Cascading behavior in networks

- Choices made by individuals with reference to the previous choices made by everyone else.
  - information cascades
  - network effects
  - rich-get-richer dynamics
- Structure of the network and how individuals are influenced by their particular network neighbors.
  - Cascade behavior in networks

Diffusion of Innovations

- The diffusion of innovations
  - informational effects
  - direct-benefit effects
- Why an innovation can fail to spread through a population, even when it is has significant relative advantage compared to existing practices ?
  - homophily
  - barrier to diffusion

Diffusion of Innovations

- In Ryan and Gross's study,
  - interviewed farmers to determine how and when they decided to begin using hybrid seed corn.
  - Most of the farmers in their study first learned about hybrid seed corn from salesmen,
  - but most were first convinced to try using it based on the experience of neighbors in their community.

Diffusion of Innovations

- Why an innovation can fail to spread through a population ?
  - It can be difficult for these innovations to make their way into a tightly-knit social community;
  - even when it is has significant relative advantage compared to existing practices;
  - complexity for people to understand and implement;
  - its observability; people can become aware that others are using it;
  - trialability, people can mitigate its risks by adopting it gradually and incrementally;
  - compatibility with the social system that it is entering.

Modeling Diffusion through a Network

- individuals make decisions based on the choices of their neighbors
  - informational effects
  - direct-benefit effects

A Coordination Game

w

		A	B
v	A	a, a	0,0
	B	0,0	b, b

- Nodes v and w
- Two behaviors : A and B
- If v and w are linked, an incentive for them to have their behaviors match
  - If v and w adopt behavior A, they each get a payoff $a > 0$

  - If they adopt behavior B, they each get a payoff $b > 0$

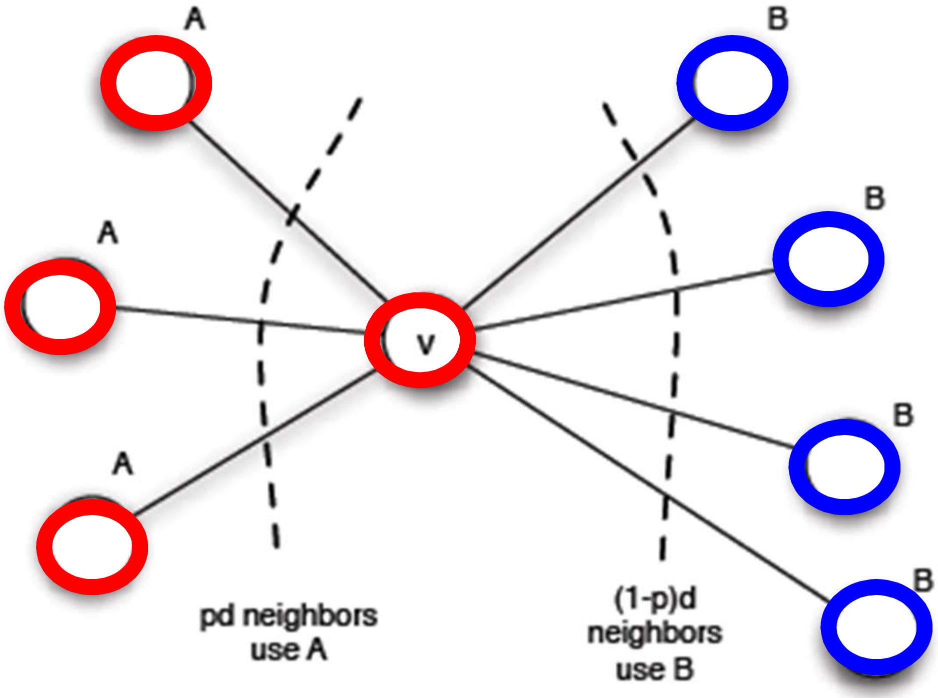
  - If they adopt opposite behavior, they each get a payoff 0

A Networked Coordination Game

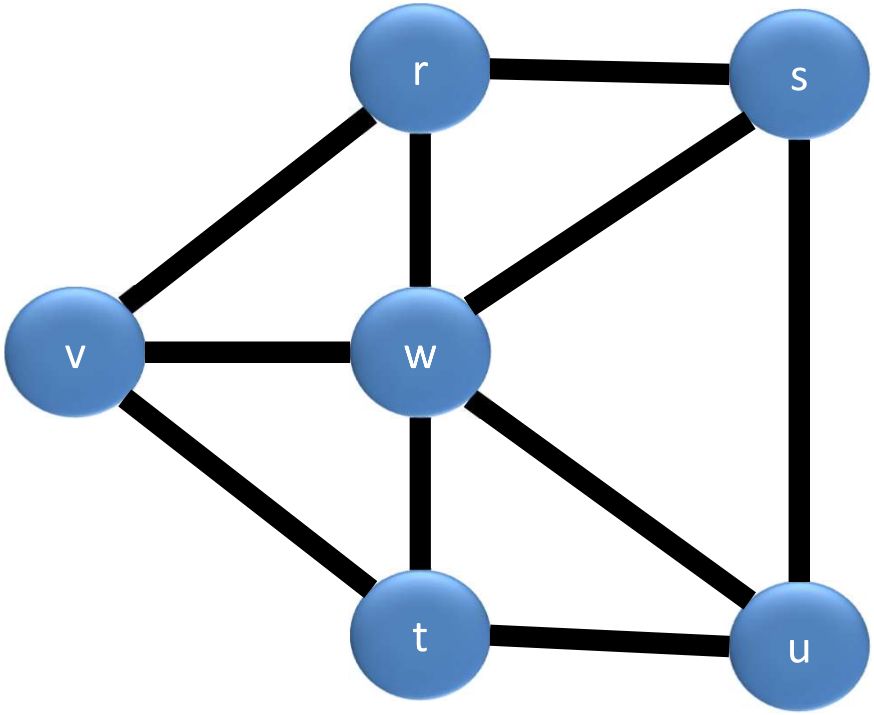
- Each node is playing this game with each of its neighbors and the payoff is the sum of all payoffs

- v has d neighbors
- p fraction of v's neighbors is A
- $1\text{-}p$ fraction of v's neighbors is B
- If v chooses A, payoff = pda
- If v chooses B, payoff = (1-$p)db$
- A is better if

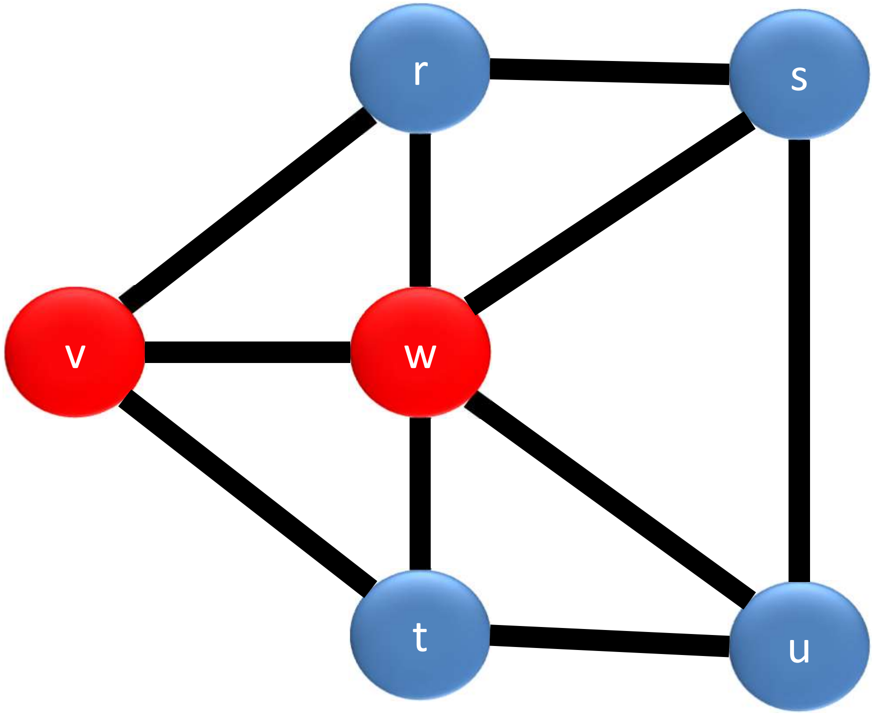
$$pda \ \geq (1\text{-}p)db \quad \text{or} \quad p \geq \frac{b}{a+b} = q$$



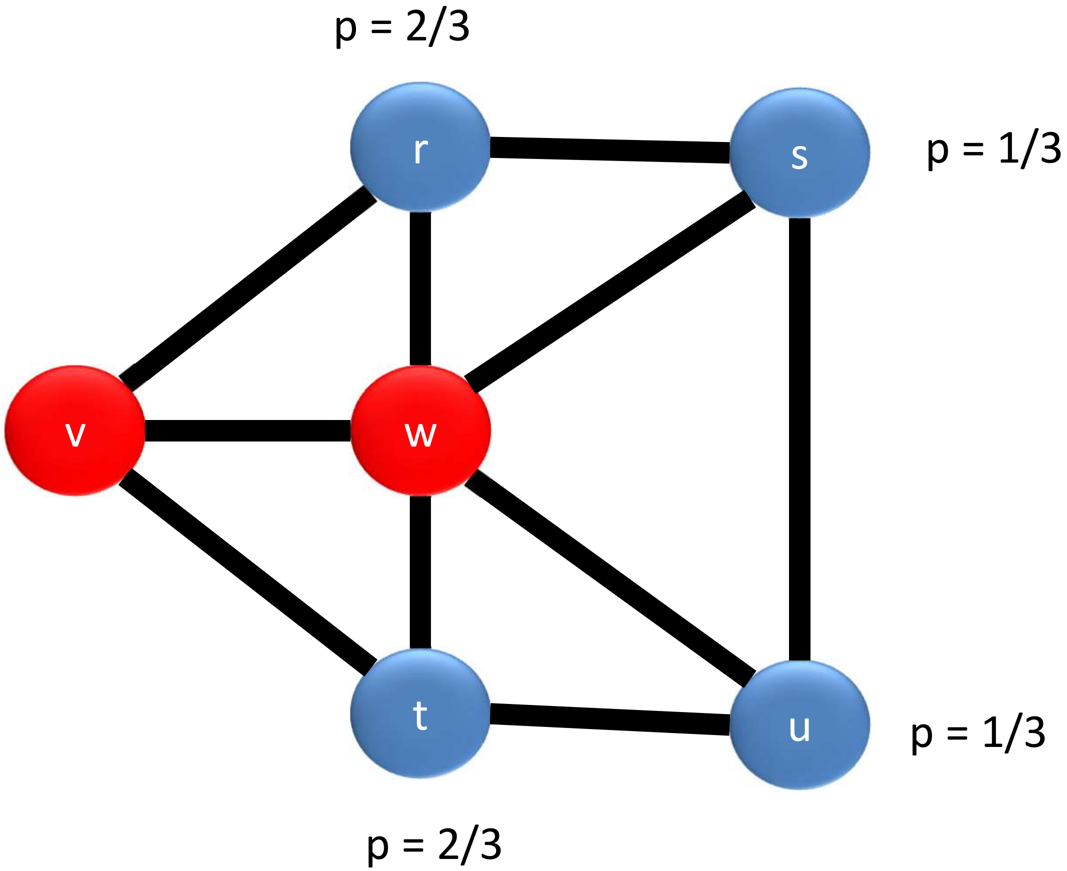
- $a = 3$, $b = 2$
- q=$\frac{b}{a+b}=\frac{2}{5}$



- $a = 3$, $b = 2$
- q=$\frac{b}{a+b}=\frac{2}{5}$
- v and w are initial adopters



