



# Analisi e Visualizzazione delle Reti Complesse

**NS16 - Cascading behaviors in networks**

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# Agenda

- Diffusion in Networks
- Modeling Diffusion through a Network
- Cascades and Clusters
- Diffusion, Thresholds, and the Role of Weak Ties
- Extensions of the Basic Cascade Model

# The diffusion of innovations

- Let's consider how new behaviors, practices, opinions, conventions, and technologies spread from person to person through a social network, as people influence their friends to adopt new ideas
- diffusion of innovation: long list of classic studies in the middle of the 20th century
  - focus on informational and network effects
- **direct benefit effects** to understand how technologies spread: incentives to adopt telephone, fax, emails based on friends that already adopted those technologies
- we need to take into account **network effects on a local network level**
- Objective of this lecture: **formulating a model for the spread of an innovation through a social network**

## A diffusion of a new behavior

- Assumption: individuals make decisions based on the choices of their neighbors
  - focus on links
- In this lecture, let's focus on **direct-benefit effects** instead of informational effects
- Natural model introduced by Stephen Morris in 2000
- Reading material:
  - [Stephen Morris. Contagion. Review of Economic Studies, 67:57–78, 2000.](#)



## Examples



VHS

VS



Betamax



VS



# A networked coordination game

- It is natural to use a **coordination game**
  - each node has a choice between two possible behaviors, A and B
  - players have an incentive to adopt the same behavior

|          |          |          |
|----------|----------|----------|
|          |          | <i>w</i> |
| <i>v</i> | <i>A</i> | <i>A</i> |
|          | <i>B</i> | <i>B</i> |

|          |          |          |
|----------|----------|----------|
|          |          | <i>w</i> |
| <i>v</i> | <i>A</i> | <i>A</i> |
|          | <i>B</i> | <i>B</i> |

|          |          |             |
|----------|----------|-------------|
|          |          | <i>w</i>    |
| <i>v</i> | <i>A</i> | <i>a, a</i> |
|          | <i>B</i> | <i>0, 0</i> |

|          |          |             |
|----------|----------|-------------|
|          |          | <i>w</i>    |
| <i>v</i> | <i>A</i> | <i>0, 0</i> |
|          | <i>B</i> | <i>b, b</i> |

