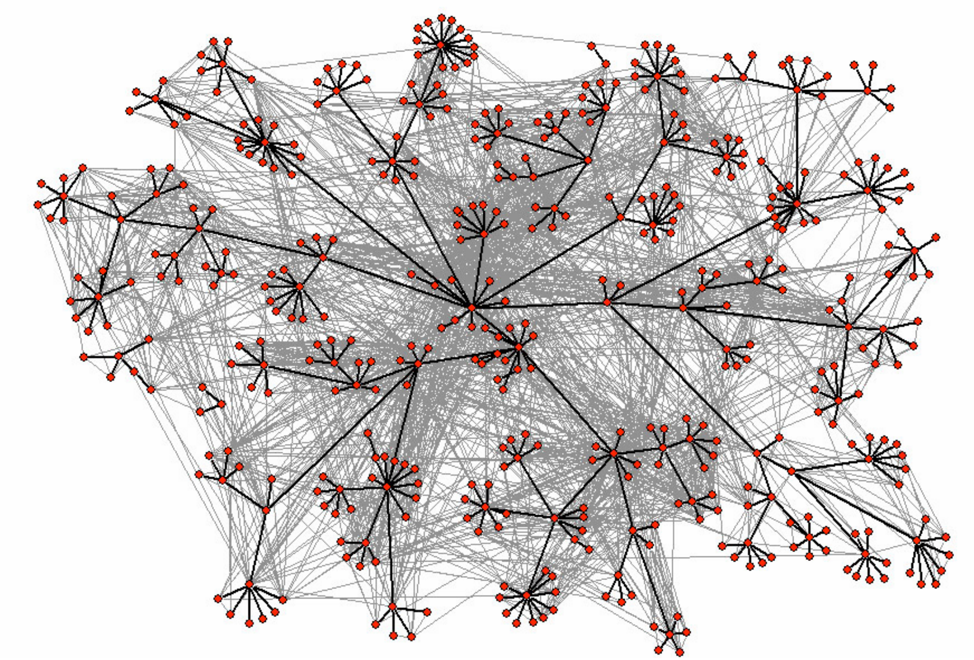
Epidemics in Social Networks



Epidemic Processes

Epidemics, Influence, Propagation

- Viruses, diseases
- Online viruses, worms
- Fashion
- Adoption of technologies
- Behavior
- Ideas

Example: Ebola virus

- First emerged in Zaire 1976 (now Democratic Republic of Kongo)
- Very lethal: it can kill somebody within a few days
- A small outbreak in 2000
- From 10/2000 – 01/2009 173 people died in African villages

Example: HIV

- Less lethal than Ebola
- Takes time to act, lots of time to infect
- First appeared in the 70s
- Initially confined in special groups: homosexual men, drug users, prostitutes
- Eventually escaped to the entire population

Example: Melissa computer worm

- Started on March 1999
- Infected MS Outlook users
- The user
  - Receives email with a word document with a virus
  - Once opened, the virus sends itself to the first 50 users in the outlook address book
- First detected on Friday, March 26
- On Monday had infected >100K computers

Example: Hotmail

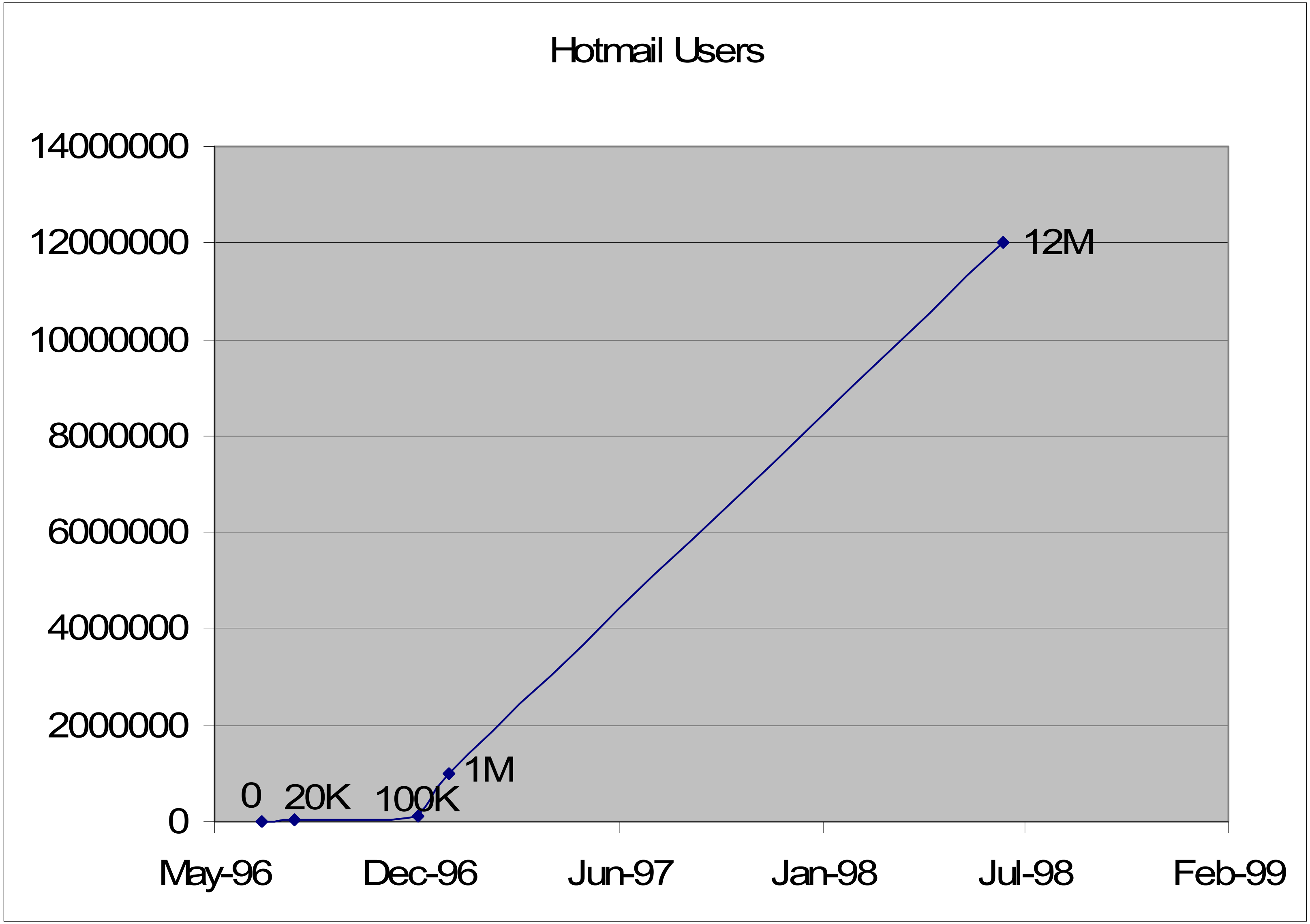
- Example of Viral Marketing: Hotmail.com