- $a = 3$, $b = 2$
- $q = \frac{b}{a+b} = \frac{2}{5}$



- $a = 3, b = 2$
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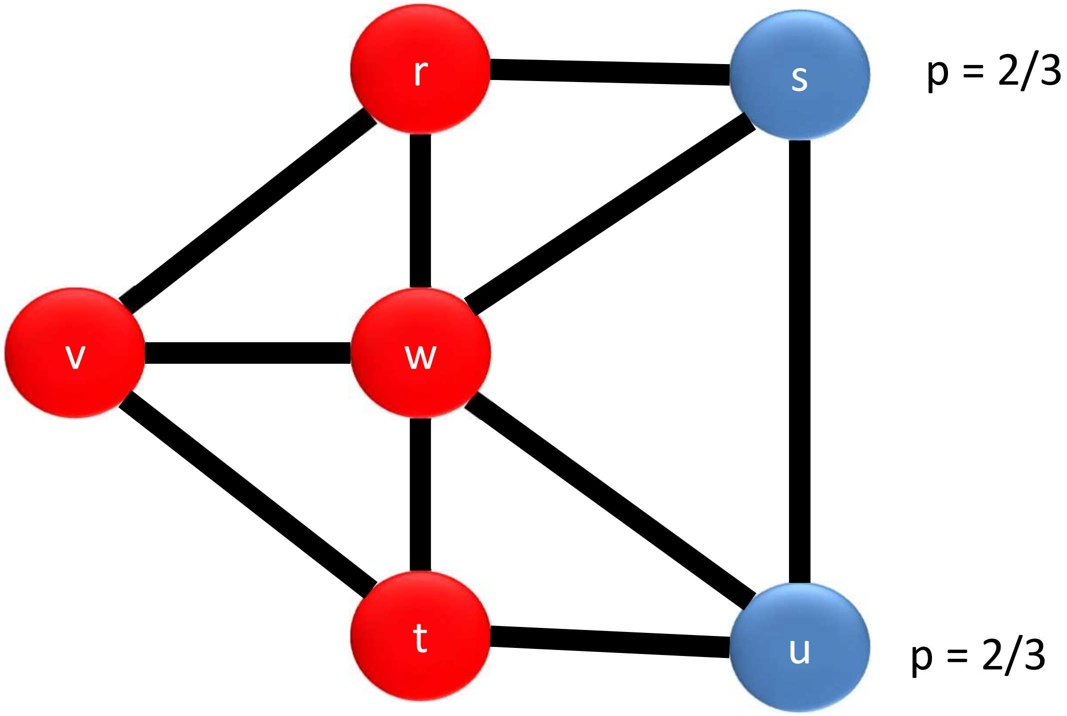

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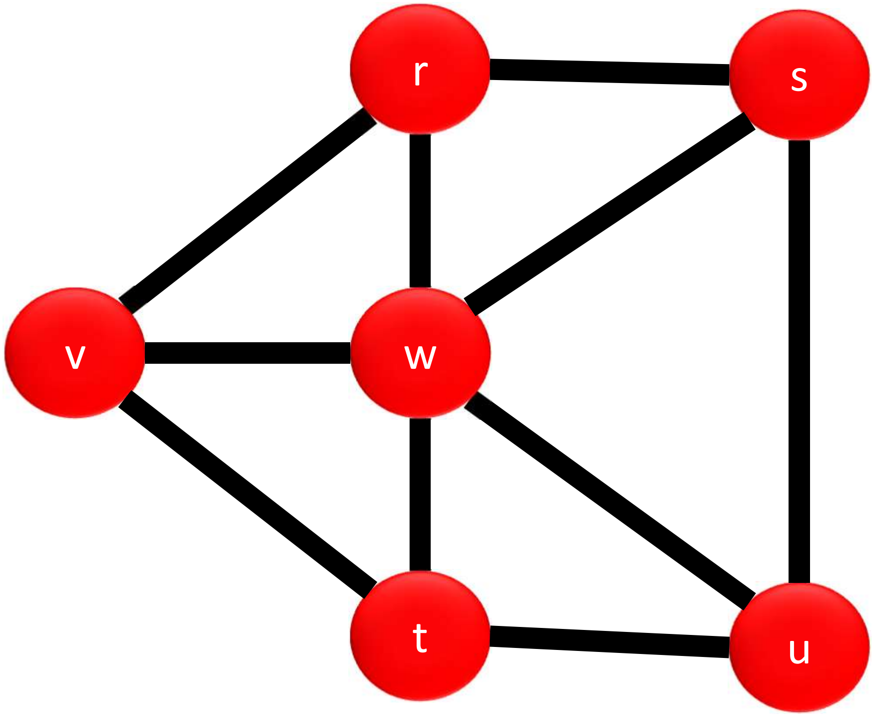

- $a = 3$, $b = 2$
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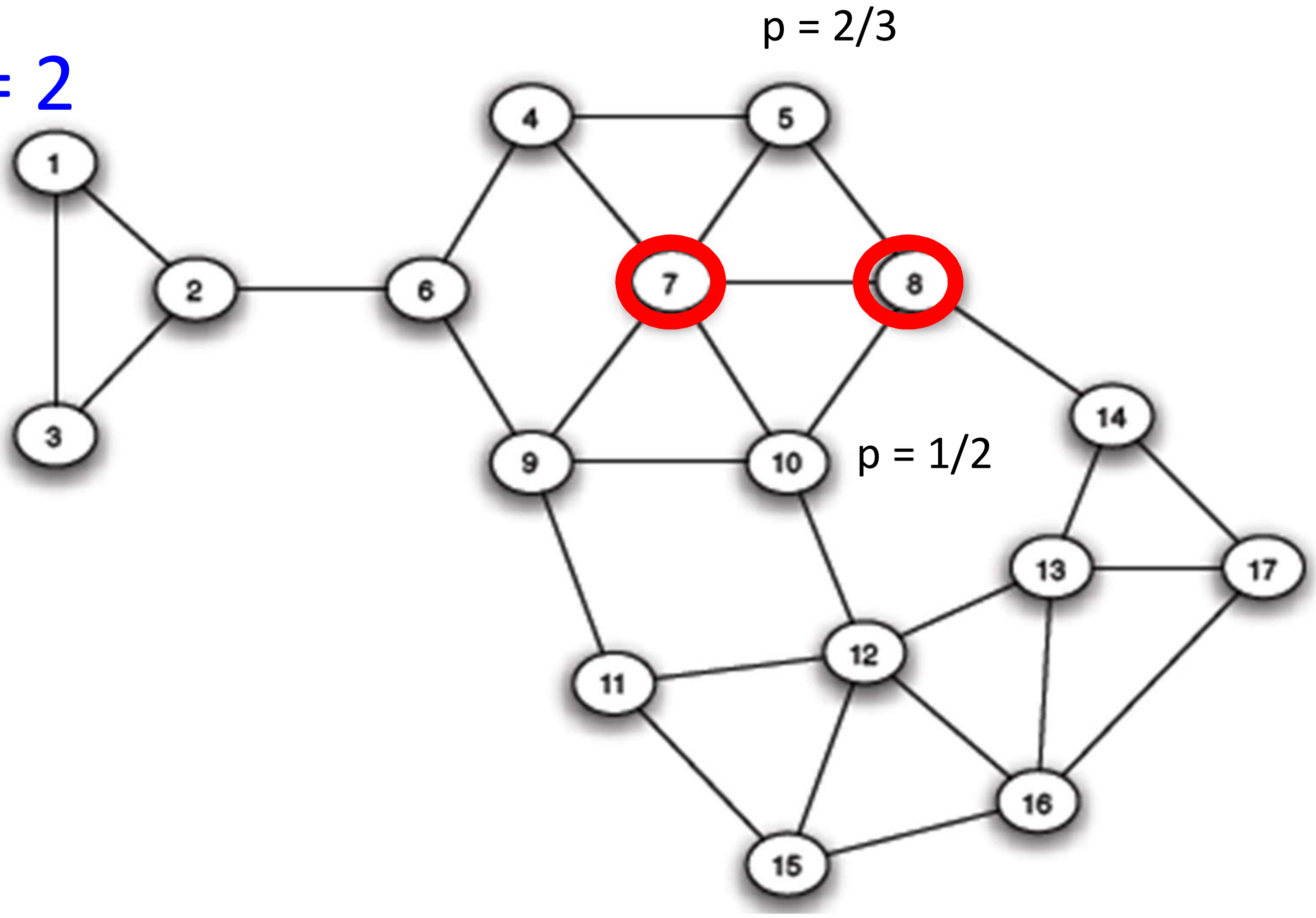

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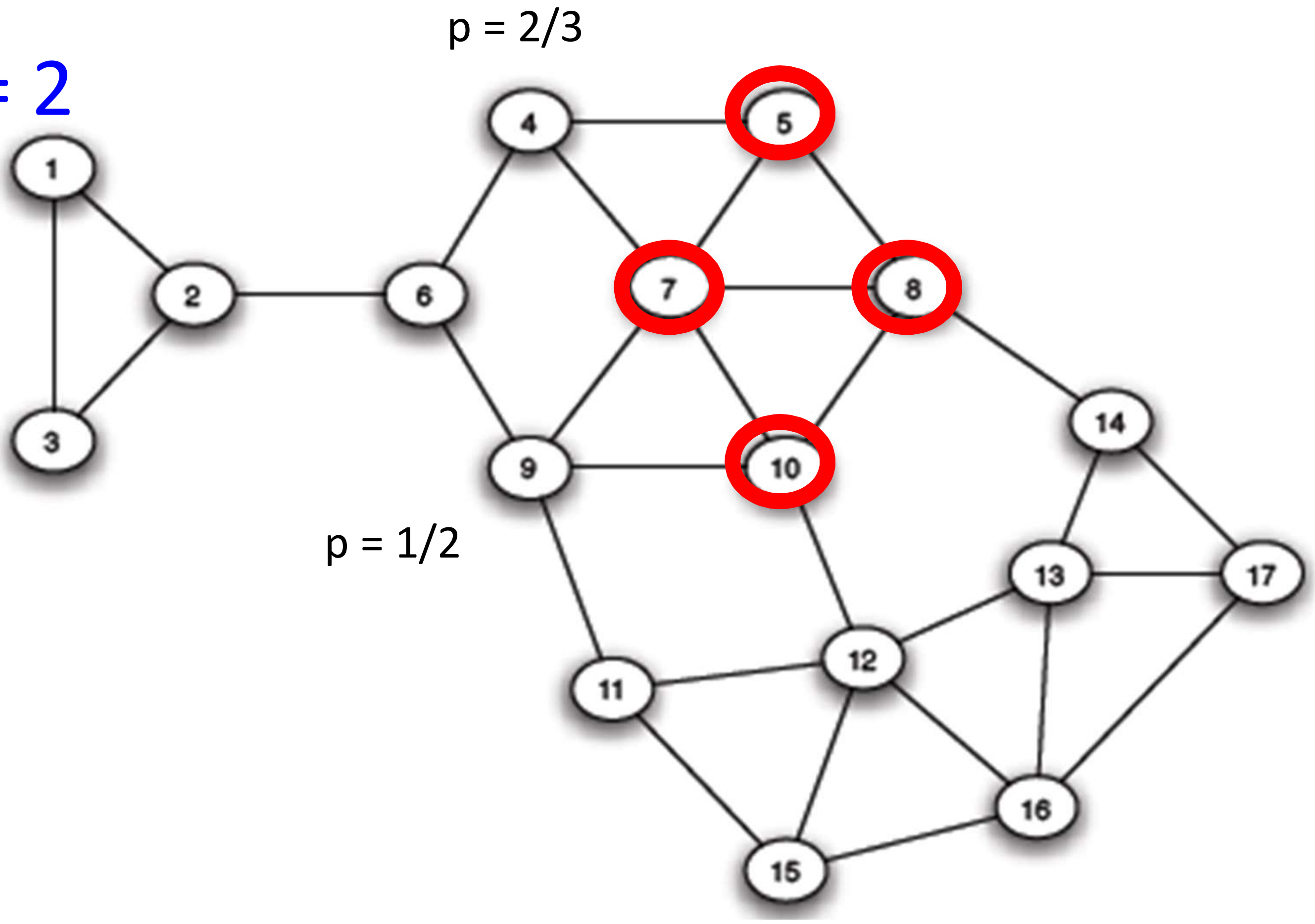
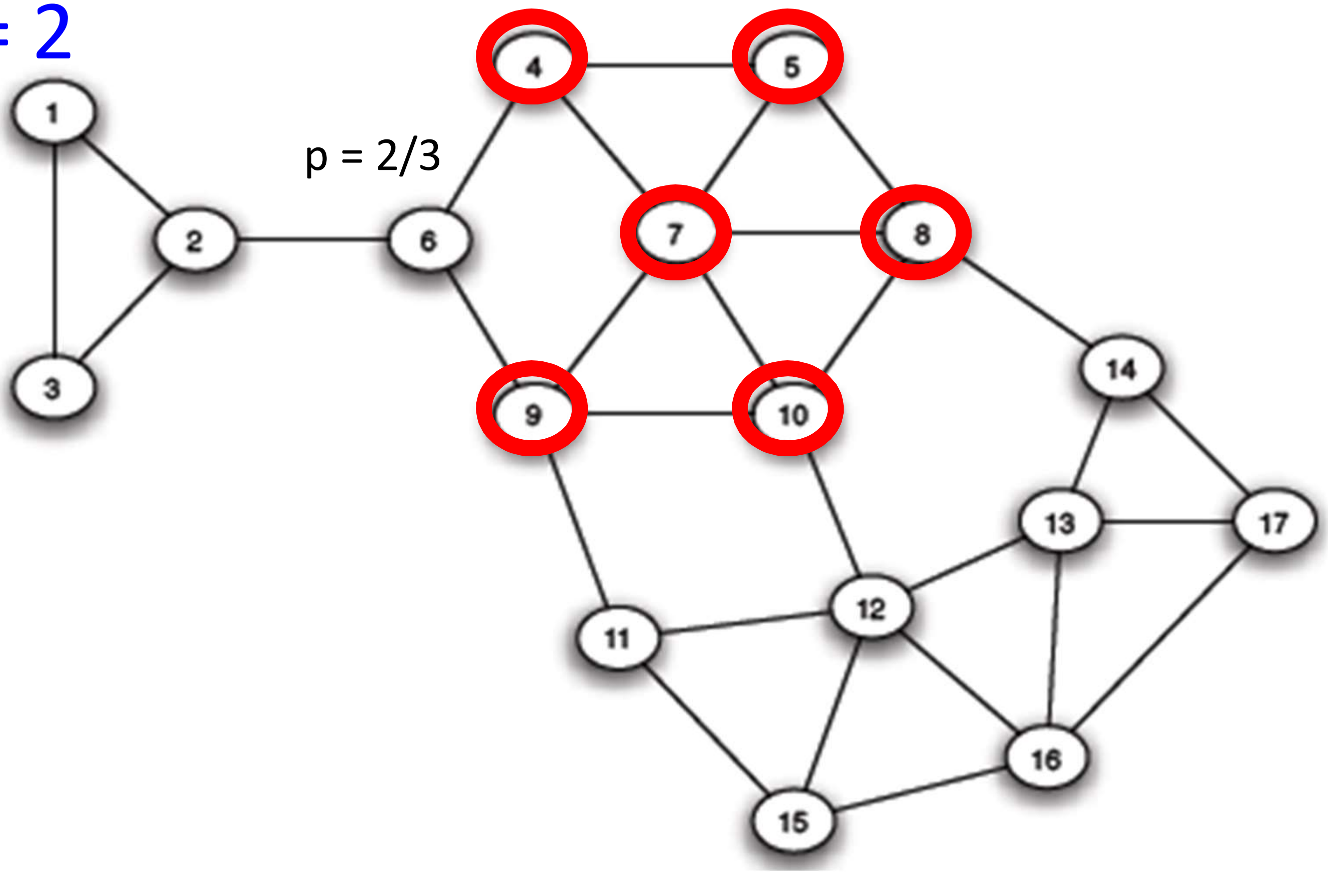