## A networked coordination game

$p$  fraction of neighbors adopting  $A$

$1 - p$  fraction of neighbors adopting  $B$

$d$  is the number of neighbors

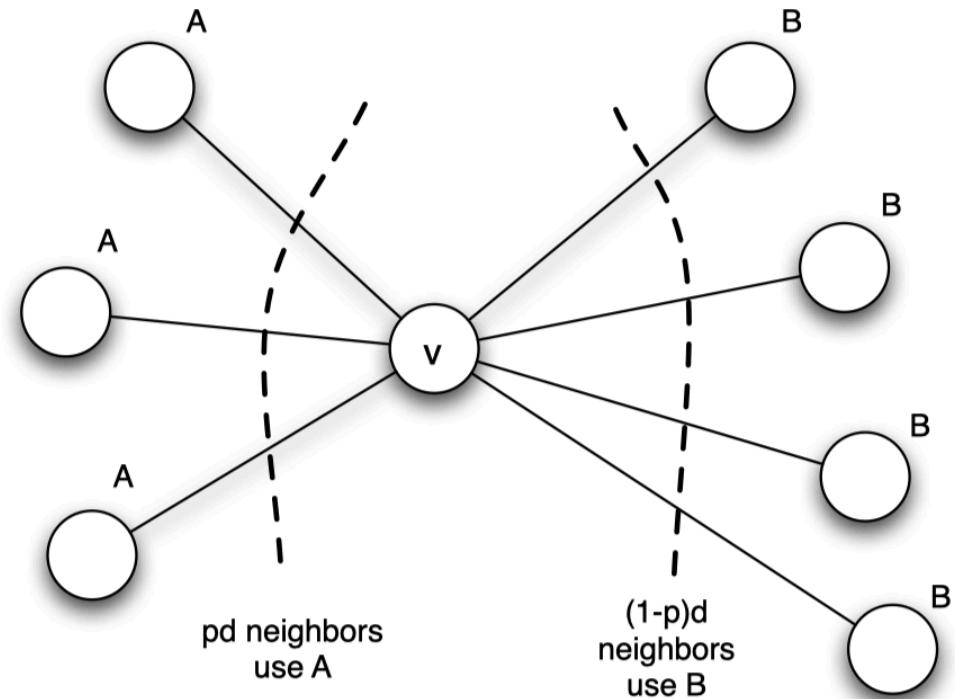
Node  $v$  chooses  $A$  if

$$pda \geq (1 - p)db$$

$$pa \geq b - pb$$

$$(a + b)p \geq b$$

$$p \geq \frac{b}{a + b} = q$$



## Threshold rule

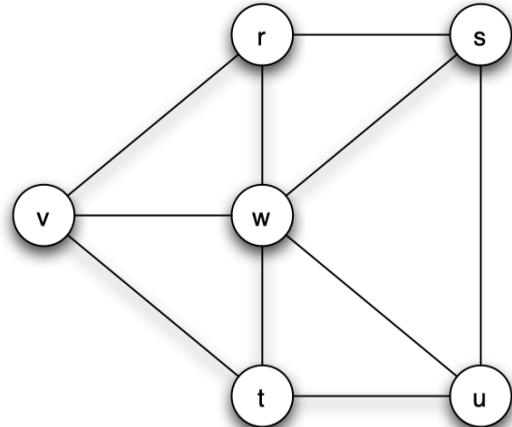
- In order to adopt  $A$  or  $B$ , we just need to check if  $p \geq q$ .
- Very simple - and myopic - model of individual decision making
- It is a research question to think about richer models that incorporate more long-range considerations

# Cascading behavior

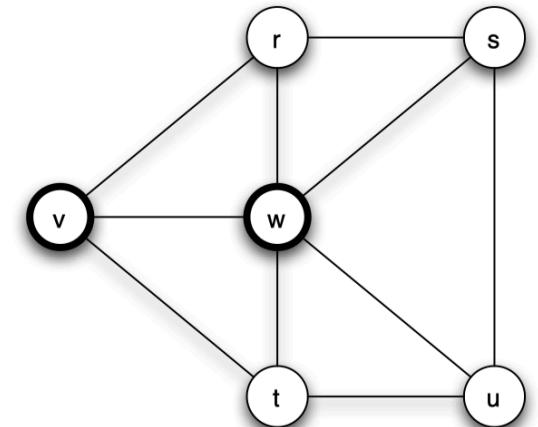
- Two obvious equilibria in the network:
  - one in which everyone adopts  $A$
  - another in which everyone adopts  $B$
- We want to understand how easy is to get one of these equilibria
- Also, we want to understand if other intermediate equilibria exist and how they look like
- **Assumptions:**
  - everyone is using  $B$  at the beginning
  - $S$ : small set of **initial adopters** of  $A$
- Will the spread of  $A$  make everyone to switch to the new technology, or will the spread stop?
- **Answer:** it depends on the network structure, the choice of nodes in  $S$ , and the value of  $q$ .

## Example

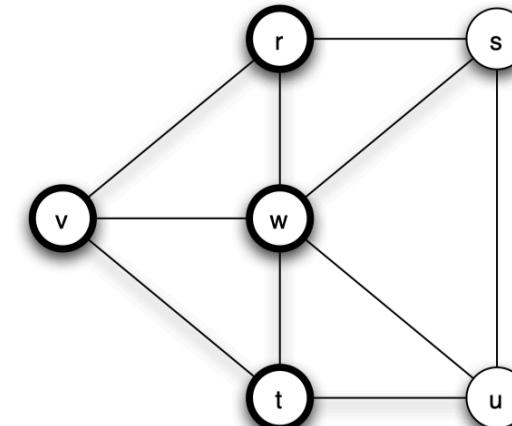
- $a = 3, b = 2 \Rightarrow q = \frac{2}{5}$
- $S = \{u, v\}$
- **complete cascade**