- Jul 1996: Hotmail.com started service
- Aug 1996: 20K subscribers
- Dec 1996: 100K
- Jan 1997: 1 million
- Jul 1998: 12 million

Bought by Microsoft for $400 million

Marketing: At the end of each email sent there was
a message to subscribe to Hotmail.com
“Get your free email at Hotmail"

Example: Hotmail



The Bass model

- Introduced in the 60s to describe product adoption
- Can be applied for viruses
- No network structure

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

- F(t): Ratio of infected at time t
- p: Rate of infection by outside
- q: Rate of contagion

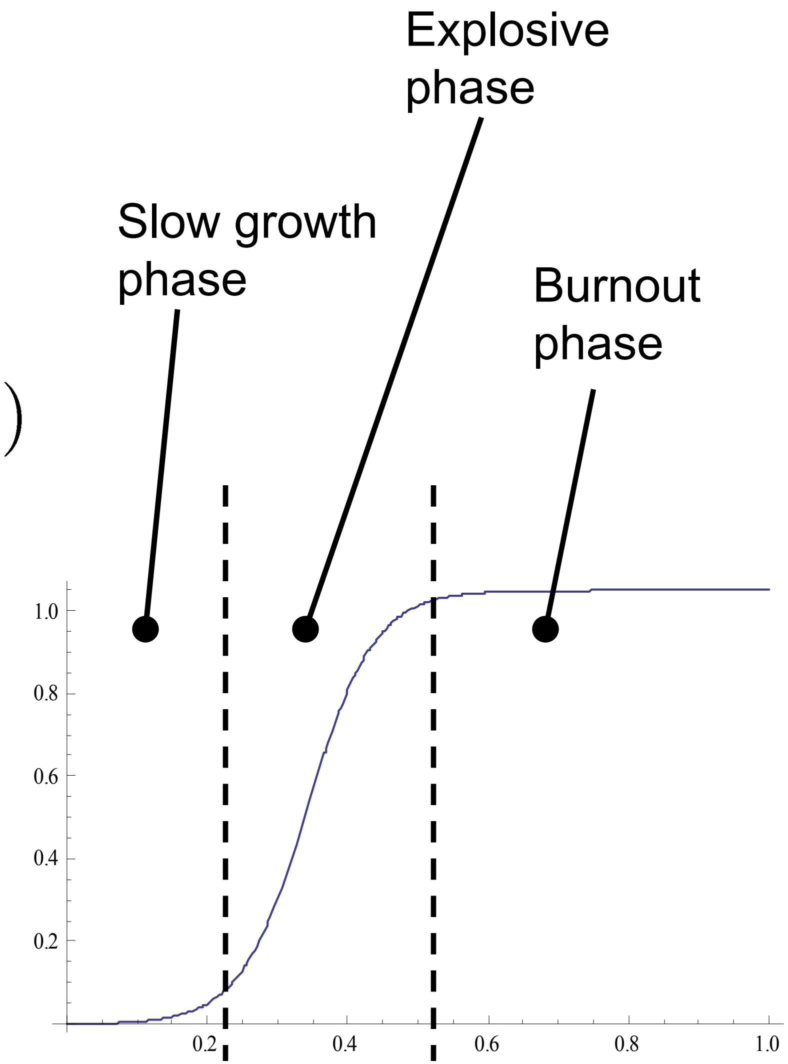
$$\begin{aligned} \frac{dF}{dt} &= p(1-F) + qF(1-F) \\ &= (p+qF)(1-F) \end{aligned}$$