- $a = 3$, $b = 2$
- $q = \frac{b}{a+b} = \frac{2}{5}$



- $a = 3$, $b = 2$
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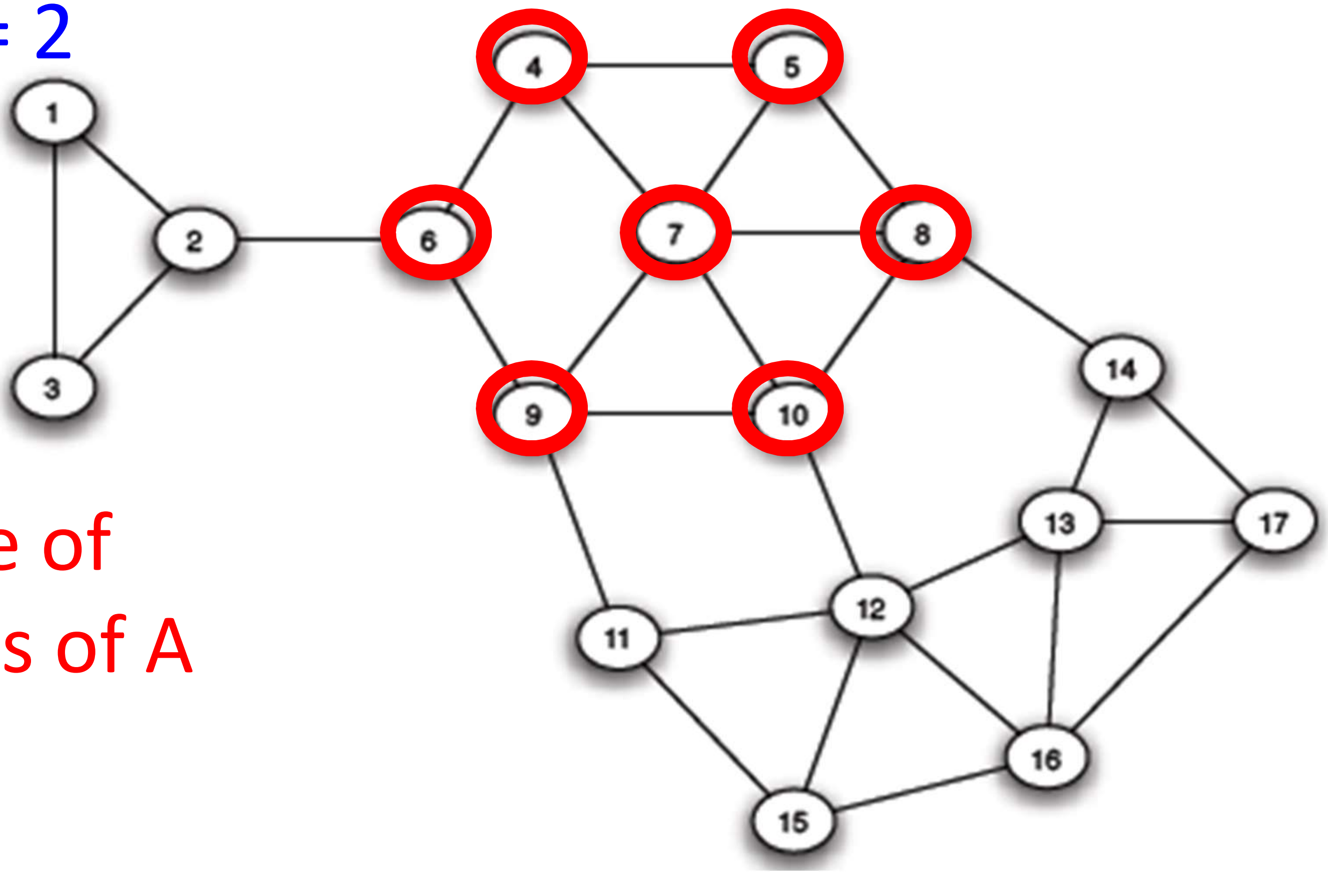


a cascade of adoptions of A

Cascading Behavior

- At least two equilibria to the network coordination game :
  - all A or
  - all B.
  - Are there other equilibria ?
- Is it easy to "tip" from one equilibrium to another one ?
- Can we change from all B to all A with some initial adopters ?

cascade of adoptions of A

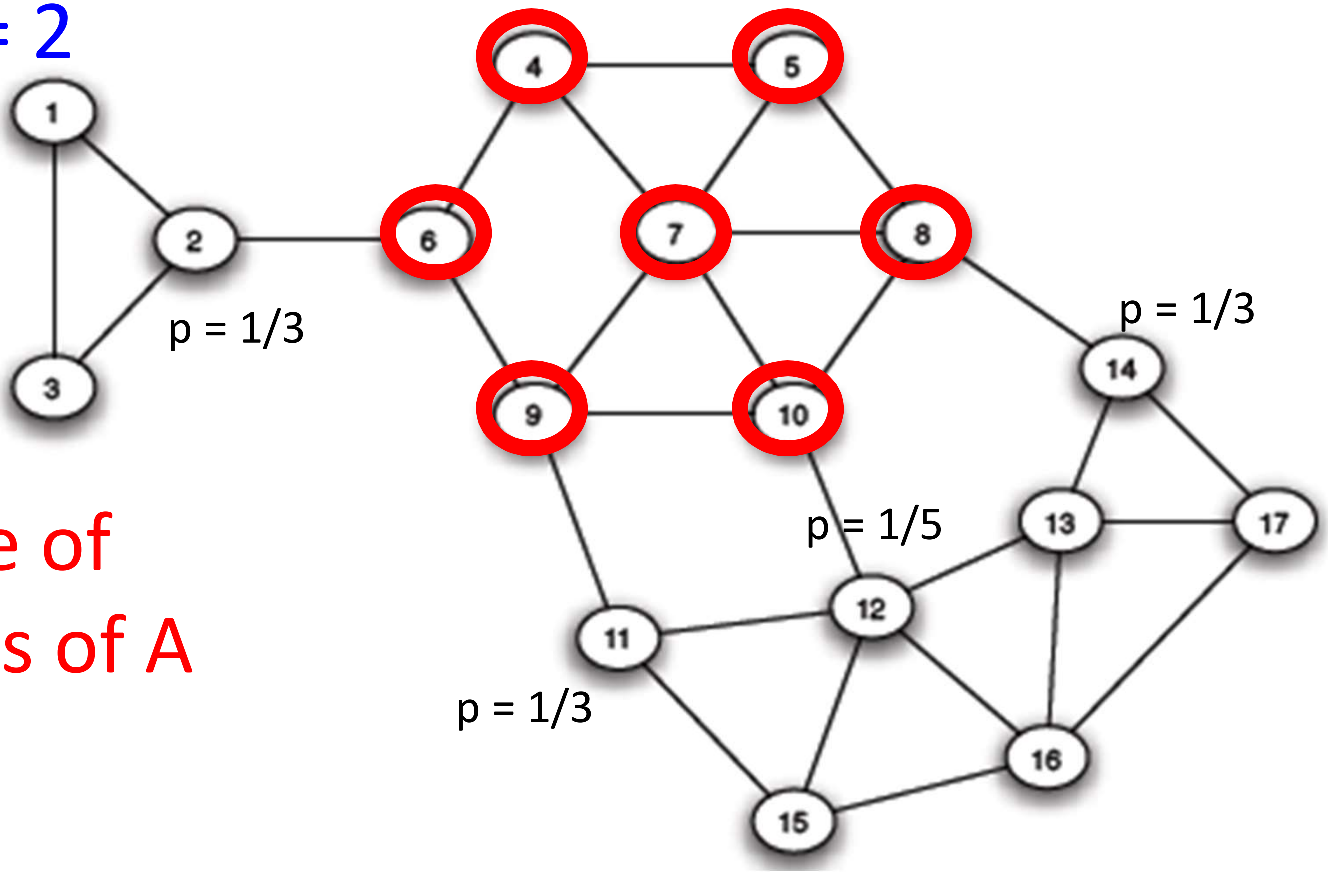
- 2 possible outcomes
  - – the cascade stops when there are some B nodes
  - – all nodes switch to A : a complete cascade

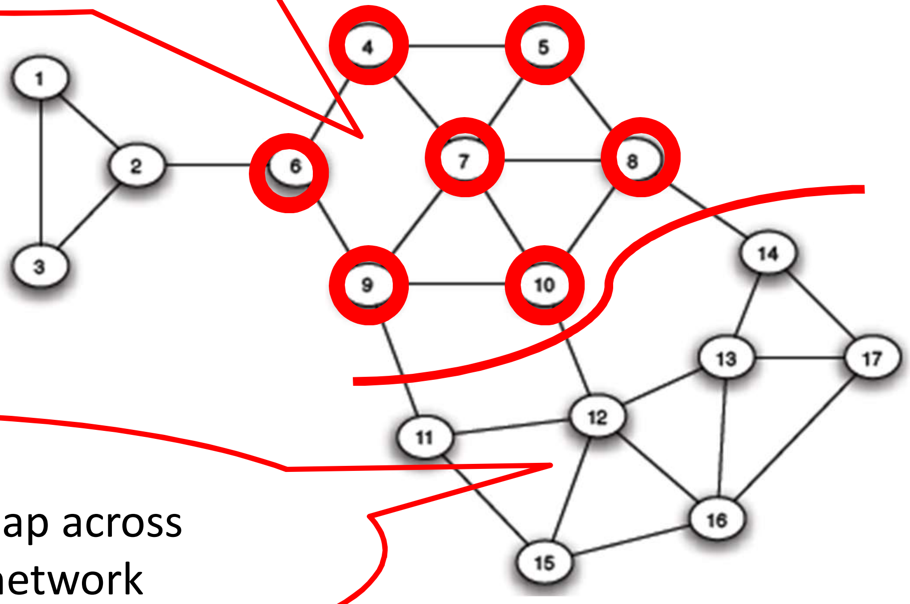
a complete cascade

- 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.