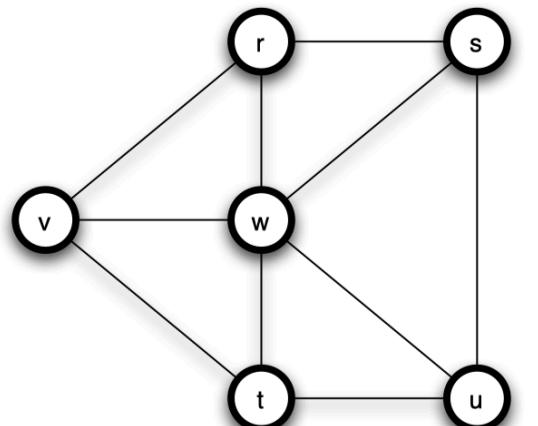
(a) *The underlying network*



(b) *Two nodes are the initial adopters*



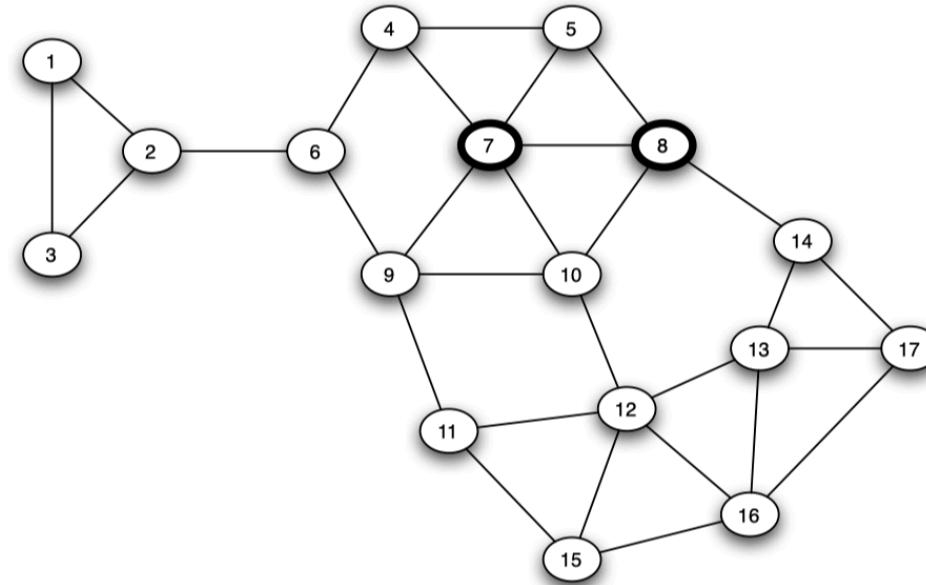
(c) *After one step, two more nodes have adopted*



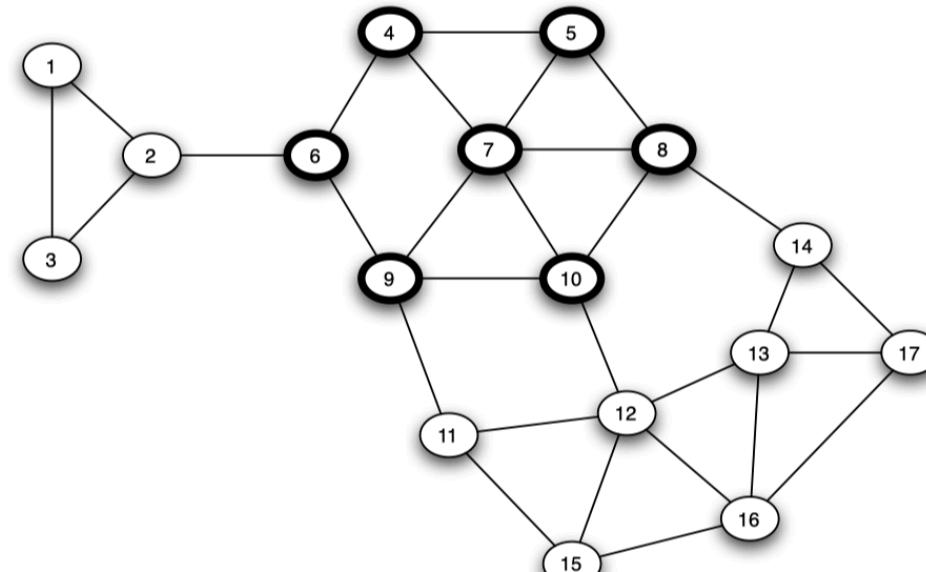
(d) *After a second step, everyone has adopted*

## Example

- $a = 3, b = 2 \Rightarrow q = \frac{2}{5}$
- $S = \{u, v\}$
- The diffusion of A stops here
  - partial cascade



(a) Two nodes are the initial adopters



(b) The process ends after three steps

## Recap

- Consider a set of initial adopters who start with a new behavior  $A$ , while every other node starts with behavior  $B$ .
- Nodes then repeatedly evaluate the decision to switch from  $B$  to  $A$  using a threshold of  $q$ .
- If the resulting cascade of adoptions of  $A$  eventually causes every node to switch from  $B$  to  $A$ , then we say that the set of initial adopters causes a **complete cascade at threshold  $q$**

## Definition

- We say that a **cluster of density  $p$**  is a **set of nodes** such that each node in the set has **at least a  $p$  fraction of its network neighbors in the set**.