The Bass model

- F(t): Ratio of infected at time t
- p: Rate of infection by outside
- q: Rate of contagion

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

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

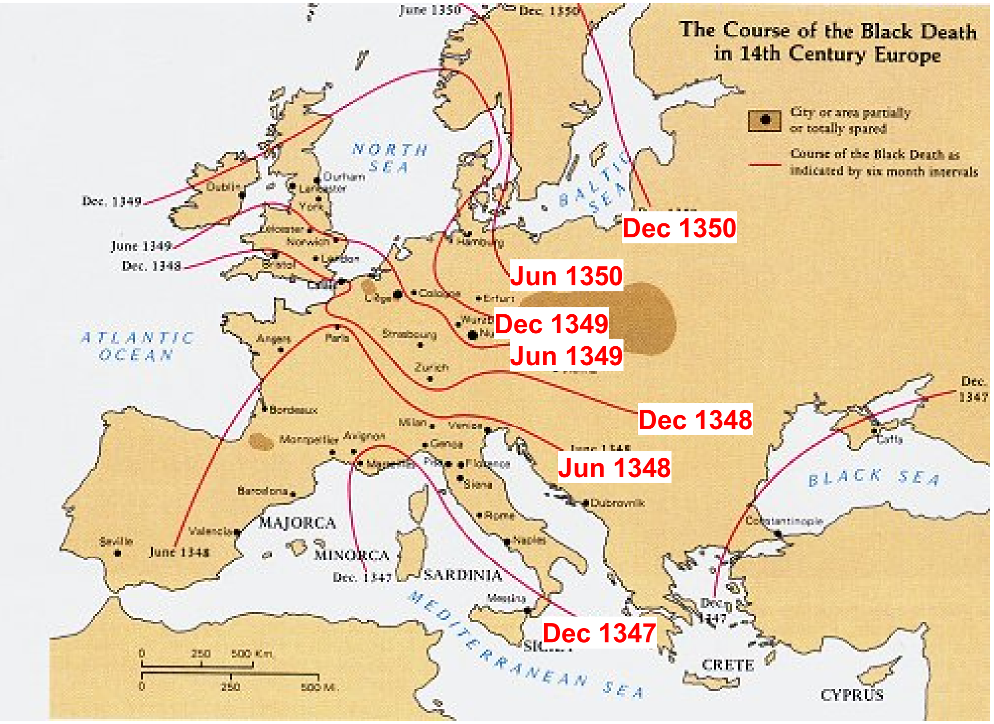


Network Structure

- The Bass model does not take into account network structure
- Let’s see some examples

Example: Black Death (Plague) (Pestilenza)

- Started in 1347 in a village in South Italy from a ship that arrived from China
- Propagated through rats, etc.



Example: Mad-cow disease

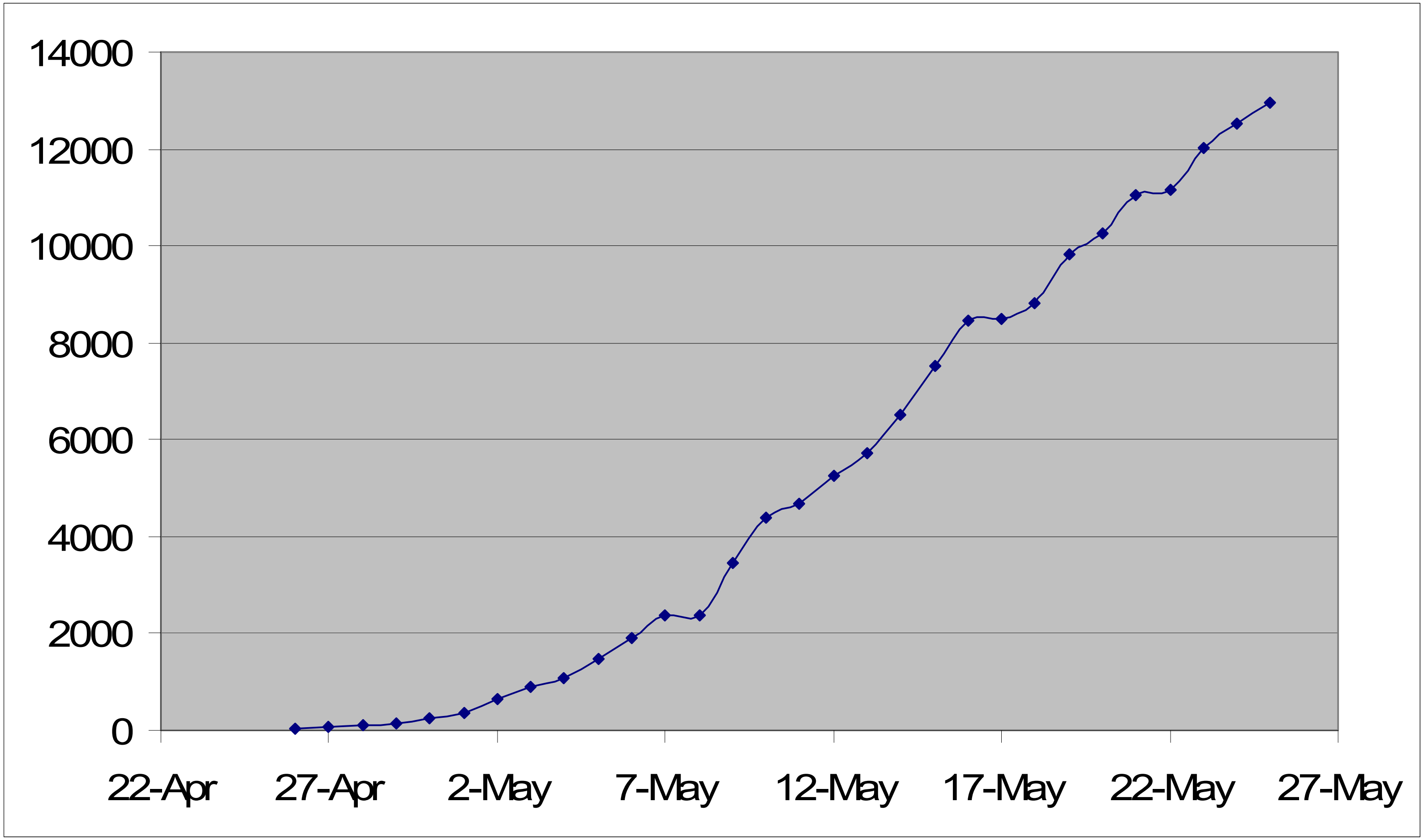
- Jan. 2001: First cases observed in UK
- Feb. 2001: 43 farms infected
- Sep. 2001: 9000 farms infected