- $a = 3$, $b = 2$
- $q = \frac{b}{a+b} = \frac{2}{5}$

a cascade of adoptions of A





A was able to spread to a set of nodes where there was sufficiently dense internal connectivity,

it was never able to leap across the “shores” in the network

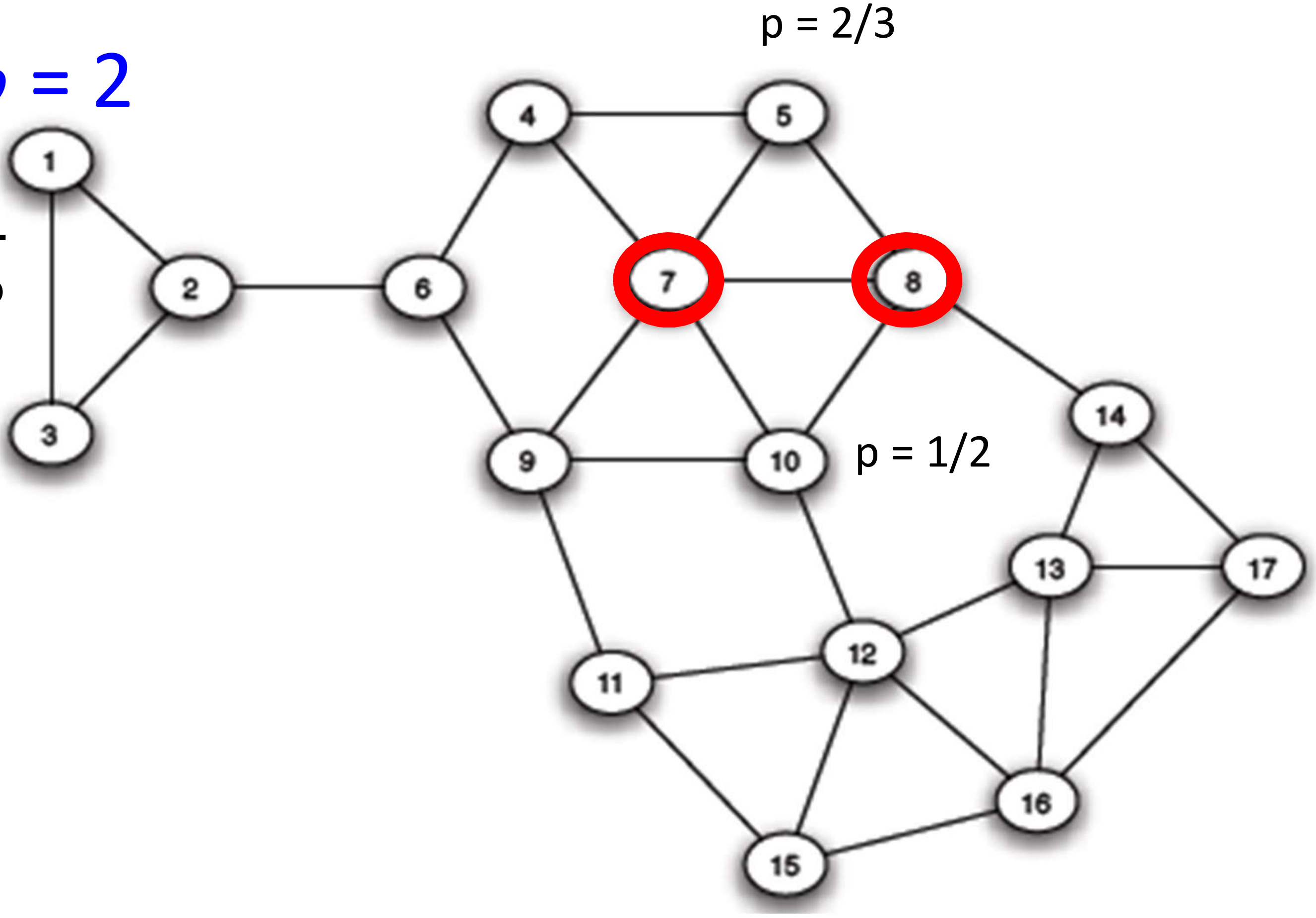
Cascading Behavior and Viral Marketing

- The cascade runs for a while but stops while there are still nodes using B
    - different dominant political views between adjacent communities
    - different social-networking sites are dominated by different age groups and lifestyles even when the rest of the world are using something else
    - certain industries heavily use Apple Macintosh computers despite the general prevalence of Windows.

complete cascade (lower threshold)

- a = ~~3~~ 4, b = 2

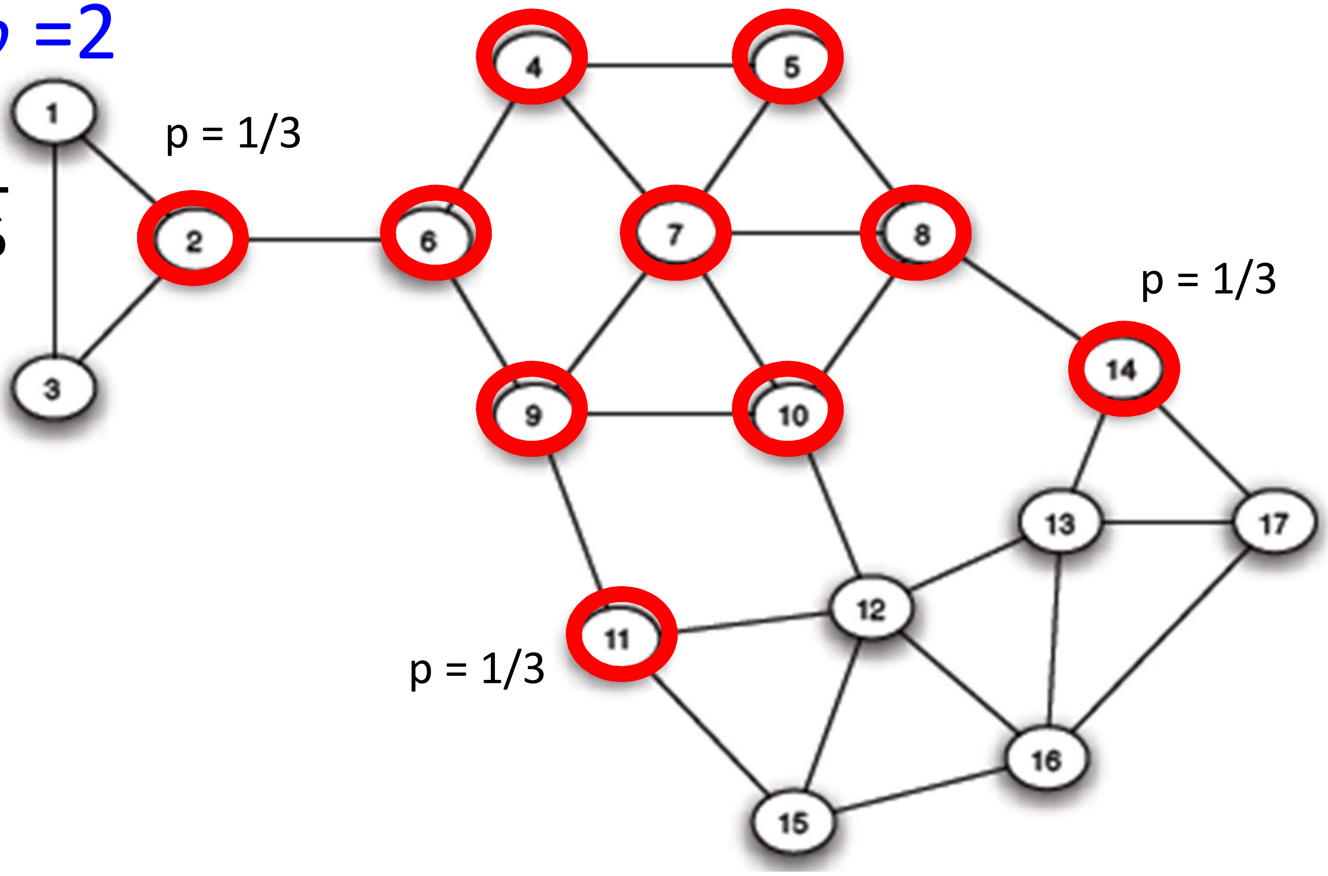
$$q = \frac{b}{a+b} = \frac{2}{\cancel{5}6} = \frac{1}{3}$$



