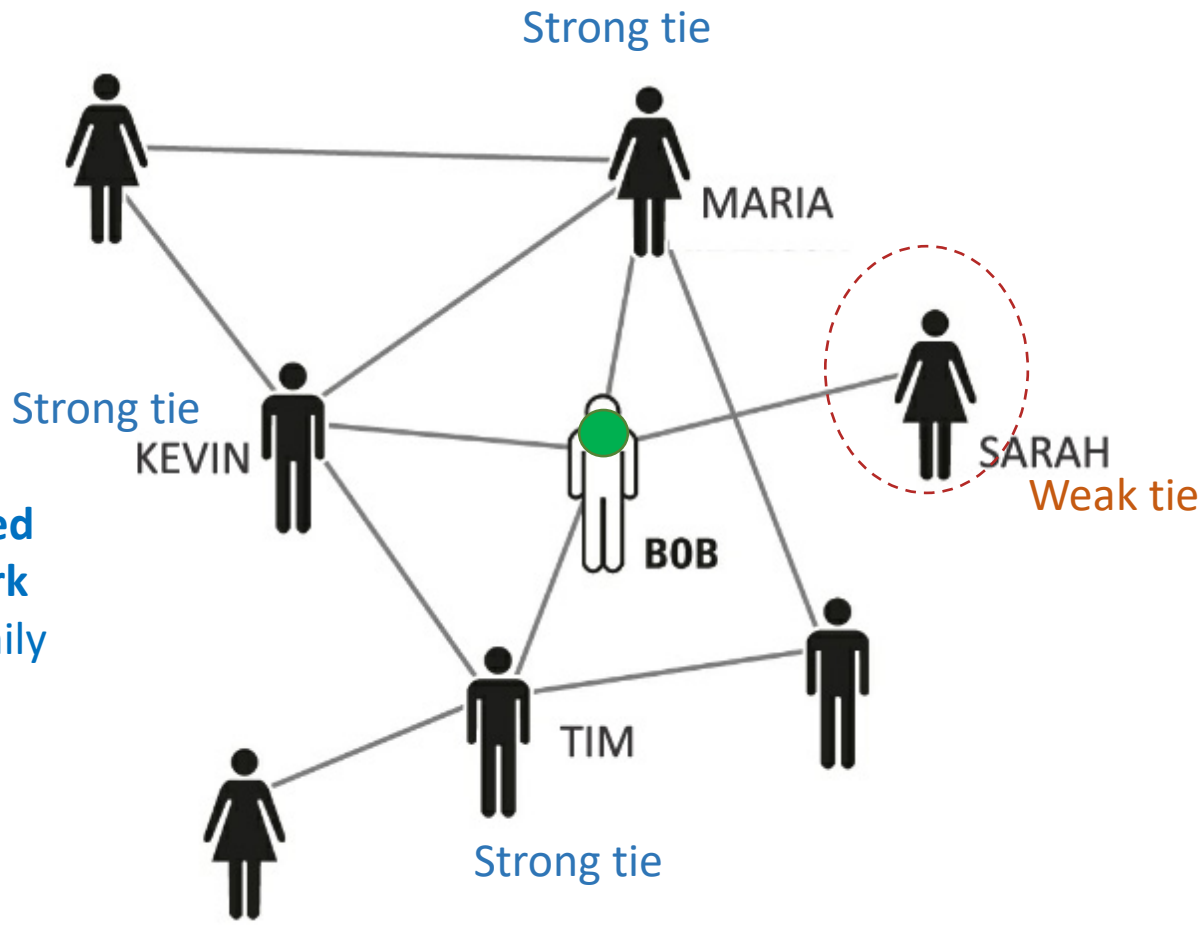
Karthik Rajkumar[1], Guillaume Saint-Jacques[1], Iavor Bojinov[2], Erik Brynjolfsson[3,4], Sinan Aral[5]*

The authors analyzed data from multiple large-scale randomized experiments on LinkedIn's People You May Know algorithm, which recommends new connections to LinkedIn users to test the extent to which weak ties increased job mobility in the world's largest professional social network. The experiments randomly varied the prevalence of weak ties in the networks of over 20 million people over a 5-year period, during which 2 billion new ties and 600,000 new jobs were created. The results provided experimental causal evidence