- Measures to stop: Banned movement, killed millions of animals

Example: H1N1

http://www.youtube.com/watch?v=tWKdSQiIFj4

Example: H1N1

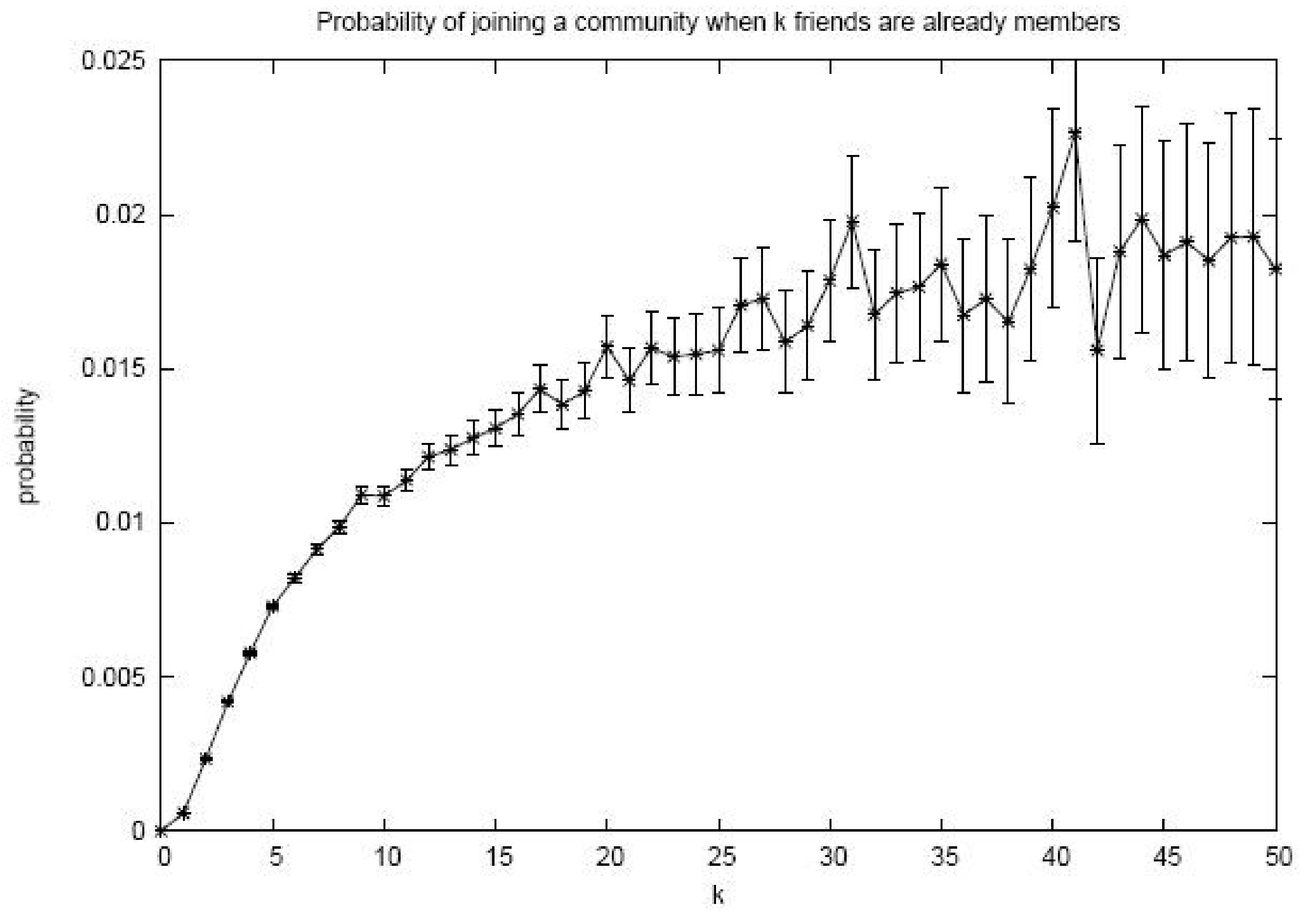


Network Impact

- In the case of the plague it moves on the plain
- In the mad cow we have weak ties, so we have a small world
  - Animals being bought and sold
  - Soil from tourists, etc.