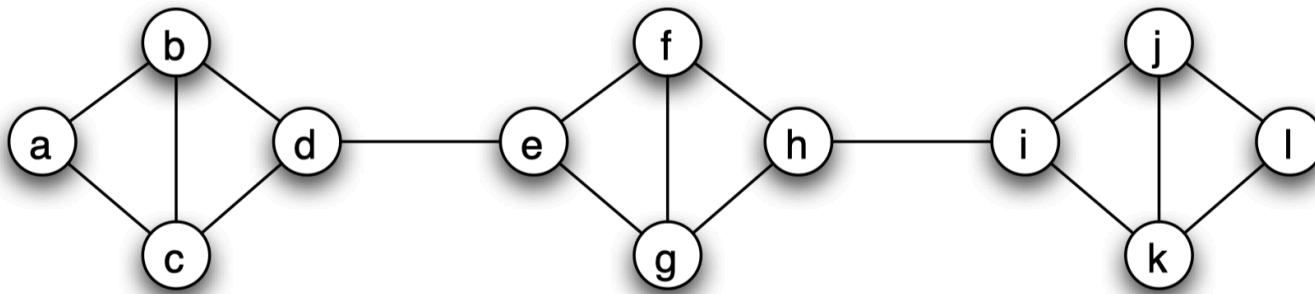
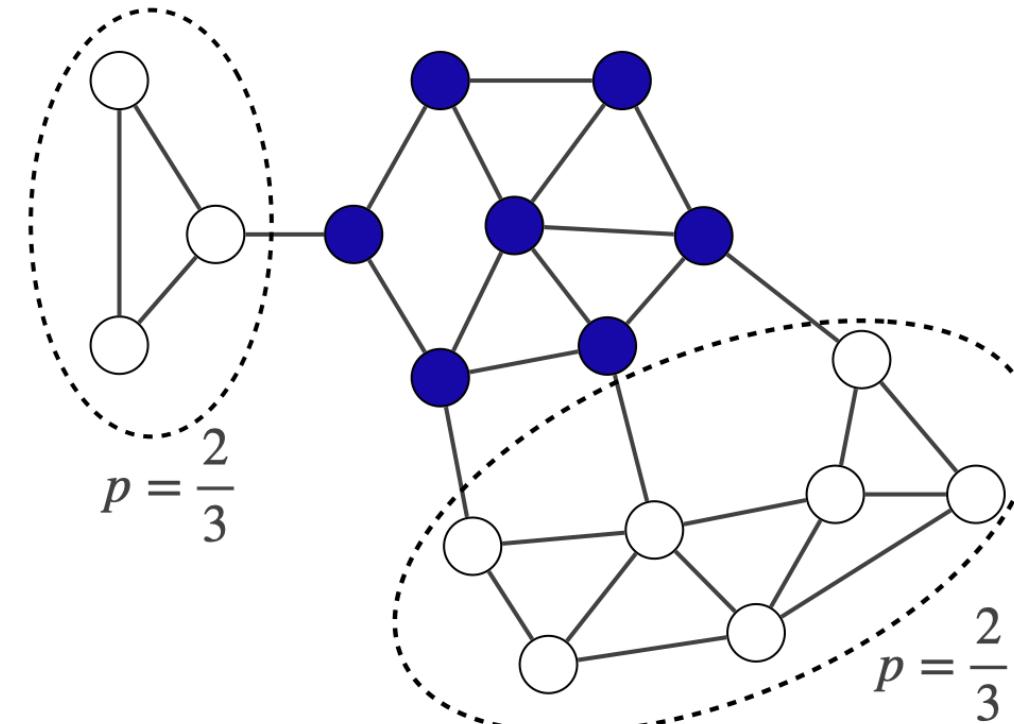


Figure 19.6: A collection of four-node clusters, each of density  $2/3$ .