Science, September 2022

# 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

1st round: Bob

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

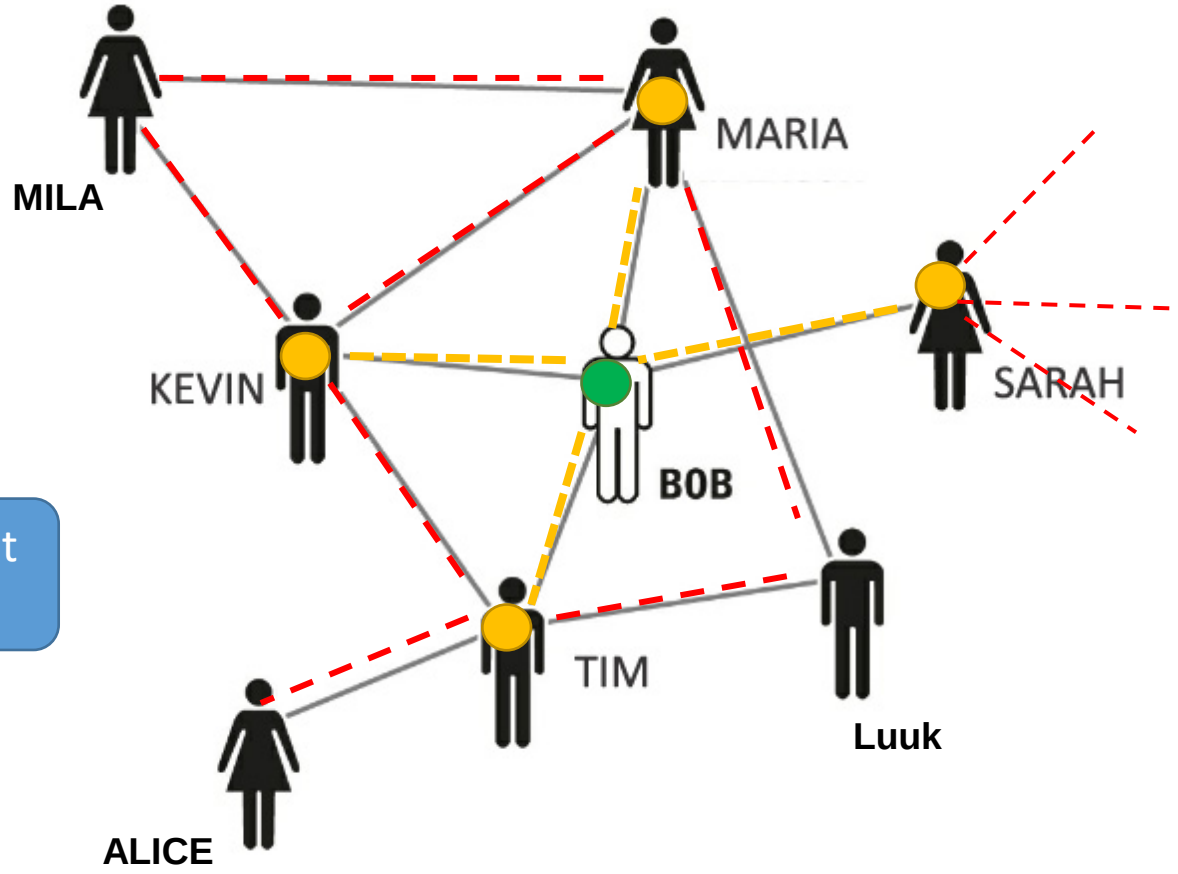
3rd round:

Kevin→ Mila, Maria

Maria→ Kevin, Mila, Luuk

Tim→ Kevin, Luuk, Alice

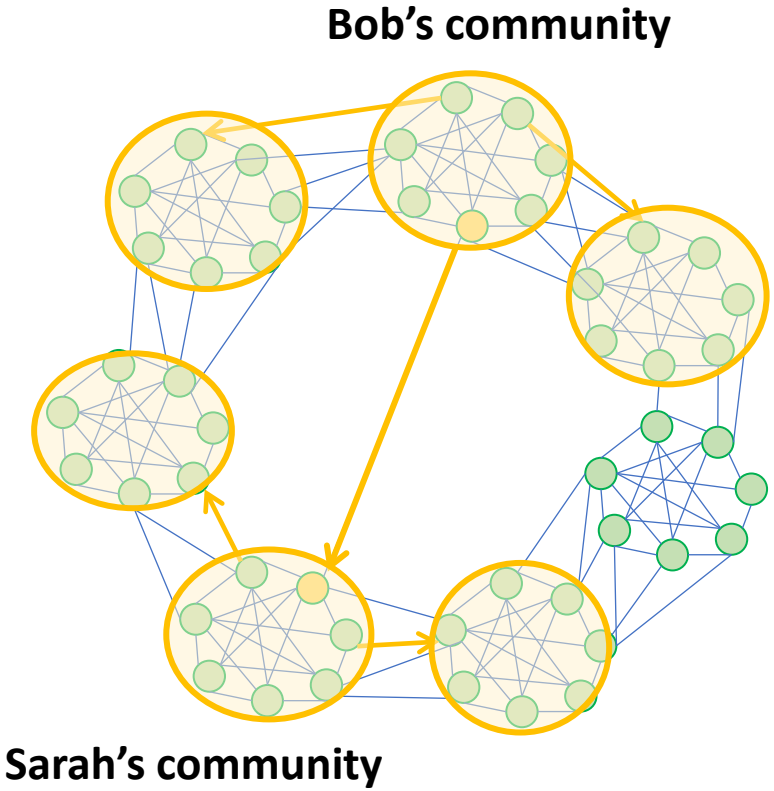
Sarah → to her other contacts




I’ve heard about it already!

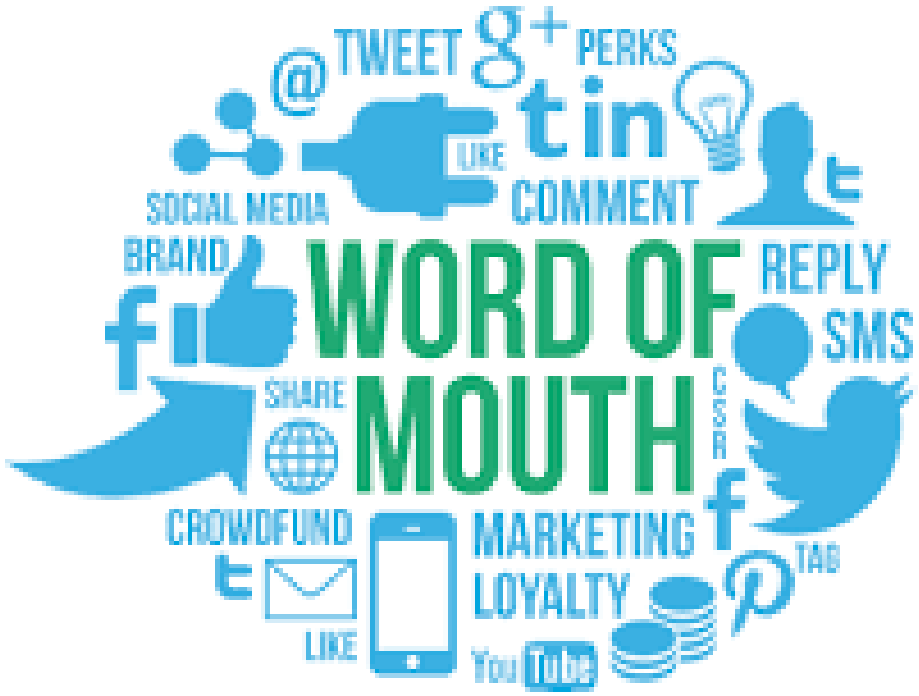
**A lot of *redundant information* within the close community of Bob, which is *not efficient*.**

# Diffusion of simple contagion via weak tie




Under simple contagion, the only tie between Bob and Sarah *can* spread the rumor/virus to Sarah's community and fasten the diffusion process

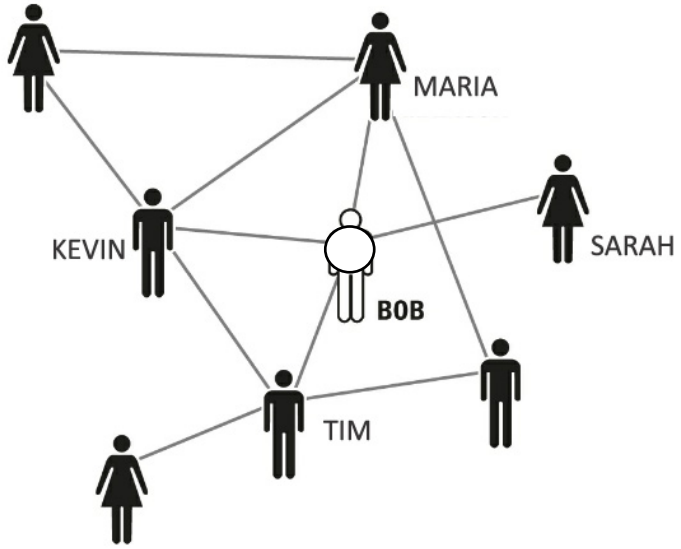
Now Bob tries out a new product and loves it.
He shares with other friends.