- a = ~~3~~ 4, b =2

$$q=\frac{b}{a+b}=\frac{2}{\cancel{5}6}$$

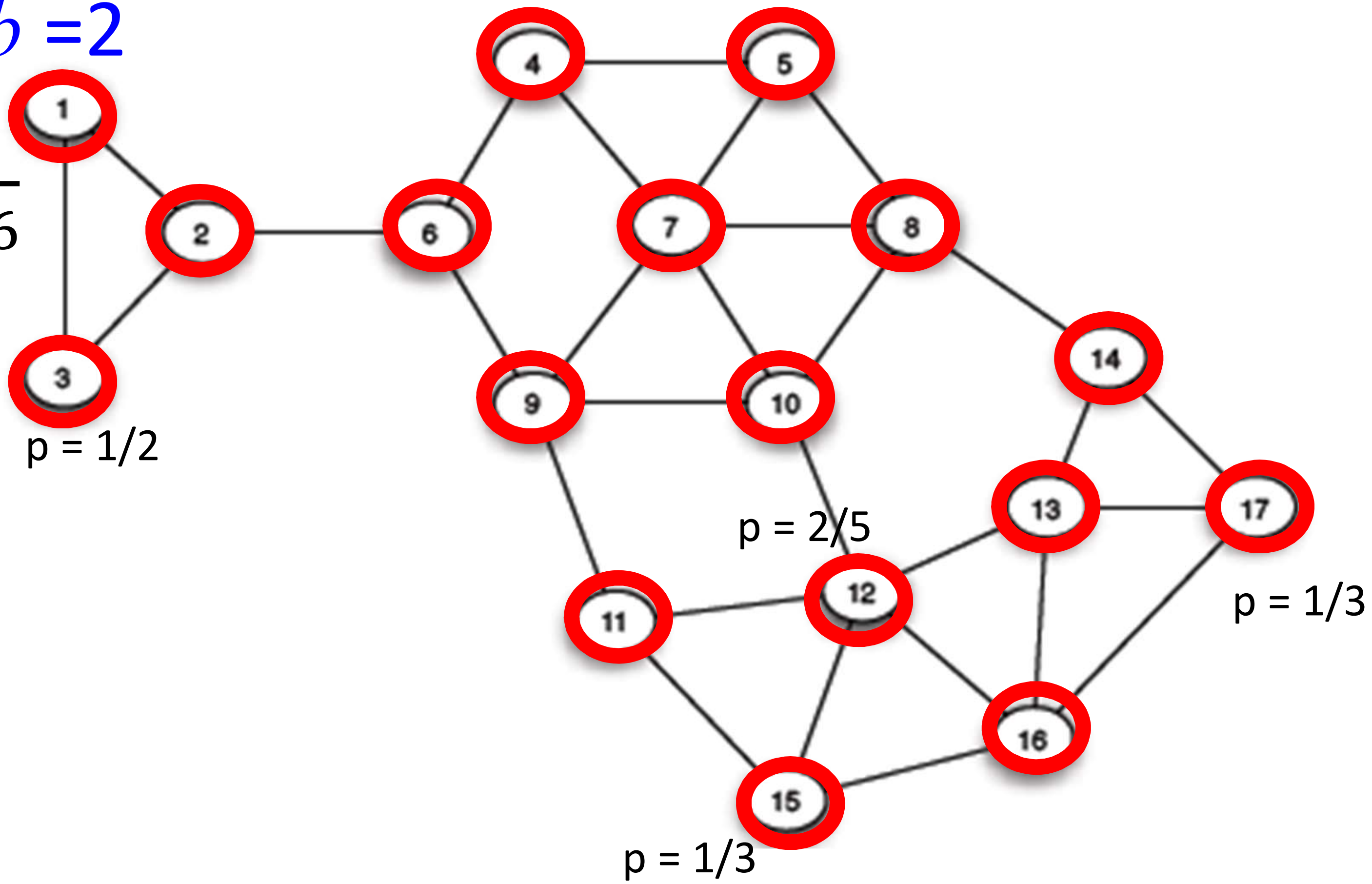
$$=\frac{1}{3}$$



- $a = \cancel{3}\ 4$, $b = 2$

$$q = \frac{b}{a+b} = \frac{2}{\cancel{5}6}$$

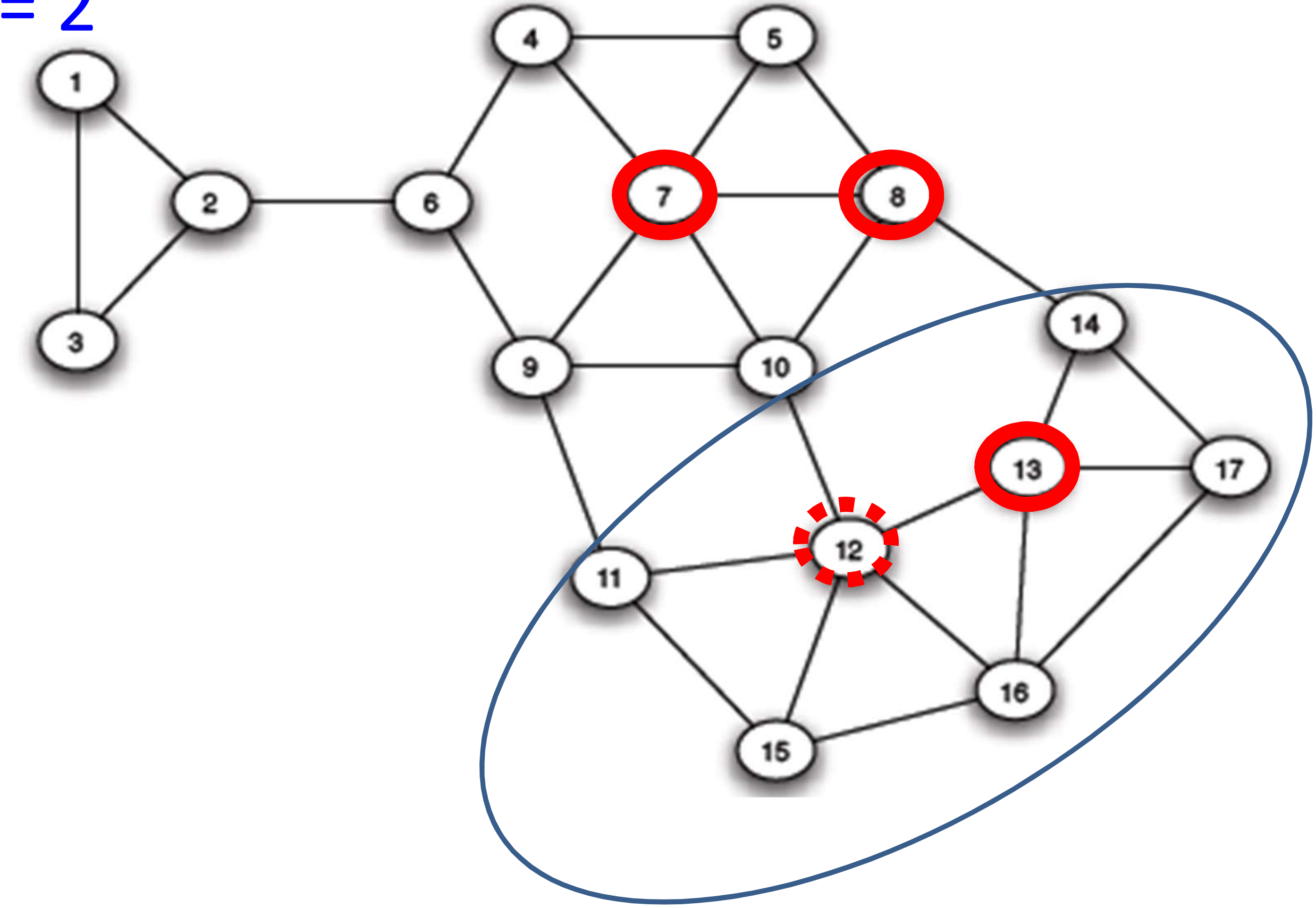
$$= \frac{1}{3}$$



complete cascade (choosing key nodes)

- $a = 3$, $b = 2$

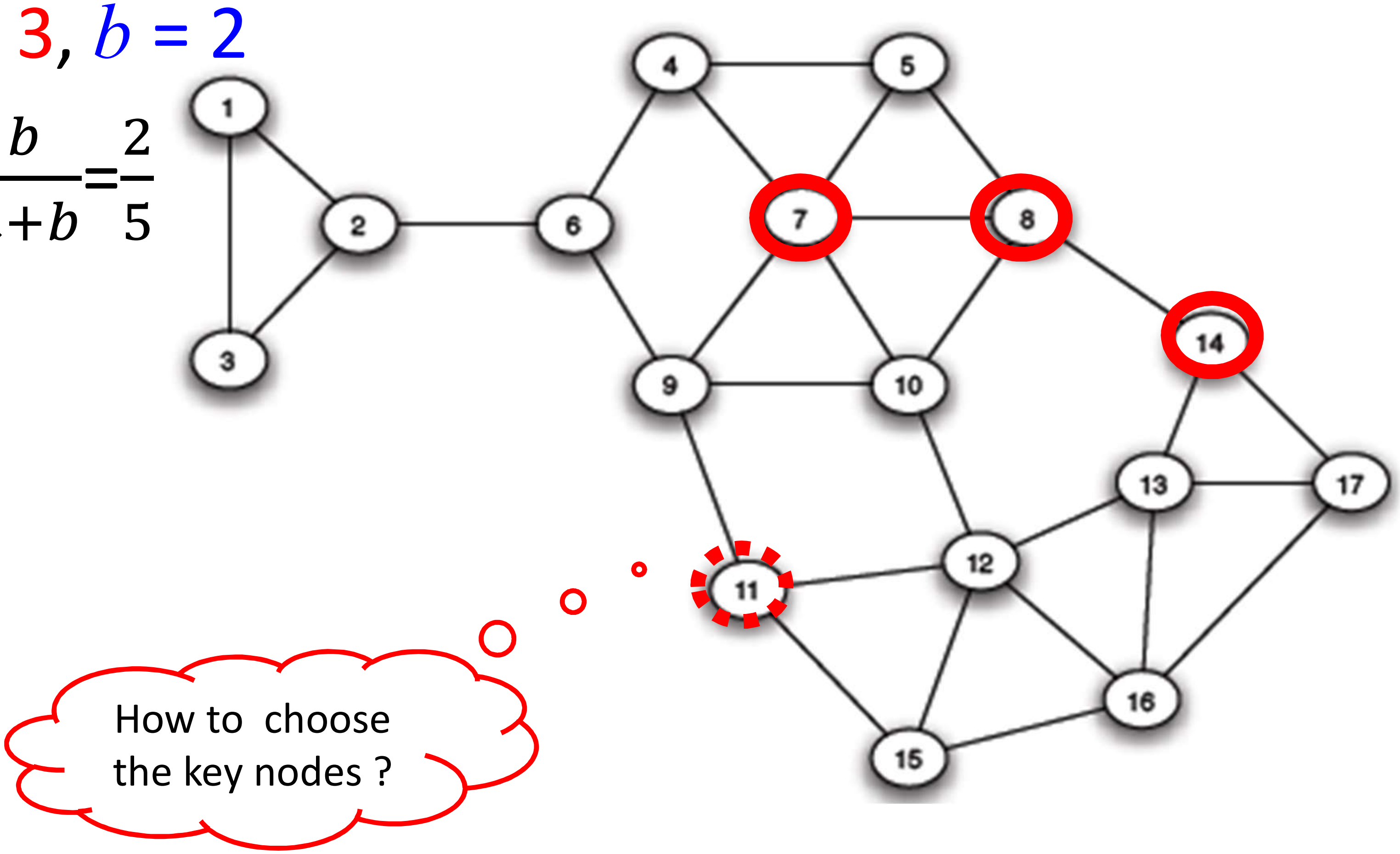
$$q = \frac{b}{a+b} = \frac{2}{5}$$



NO complete cascade

- $a = 3$, $b = 2$

$$q = \frac{b}{a+b} = \frac{2}{5}$$

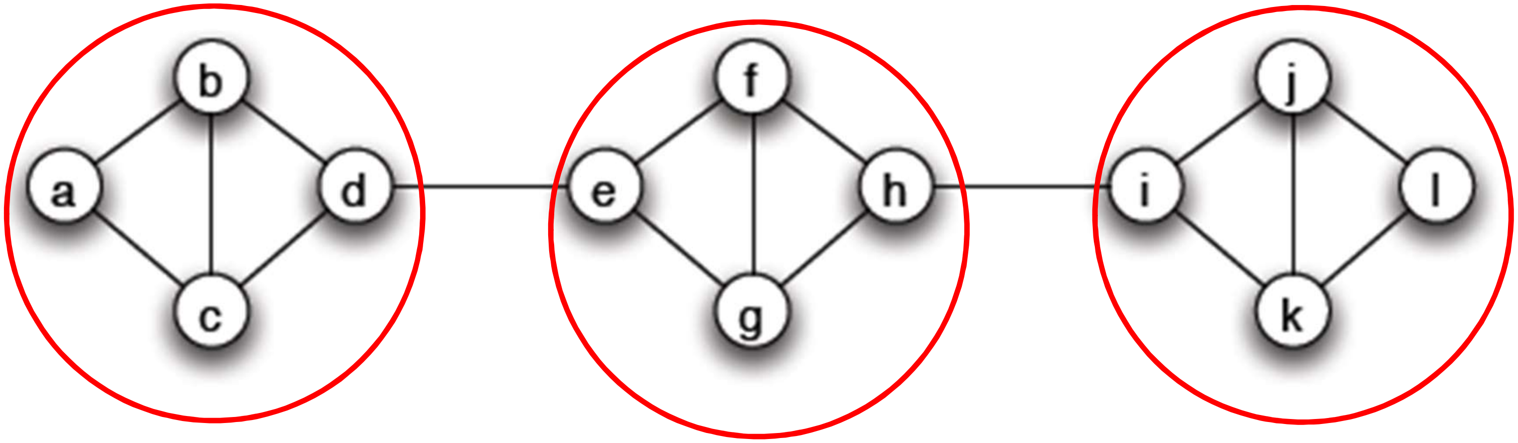


How to choose the key nodes ?

- Population-level model
  - Adoption decisions are evaluated based on the fraction of the entire population.
  - It can be very hard for a new technology to get started, even when it is an improvement on the status quo.
- Network-level model
  - People only care about what the immediate neighbors are doing.
  - It's possible for a small set of initial adopters to essentially start a long fuse running that eventually spreads the innovation globally.

a cluster of density p

- a cluster of density p = a set of nodes such that each node in the set has at least a p fraction of its network neighbors in the set.



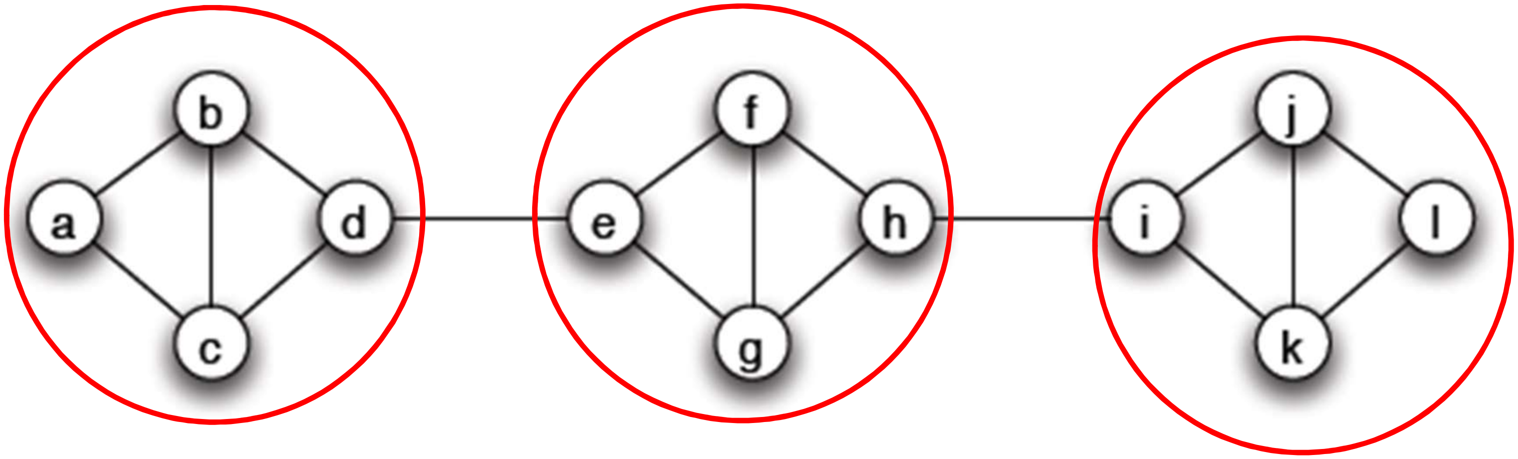
p = 2/3

p = 2/3

p = 2/3

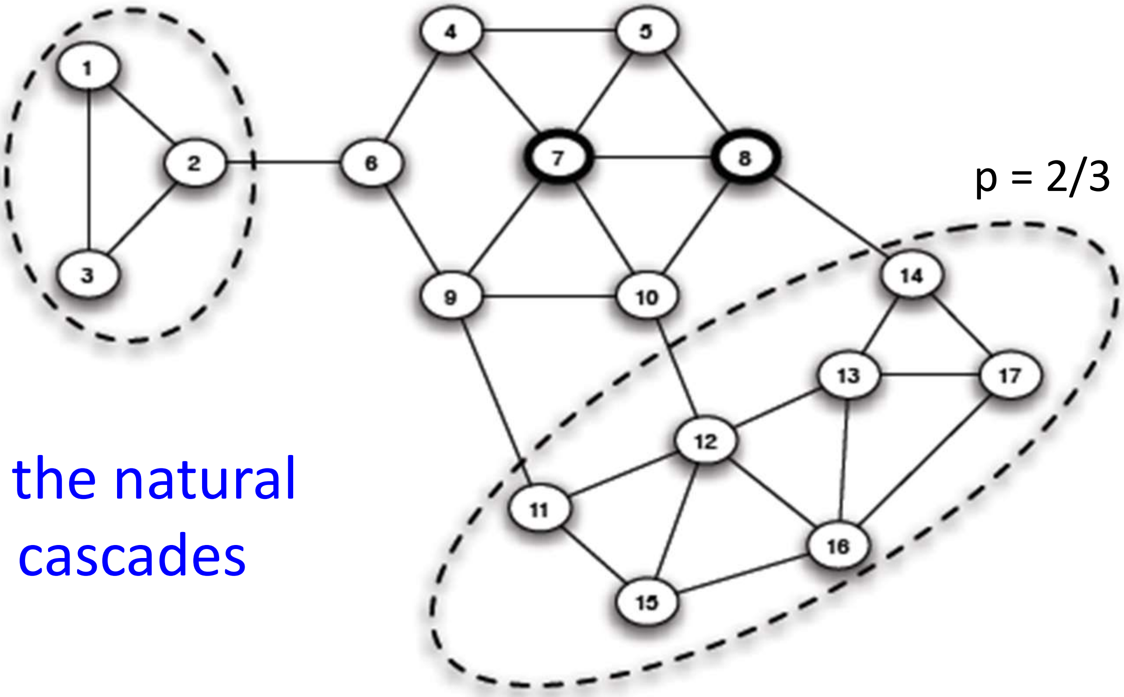
Some properties

- The set of all nodes is always a cluster of density 1.
- The union of two clusters of density p is also a cluster of density p.