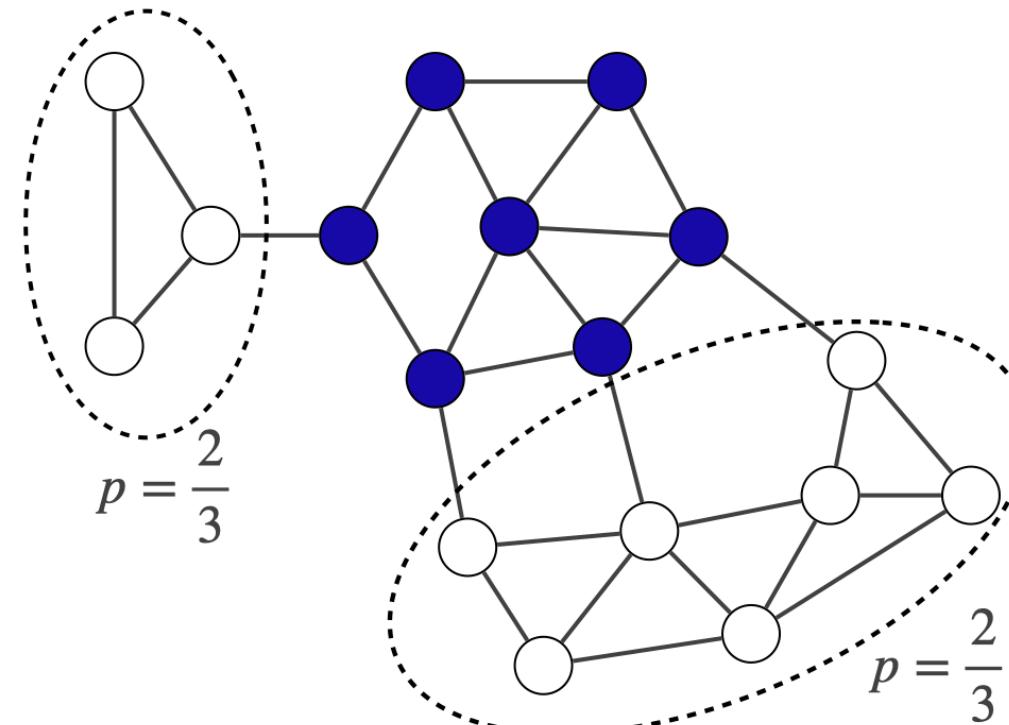
## Stopping cascades

- What prevents cascades from spreading?
  - **Homophily** can serve as a barrier to diffusion: it is hard for innovation to arrive from outside densely connected communities
- Let's try to quantify this intuition:
  - **Cluster of density  $p$**



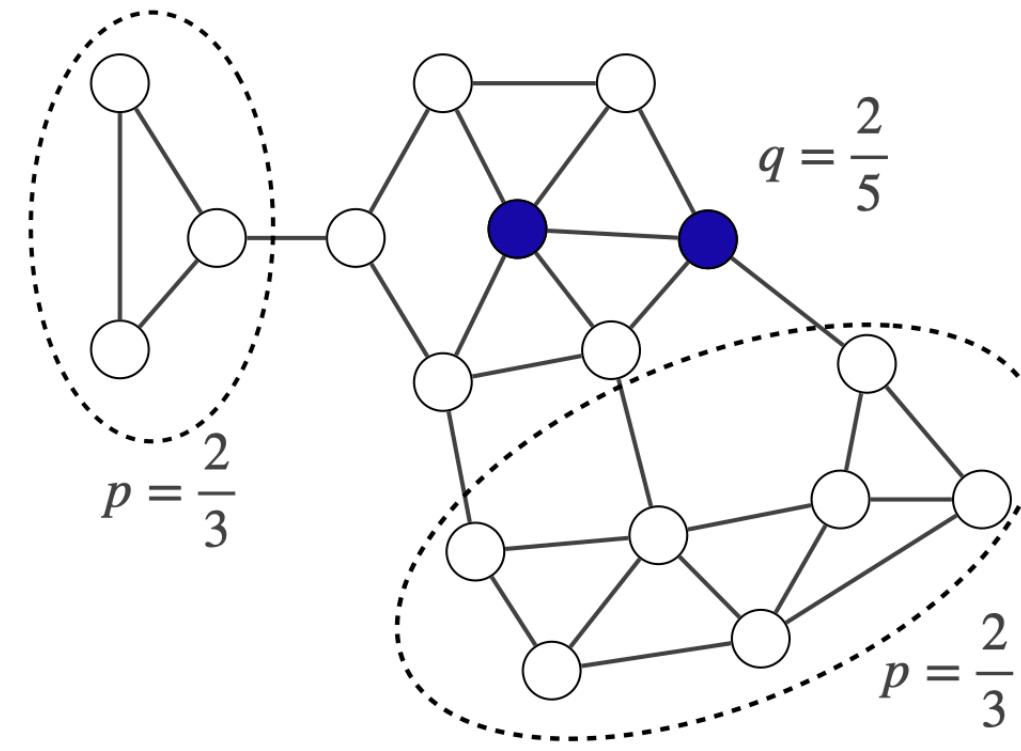
## Internal cohesion

- Each node in a cluster has a prescribed fraction of its friends residing in the cluster: **cohesion**
- Nodes in the same clusters do not necessarily have much in common
  - Any network is a cluster of density  $p = 1$ .
  - The union of two clusters of density  $p$  is still a cluster of density  $p$ .
- In fact, clusters in networks can exist simultaneously at different scales.