- To protect:
  - Make contagion harder
  - Remove weak ties (e.g., mad cows, HIV)

Example: Join an online group

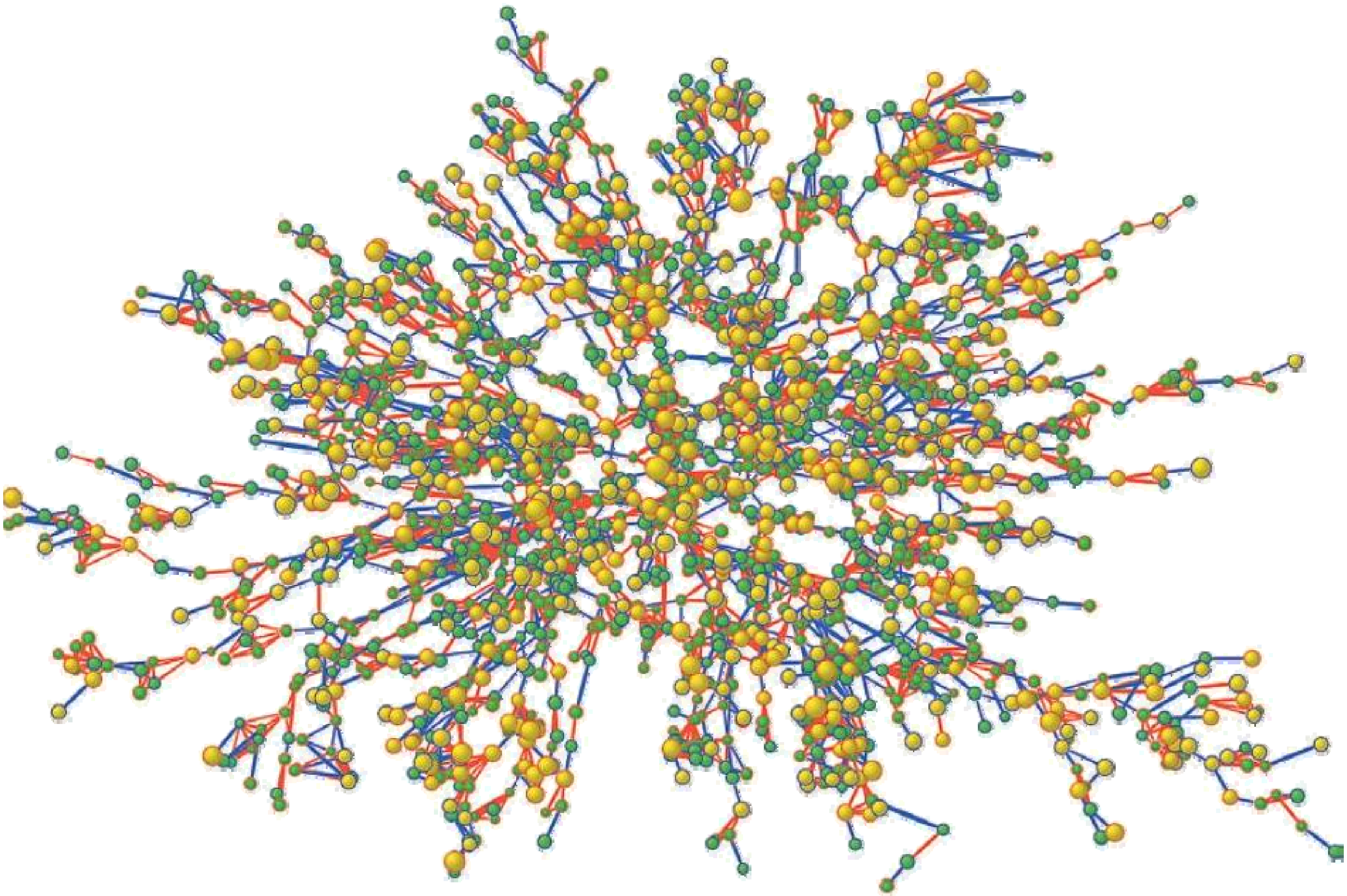


Example: obesity study

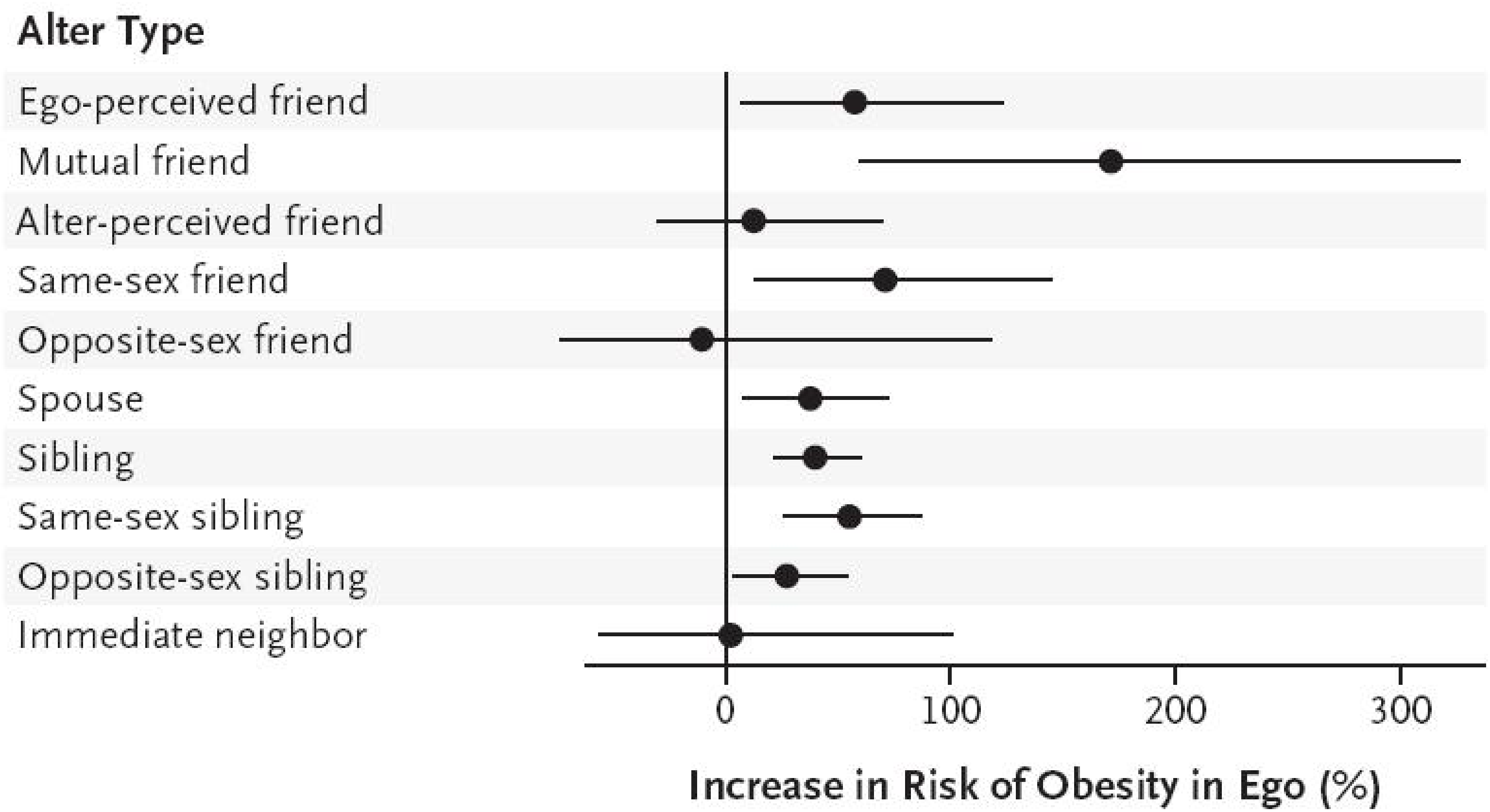
Christakis and Fowler, "The Spread of Obesity in a Large Social Network over 32 Years", New England Journal of Medicine, 2007.

- Data set of 12,067 people from 1971 to 2003 as part of Framingham Heart Study
- Results
  - Having an obese friend increases chance of obesity by 57%.
  - obese sibling $\rightarrow$ 40%, obese spouse $\rightarrow$ 37%
- Methodology
  - Logistic regression, taking many attributes into account (e.g., age, sex, education level, smoking cessation)
  - Taking advantage of data that is available over time
  - "edge-reversal test"