Two clusters of density p = 2/3

Threshold q = $\frac{2}{5}$



p = 2/3

p = 2/3

Clusters are the natural obstacles to cascades

The Relationship between Clusters and Cascades

Claim: Consider a set of initial adopters of behavior A, with a threshold of q for nodes in the remaining network to adopt behavior A.

Clusters are Obstacles to Cascades

(i) If the remaining network contains a cluster of density greater than 1 – q, then the set of initial adopters will not cause a complete cascade.

(ii) Moreover, whenever a set of initial adopters does not cause a complete cascade with threshold q, the remaining network must contain a cluster of density greater than 1 – q.

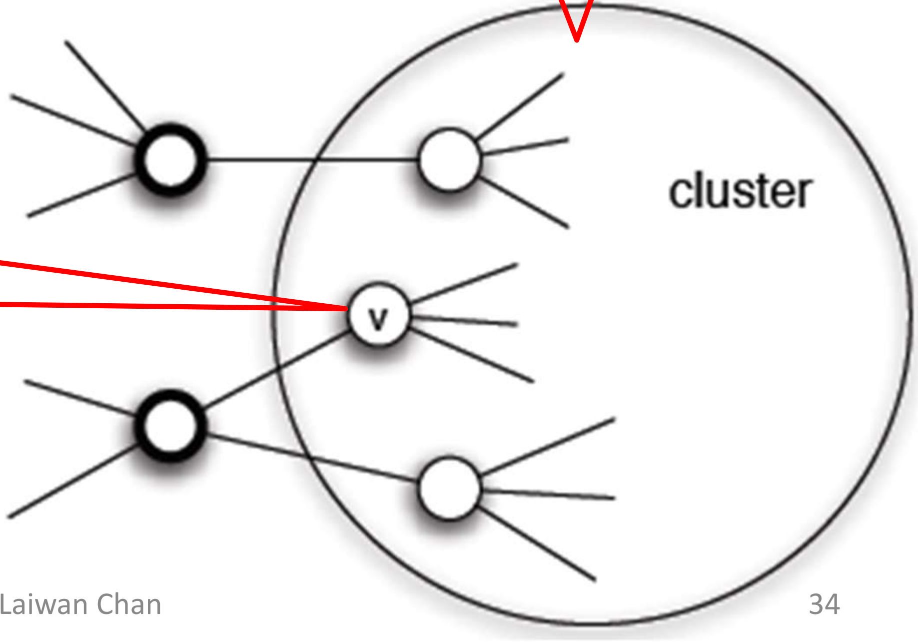
Clusters are the only Obstacles to Cascades

(i) Clusters are Obstacles to Cascades

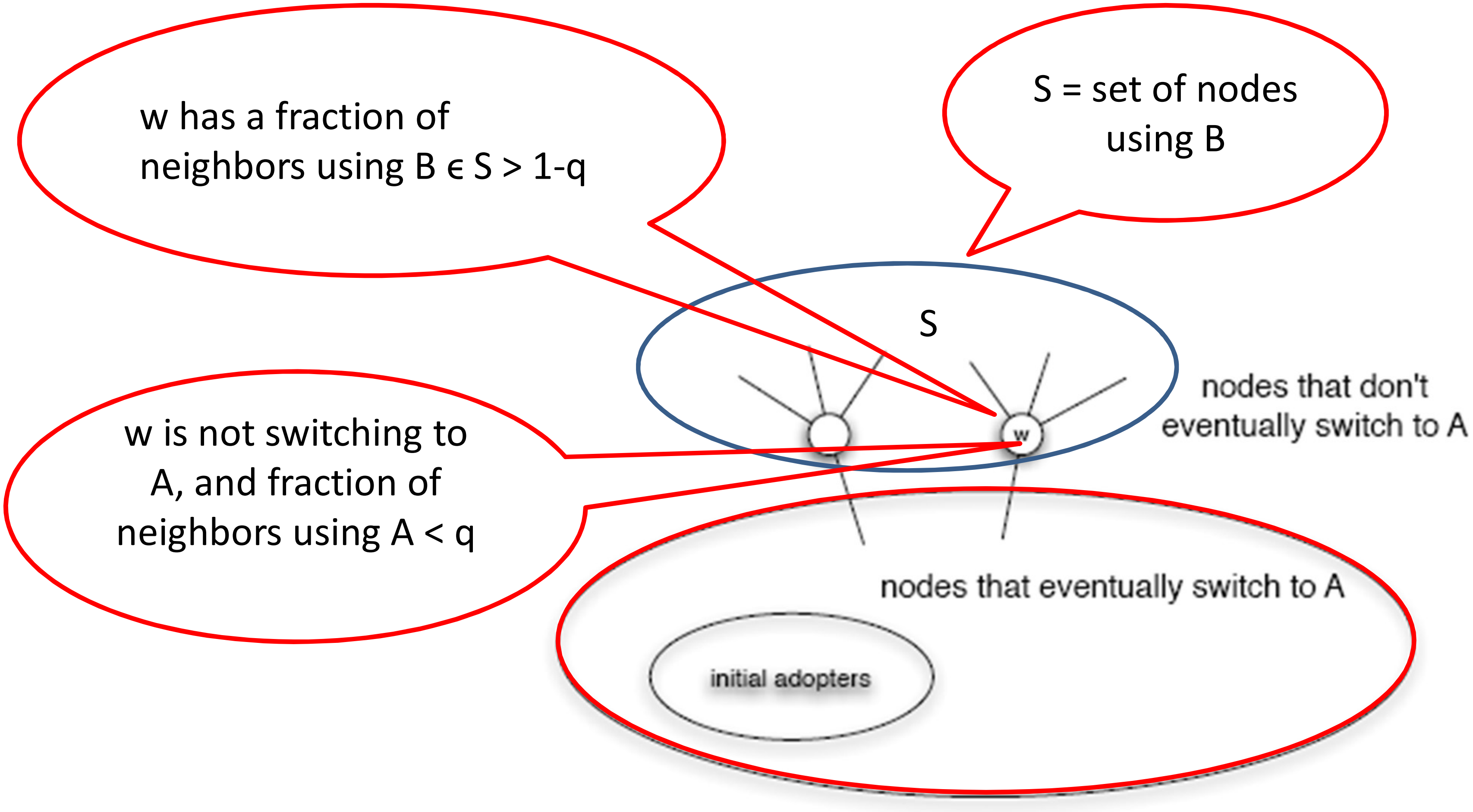
No nodes in the cluster adopt A

Cluster density > 1-q
→ less than q
fraction of nodes
outside the cluster

If v has to adopt A,
at least q fraction of
nodes using A.



(ii) Clusters are the only Obstacles to Cascades



w has a fraction of neighbors using B ϵ S > 1-q

S = set of nodes using B

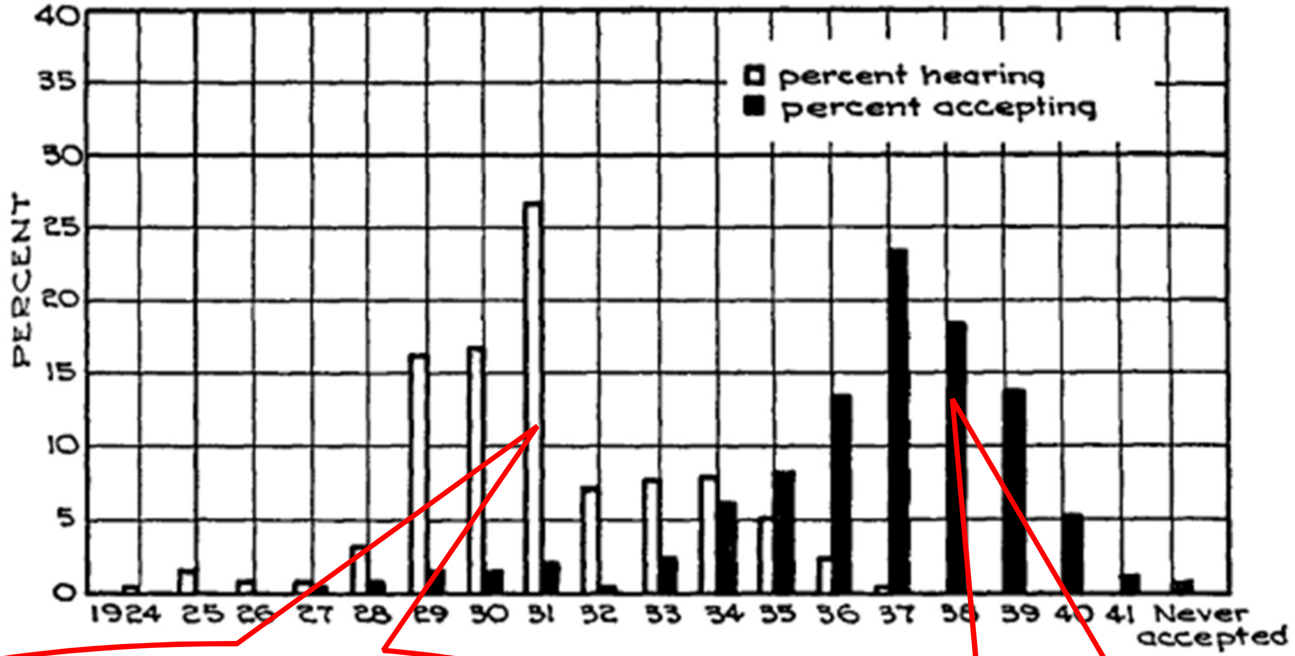
w is not switching to A, and fraction of neighbors using A < q

- Clusters block the spread of cascades
- When a cascade comes to a stop, there’s a cluster !!