## Relationship between clusters and cascades

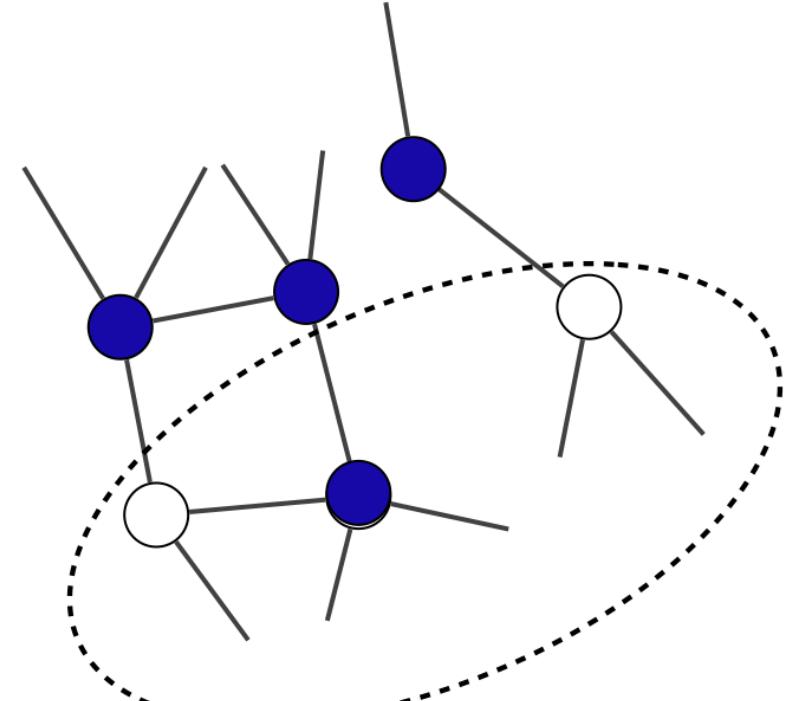
- A cascade stops iff it runs into a dense cluster
  - i.e., clusters are natural obstacles to cascades
- **Claim:** Let  $S$  be the set of **initial adopters** of  $A$ , with a threshold of  $q$ 
  - (i) if the remaining network contains a cluster of density  $p > (1 - q)$  then **S cannot cause a complete cascade**
  - (ii) if  $S$  fails to cause a cascade, then **there is a cluster of density  $p > (1 - q)$  in the remaining network**



## Clusters implies no cascade

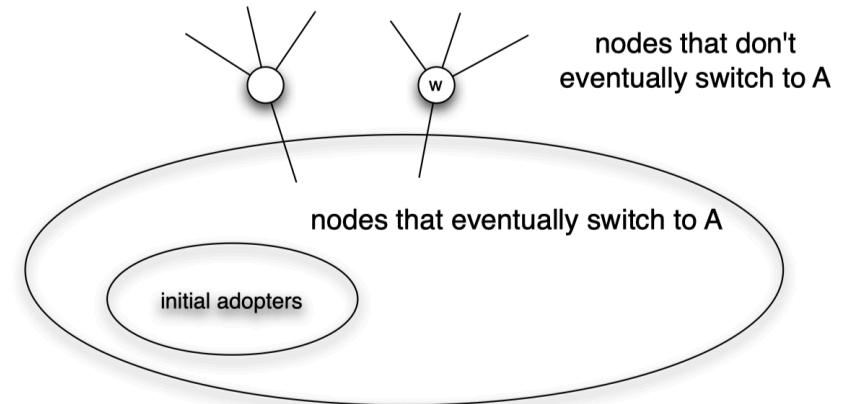
Proof by contradiction:

- some node inside the cluster  $C$  of density  $p > (1 - q)$  will adopt  $A$  at time  $t$  (the first to adopt in its cluster);
- this means that the decision was made at time  $t - 1$ , when no other node in the cluster  $C$  adopted  $A$ ;
- since the cluster  $C$  has density  $p > (1 - q)$ , less than a  $q$  fraction of nodes are outside the cluster;
- these nodes are the only that could have adopted  $A$  and they were outside the cluster at time  $(t - 1)$
- so at time  $t - 1$  it is impossible that the threshold rule fired for  $v$  since  $p < q$ : **contradiction**