# Independent Cascade Model

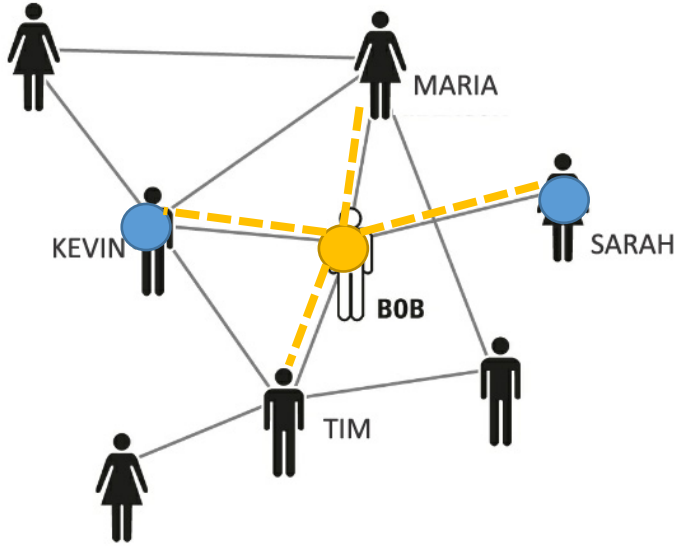
- Nodes can have two states — active ($\boldsymbol{S}=1$) and inactive states ($\boldsymbol{S}=0$); once activated, can not be inactive again (e.g., Bob used the product)
- At time $t$=0, $\boldsymbol{k}$ nodes are selected (i.e., activated). These nodes are called "*seed nodes*"
- When a node $\boldsymbol{u}$ is activated at time $\boldsymbol{t}$, *it can activate neighbors* $\boldsymbol{v}$ *in subsequent time points* (Bob can talk about the same product with his friends again and again). The success depends on the probability $\boldsymbol{p_{uv}}$ assigned to the edge connecting $\boldsymbol{u}$ and $\boldsymbol{v}$. ($\boldsymbol{p_{uv}}$ can be the same for every edge or different by edges)
- Stop when all the nodes are activated or the number of activated nodes is saturated.

$p_{uw}$=60% for all edges




*t=0*

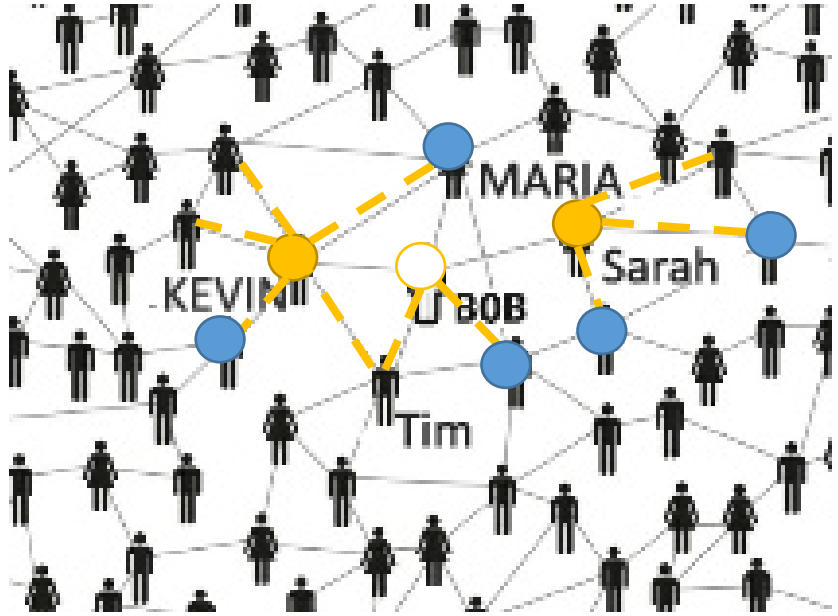
All nodes are inactive;
Bob is activated.




*t=1*

Check out each neighbor of Bob:
Generate a random number [0,1], if smaller than 60%, activated; Otherwise, remains inactive.

Bob-Kevin: random number is 0.5, Kevin is activated;
Bob-Tim: random number is 0.7, Tim is not activated;
Bob-Sarah: random number is 0.1, Sarah is activated;
Bob-Maria: random number is 0.9, Maria is not activated.




*t=2*

Bob and the activated neighbors Kevin and Sarah can now activate others again.

# Various other versions

- How long will somebody continue to convey the message: forever, one period, or something in between?
- Transition probabilities: homogeneous, heterogeneous?
- Epidemic models as the SIR model are also very similar:
  - Susceptible (S): healthy people that can catch the virus from infected people, with probability $\beta$;
  - Infected (I): people who have been infected and are capable of infecting susceptible individuals;
  - Recovered (R): people who have been infected and have recovered.

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

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  Threshold model