Cascade

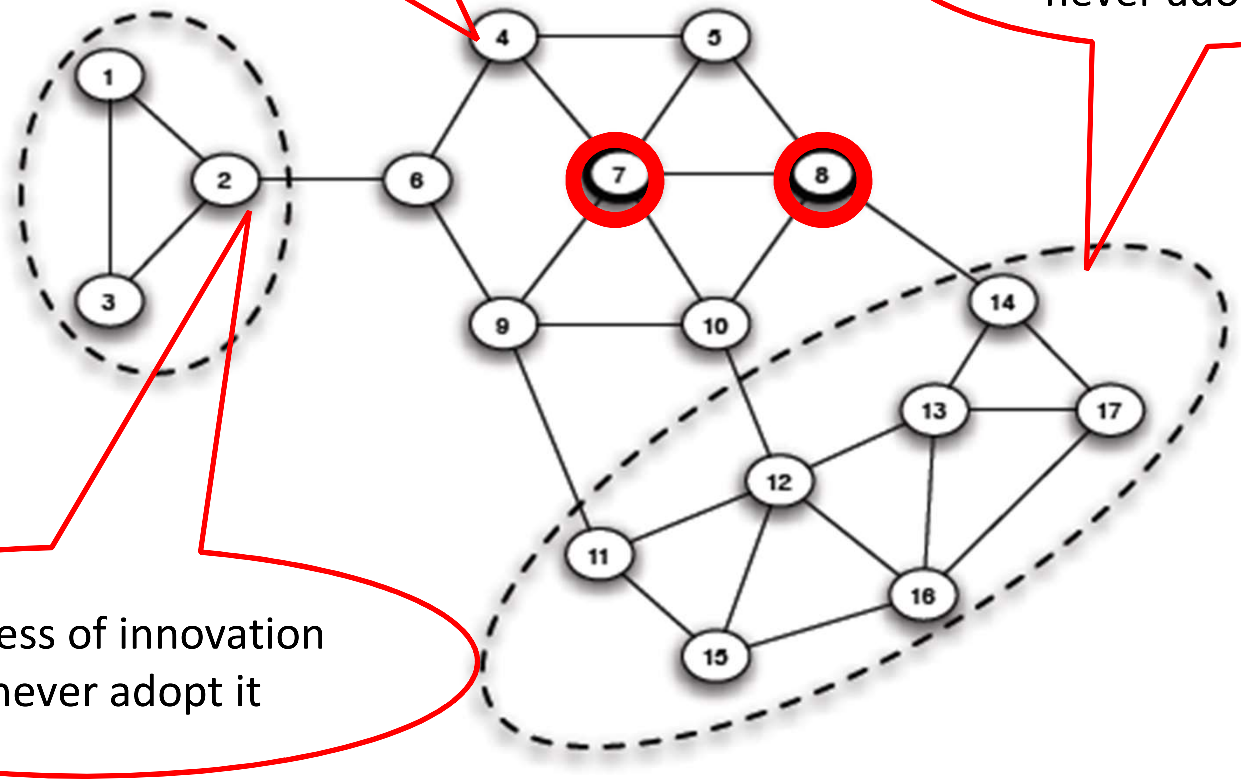
Cluster

Ryan-Gross : hybrid seed corn



Awareness of innovation

Adoption of innovation



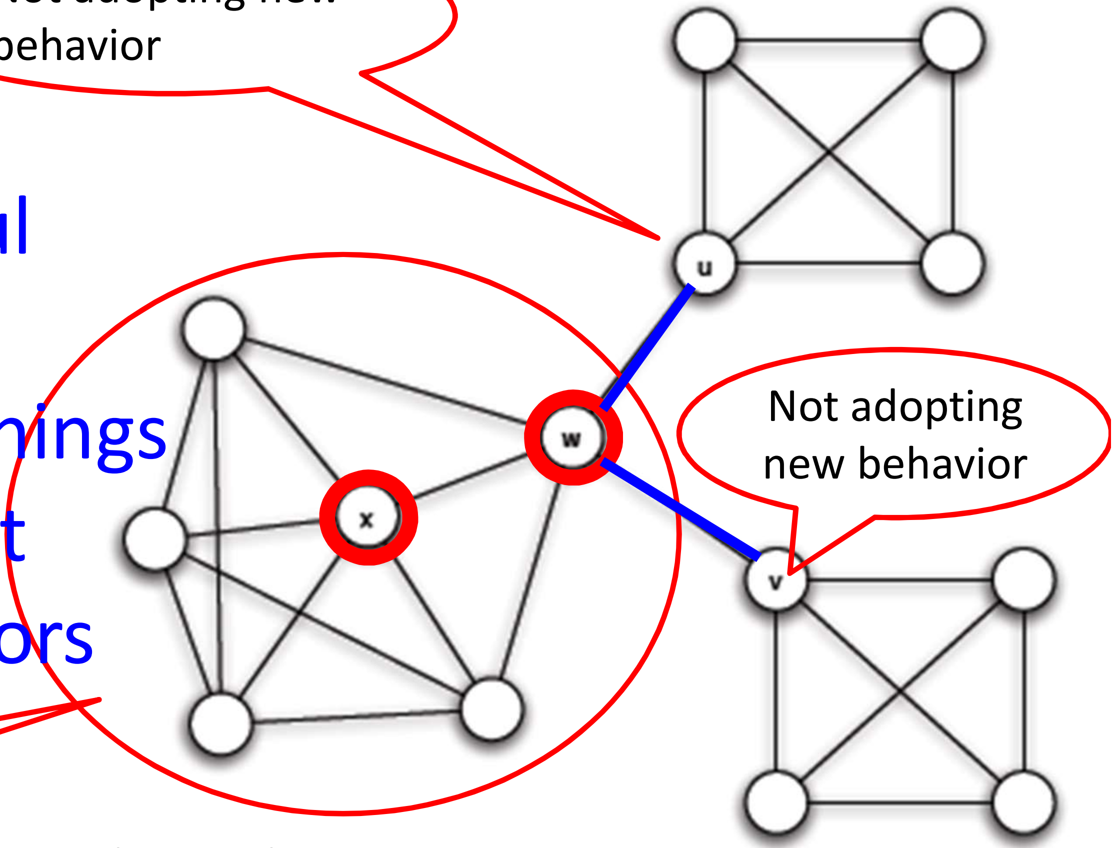
Awareness of innovation but adopt it later when neighbors have adopted it

Awareness of innovation but never adopt it

Awareness of innovation but never adopt it

- x and w are the initial adopters of a new behavior with a threshold of 1/2.

- Bridges and local bridges are powerful ways to convey awareness of new things but they are weak at transmitting behaviors

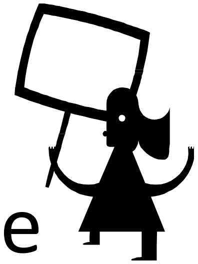


Not adopting new behavior

Not adopting new behavior

Adopting new behavior

- A world-spanning system of weak ties in the global friendship network is able to spread awareness of a joke or an on-line video with remarkable speed.
- Political mobilization moves more sluggishly, needing to gain momentum within neighborhoods and small communities. Strong ties, rather than weak ties, played the more significant role in social movements.



Extensions of the Basic Cascade Model

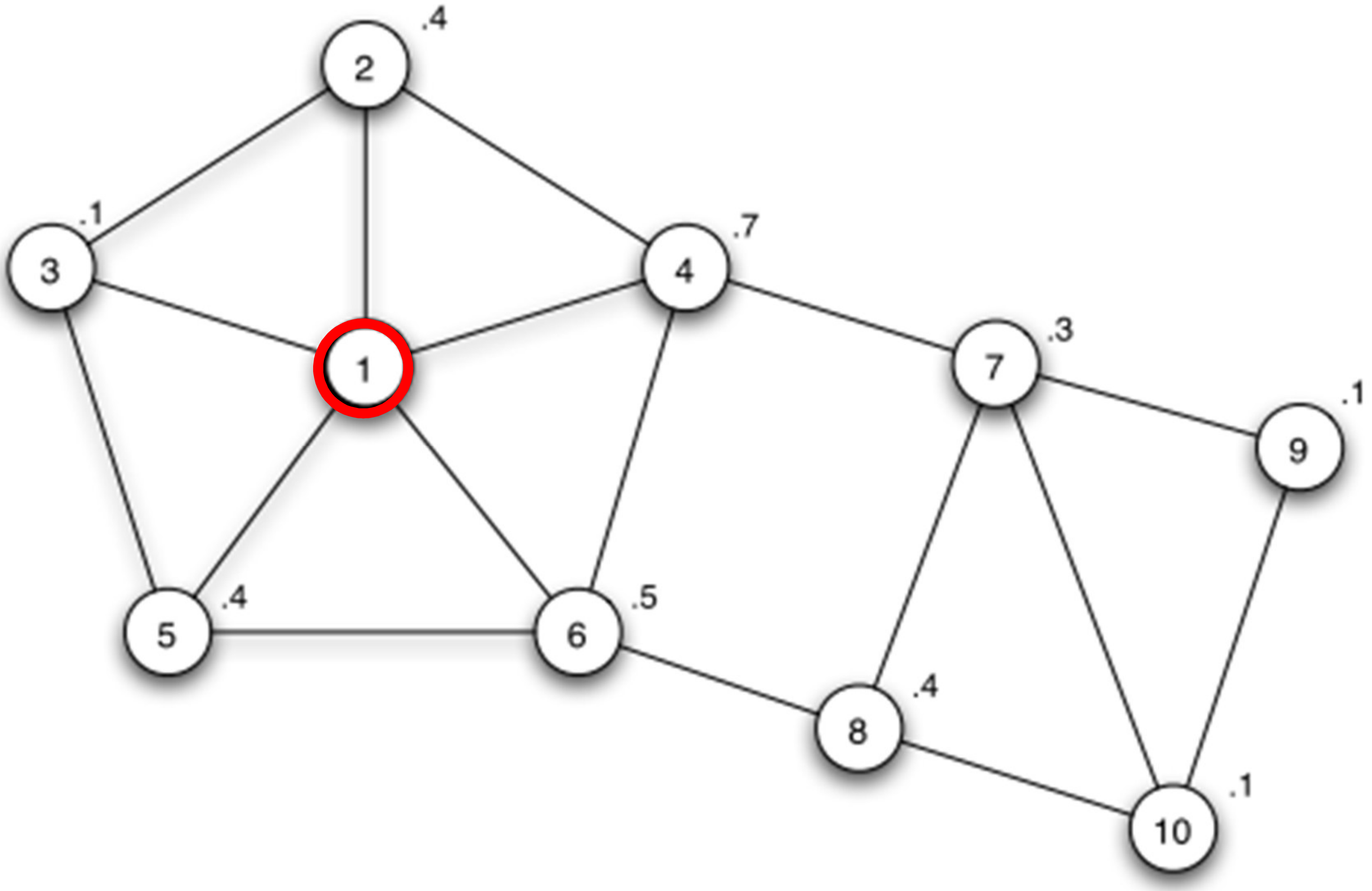
- Heterogeneous Thresholds
  - each node has a specific payoff and hence threshold

		w	
		A	B
v	A	a_v , a_w	0 , 0
	B	0 , 0	b_v , b_w

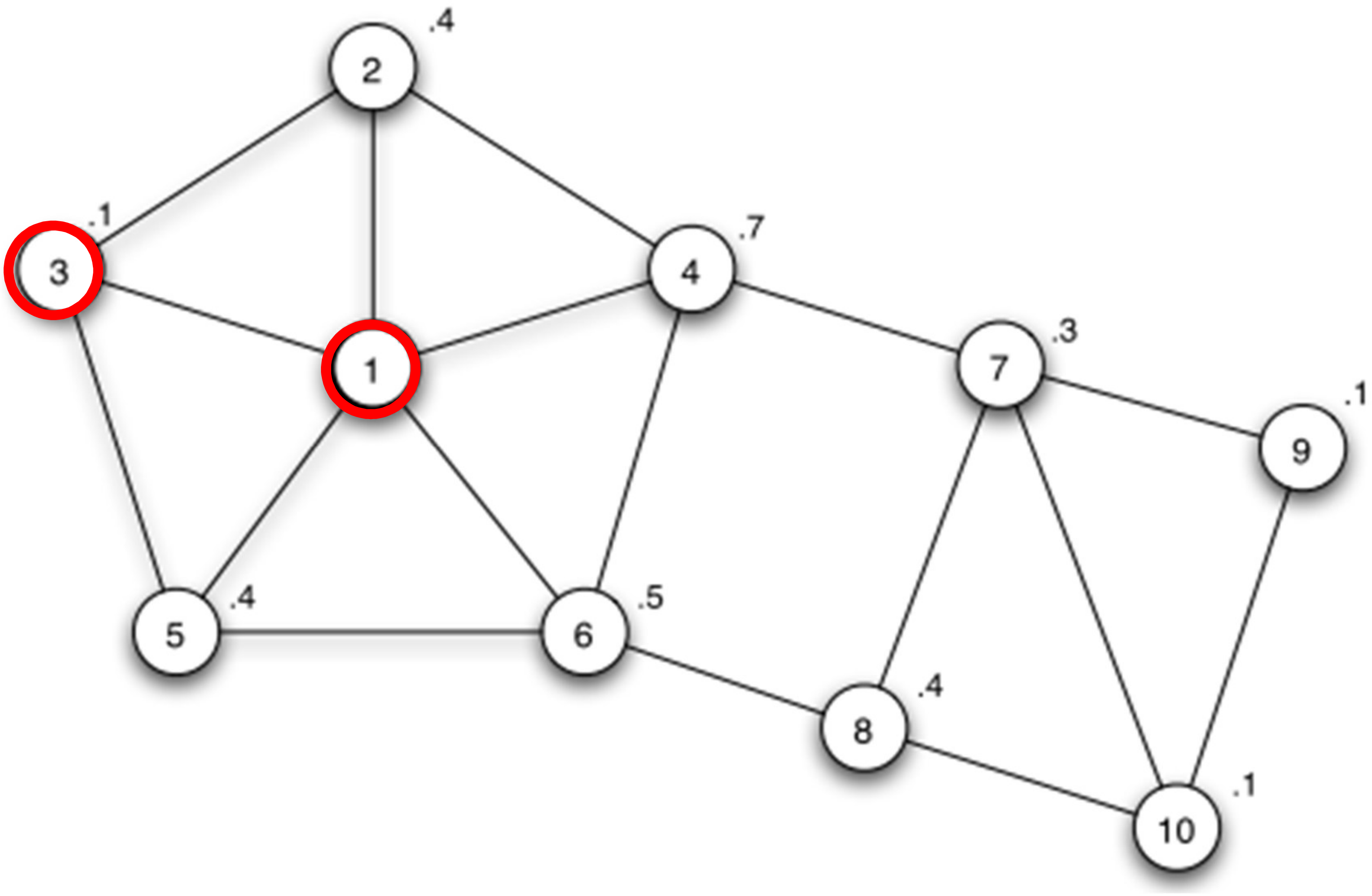
- v has d neighbors
- p fraction of v's neighbors is A
- $1\text{-}p$ fraction of v's neighbors is B
- If v chooses A, payoff = pda_v
- If v chooses B, payoff = $(1\text{-}p)db_v$
- A is better if