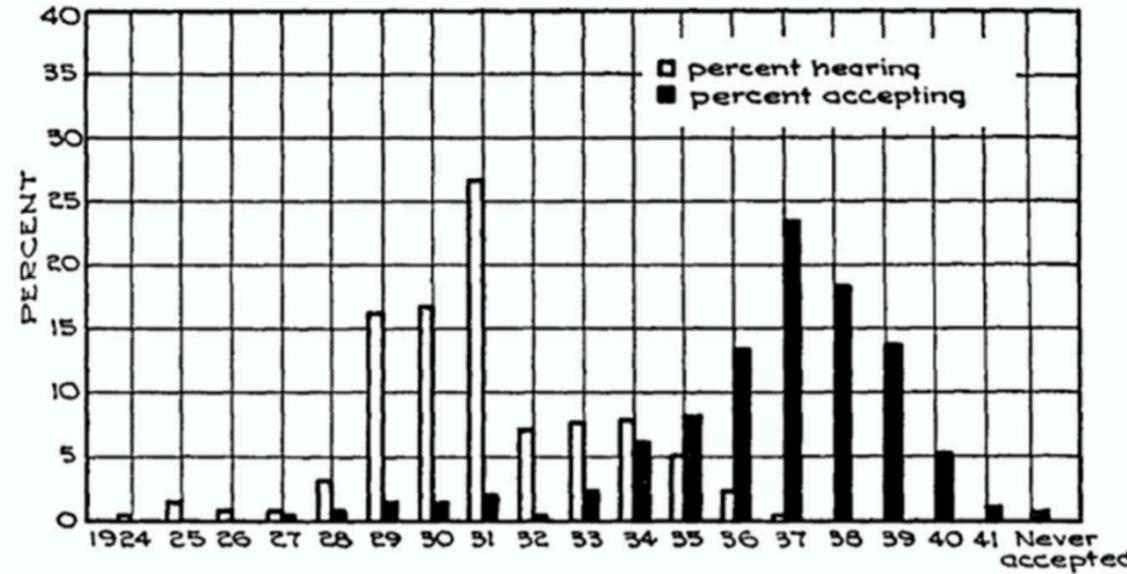
## Clusters implies no cascade

- Let  $S$  be the set of initial adopters of  $A$
- The spreading process stops: let  $S'$  be the maximum set of nodes that switched to  $A$
- Let  $R$  be the set of nodes still using  $B$  at the end of the process
- Pick one node in  $R$ : it does not want to switch to  $A$ 
  - the fraction of its friends using  $A$  is  $< q$
  - the fraction of its friends belonging to  $R$  is  $p > (1 - q)$
  - this holds for every node in  $R$
  - $R$  is a cluster of density  $p > (1 - q)$



# Viral marketing

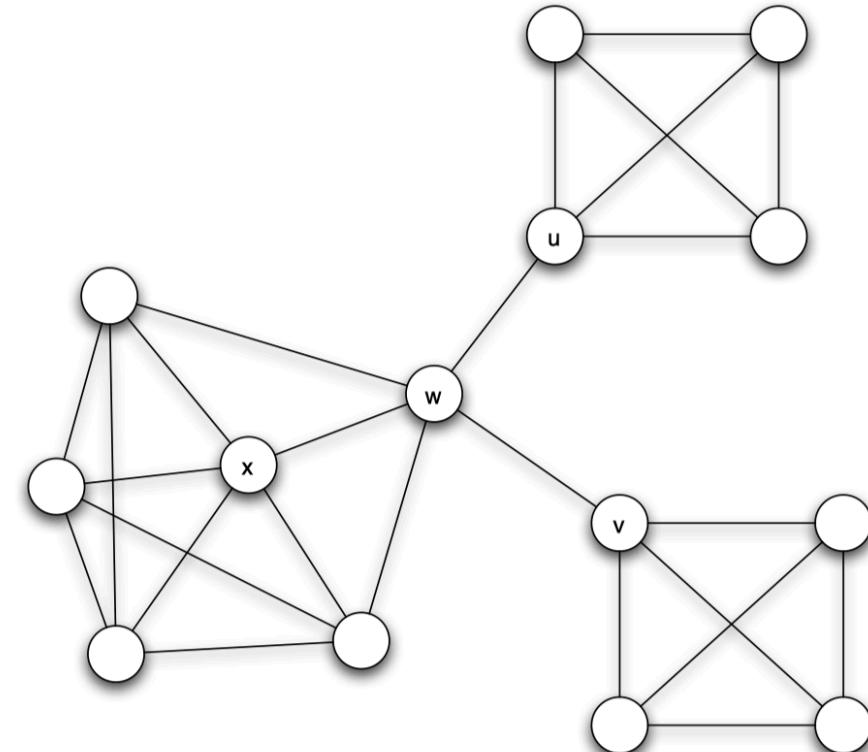
- Lesson learned: tightly-knit communities in the network can work to stop the spread of an innovation
  - We have coexistence of both behaviors (or also competing products)
- In case of coexistence, if a firm can rise the quality of product *A*, than the spread of the new technology can produce a complete cascade
- Alternative strategy (when the firm cannot rise the quality of the product): trying to **convince a small number of key people** in the part of the network still using *B*
  - how to choose key people to trigger a viral marketing strategy?
  - their position in the underlying network can be very relevant - let's explore this now



- In the Ryan-Gross study (1943) on the adoption of hybrid seed corn, it is possible to spot the difference between learning about a new idea and actually deciding to adopt it
- It is like nodes at the border in a cluster: they have been exposed to the idea, but still they decide not to adopt it.
- Reading material: [Bryce Ryan and Neal C. Gross. The diffusion of hybrid seed corn in two Iowa communities. Rural Sociology, 8:15–24, 1943.](#)