Obesity study



Obesity study



Modeling Approaches

Two main types of mathematical models

Game theoretic

- Users are rational players in a “game”
- Answer **why**

Probabilistic

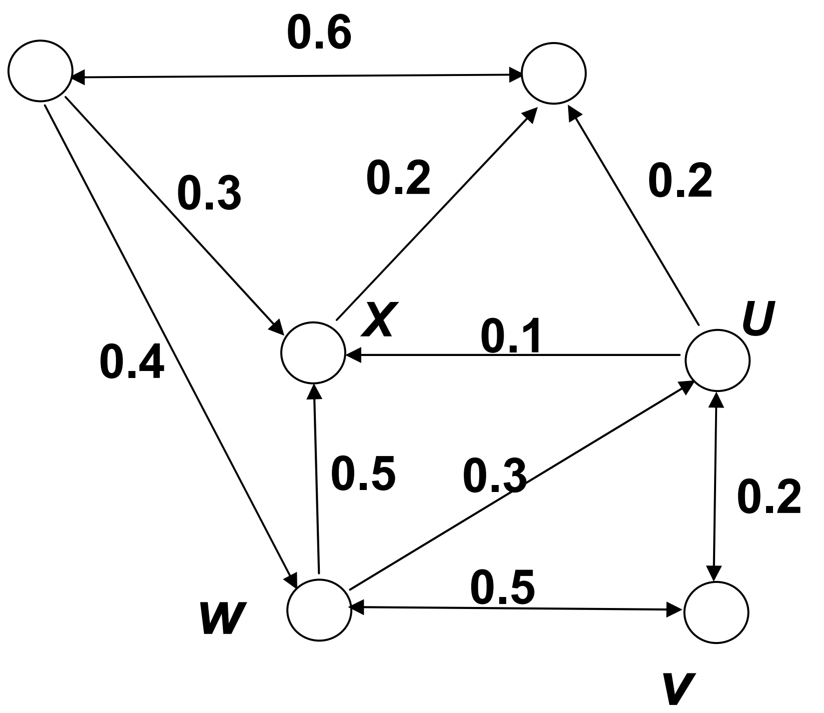
- There is a random process that governs the user actions
- Allow fitting the model to data to estimate parameters
- Can be used to make predictions
- Answer **how**

Models of Influence

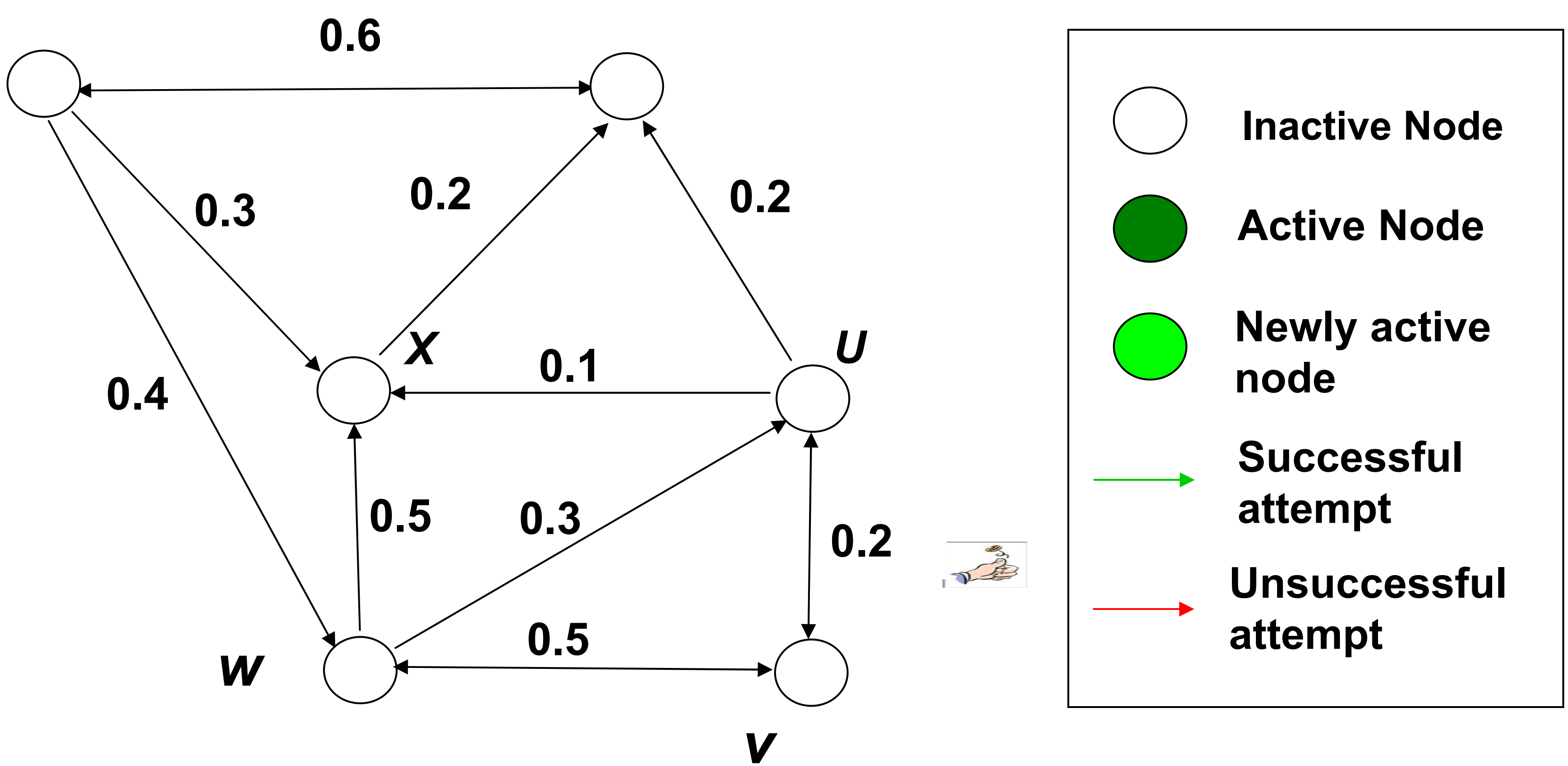
- We saw that often decision is correlated with the number/fraction of friends
- This suggests that there might be influence: the more the number of friends, the higher the influence
- Models to capture that behavior:
  - Linear threshold model
  - Independent cascade model

Independent Cascade Model

- We have a weighted directed graph with weight p_{uv} on edge (u,v).
- When node u becomes active, it has a single chance of activating each currently inactive neighbor v.
- The activation attempt succeeds with probability p_{uv}.