## The role of weak ties

- Threshold models highlight some important implications of the **strength of weak ties** theory
- They receive very fresh ideas from other communities; not enough for adoption and spread (try with  $q = \frac{1}{2}$ )
- Bridges and weak ties are great for spreading rumors or jokes across the network, but not for diffusion of innovation or social mobilization
- Strong ties can have more significant role for others in the community to take actions
- Reading material: [Damon Centola and Michael Macy. Complex contagions and the weakness of long ties. American Journal of Sociology, 113:702–734, 2007.](#)



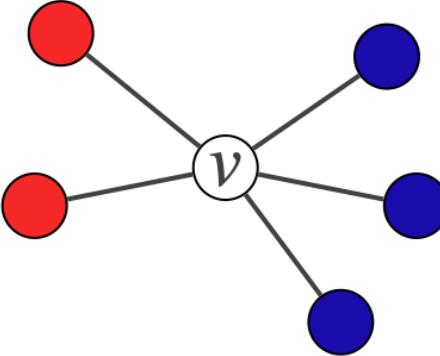
# Extensions of the Basic Cascade Model

## Heterogeneous thresholds

- Let's suppose each person gives values to  $A$  and  $B$  subjectively

|     |     | $w$        |            |
|-----|-----|------------|------------|
|     |     | $A$        | $B$        |
| $v$ | $A$ | $a_v, a_w$ | 0, 0       |
|     | $B$ | 0, 0       | $b_v, b_w$ |

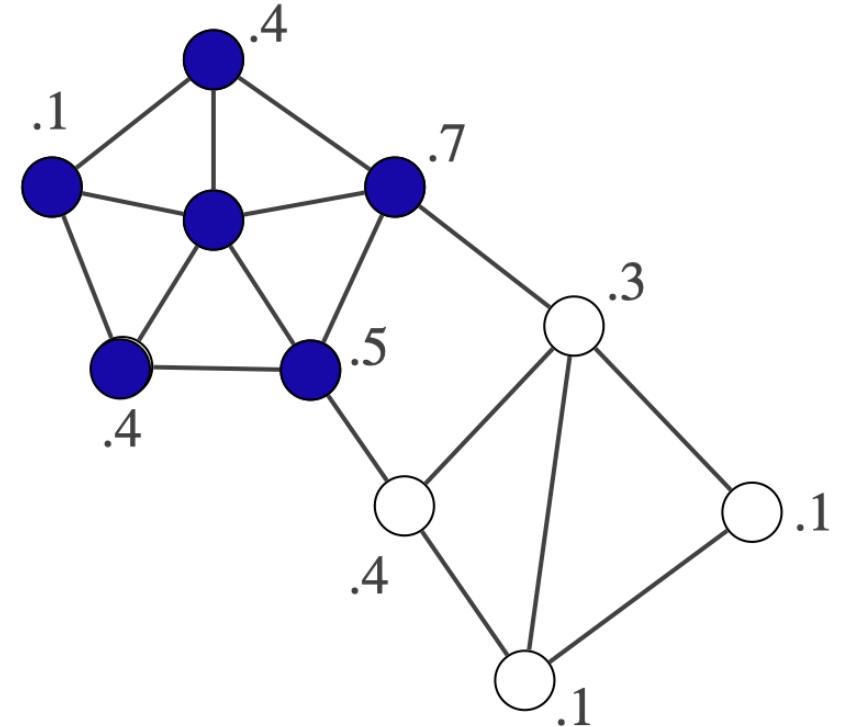
## Heterogeneous thresholds



- $p$  fraction of neighbors adopting  $A$
- $1 - p$  fraction of neighbors adopting  $B$
- $d$  is the number of neighbors
- The node chooses  $A$  if

$$pda_v \geq (1 - p)db_v \Rightarrow p \geq \frac{b_v}{a_v + b_v} = q_v$$

- Watts and Dodds: we need to take into account not just the power of influential nodes, but also the extent to which these influential nodes have access to easily **influenceable** people.
- Reformulating the notion of **blocking clusters**: set of nodes for which each node  $v$  has a fraction  $p > (1 - q_v)$  of its friends inside the set.
- The notion of density becomes **heterogeneous** as well: each node has a different requirement for the fraction of friends it needs to have in the cluster.
- Reading material: [Duncan J. Watts and Peter S. Dodds. Networks, influence, and public opinion formation. Journal of Consumer Research, 34\(4\):441–458, 2007.](#)



## Reading material

[ns2] Chapter 19 (19.1-19.5) Cascading behavior in Networks



# Q & A