Example



Stop!

Linear Threshold Model

- A node *u* has threshold θ_u ~ Uniform[0,1]
- A node *v* is influenced by each neighbor *u* according to a *weight* b_{uv} such that

$$\sum_{u:(u,v)\in E} b_{uv} \leq 1$$

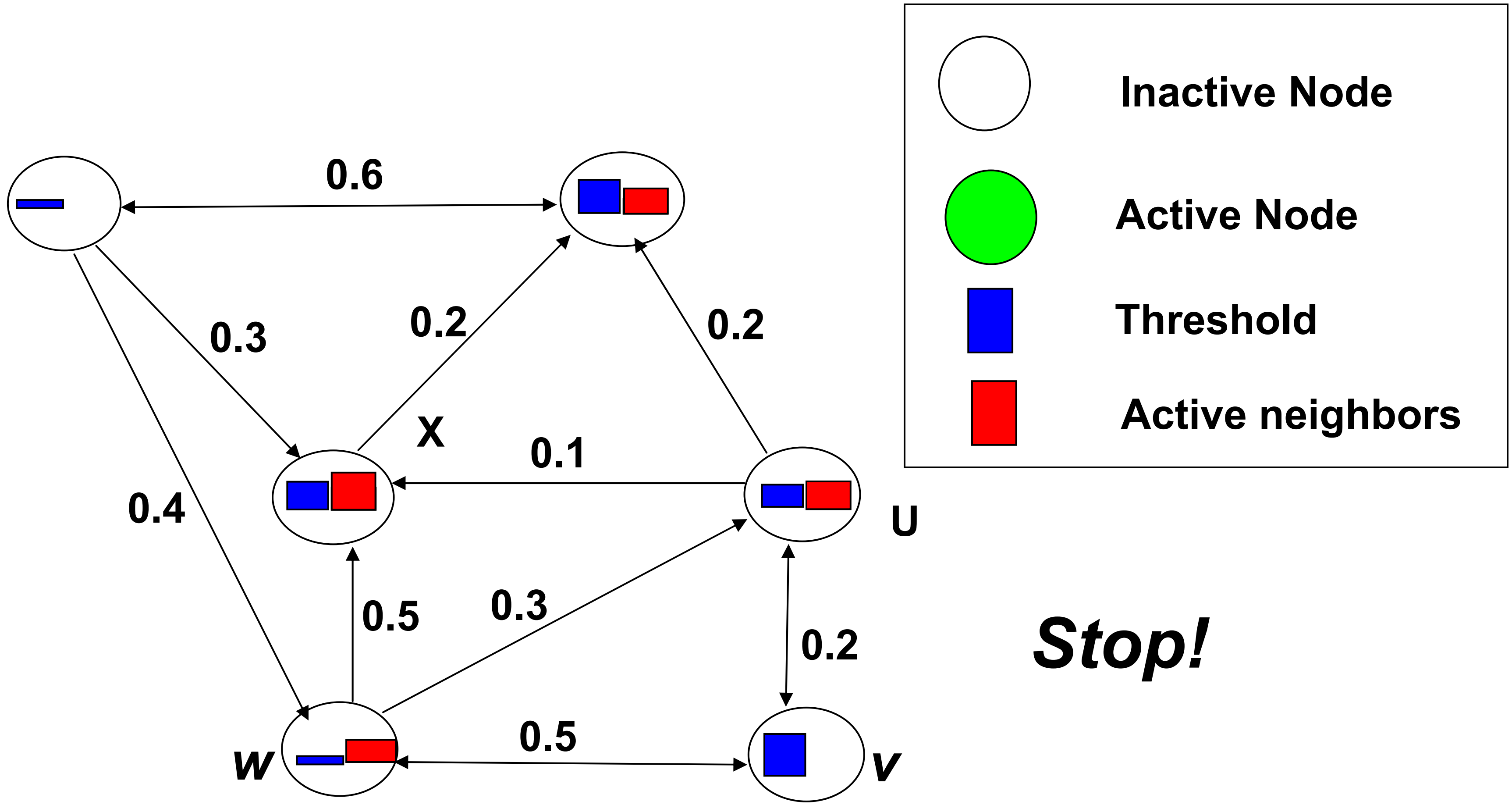
- A node *v* becomes active when at least

(weighted) θ_v fraction of its neighbors are active

$$\sum_{\substack{u:(u,v)\in E \\ u:\text{active}}} b_{uv} \geq \theta_v$$

Examples: riots, WIND / TIM

Example


0.6
0.3
0.2
0.2
X
0.1
0.4
U
0.5
0.3
0.2
0.5
w
v
Inactive Node
Active Node
Threshold
Active neighbors
Stop!

Optimization problems

- Given a particular model, there are some natural optimization problems.

1. How do I select a set of users to give coupons to in order to maximize the total number of users infected?
2. How do I select a set of people to vaccinate in order to minimize influence/infection?
3. If I have some sensors, where do I place them to detect an epidemic ASAP?