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

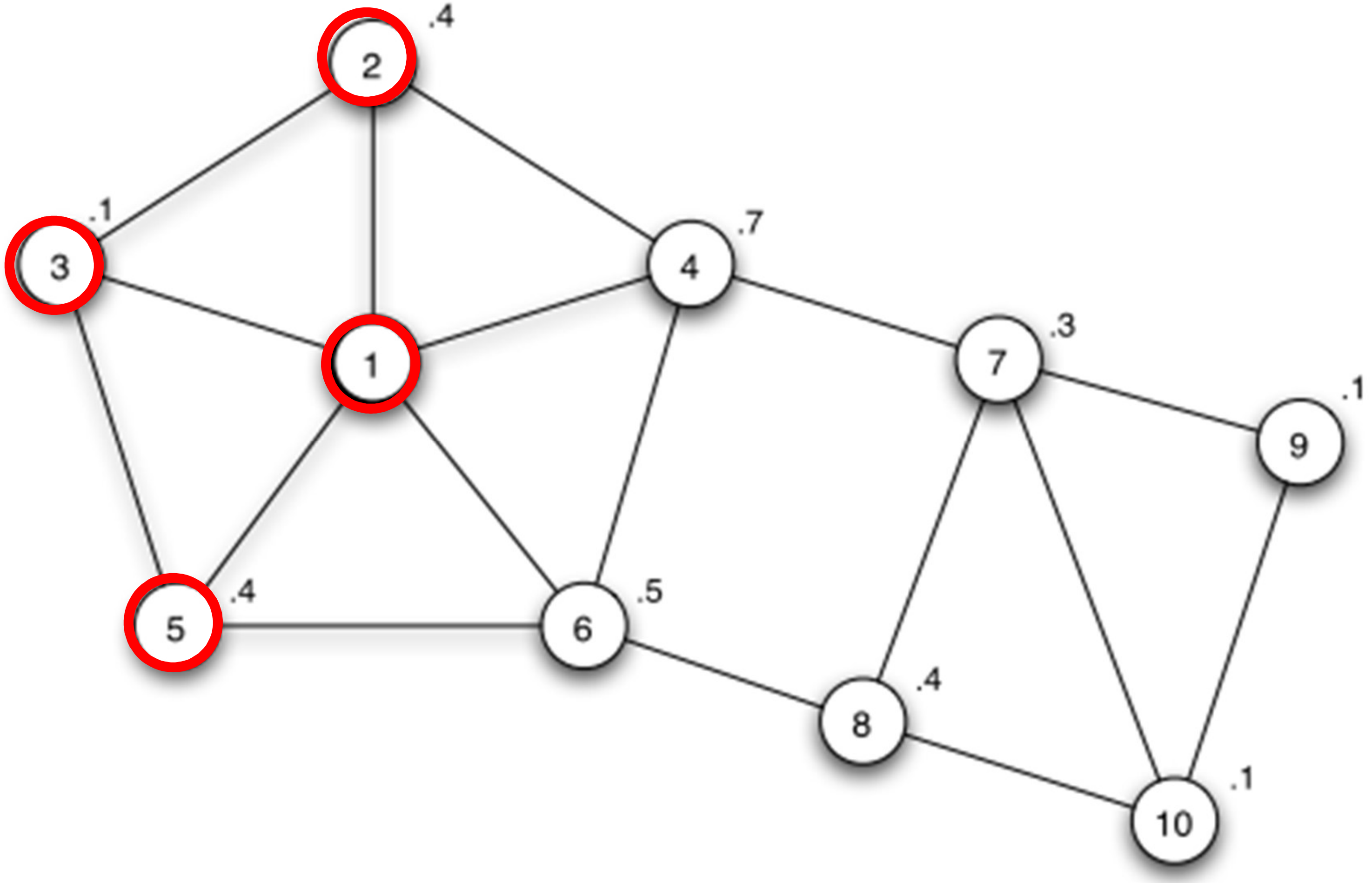
Example of heterogeneous thresholds



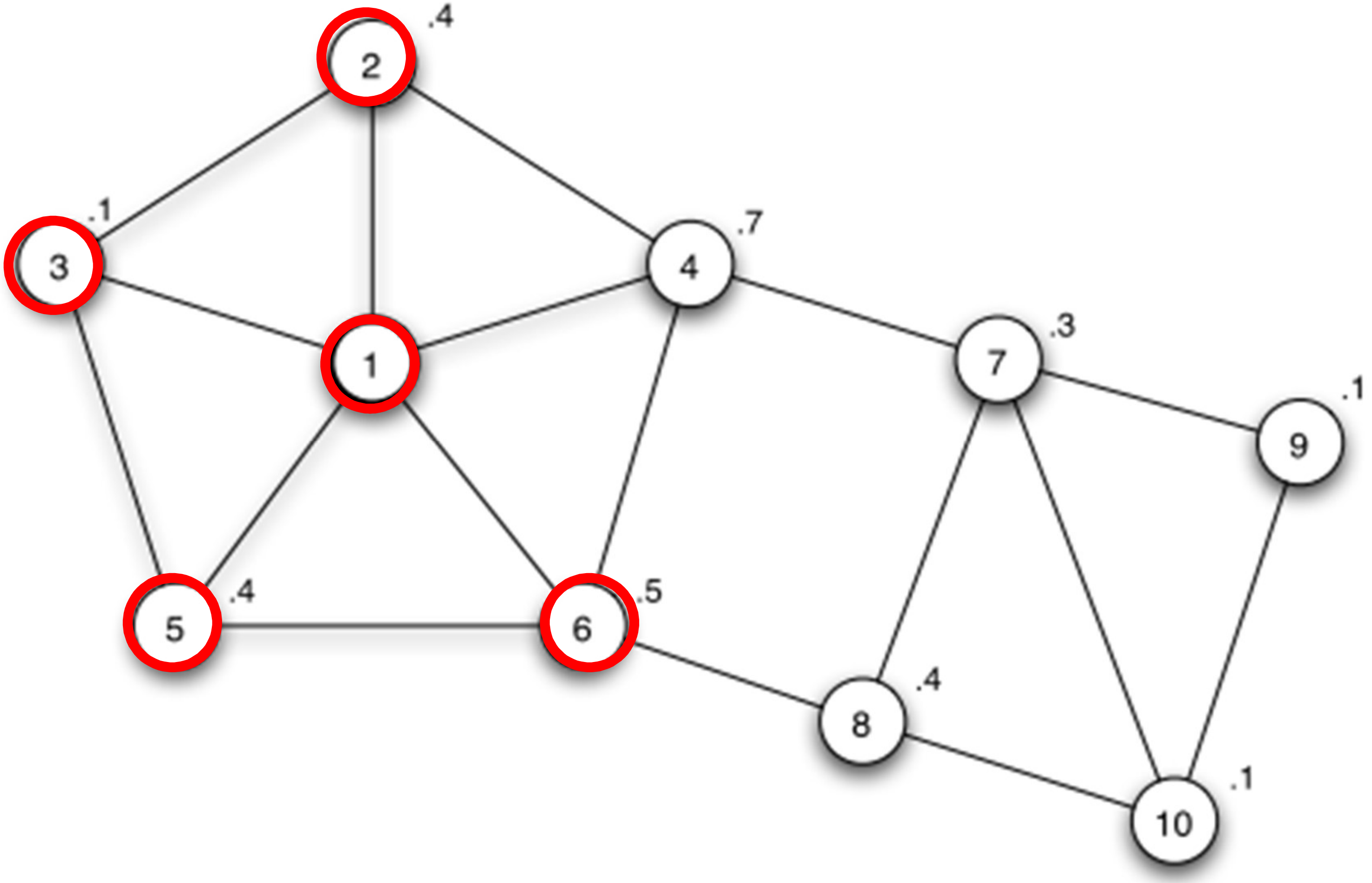
Example of heterogeneous thresholds



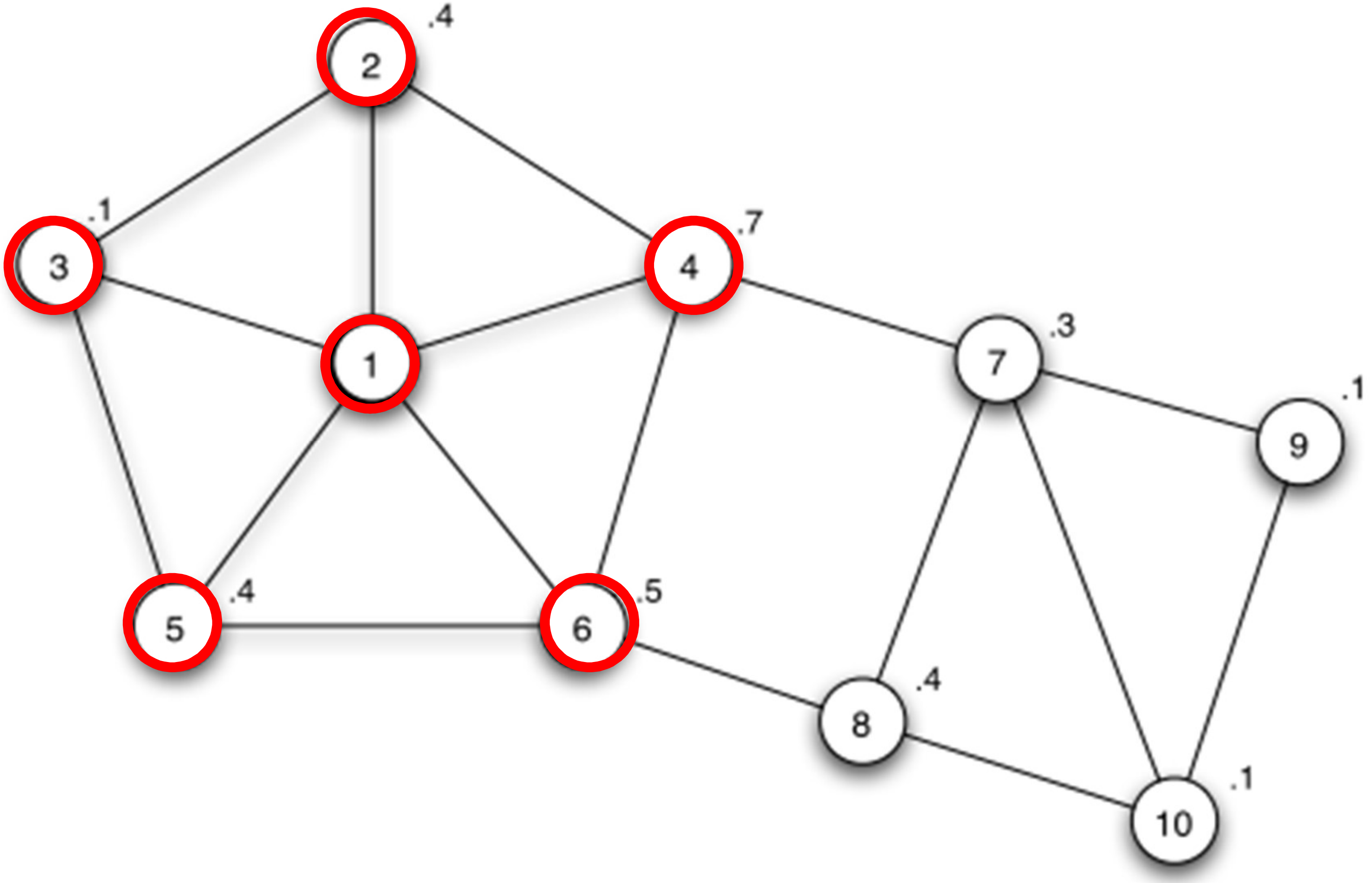
Example of heterogeneous thresholds



Example of heterogeneous thresholds

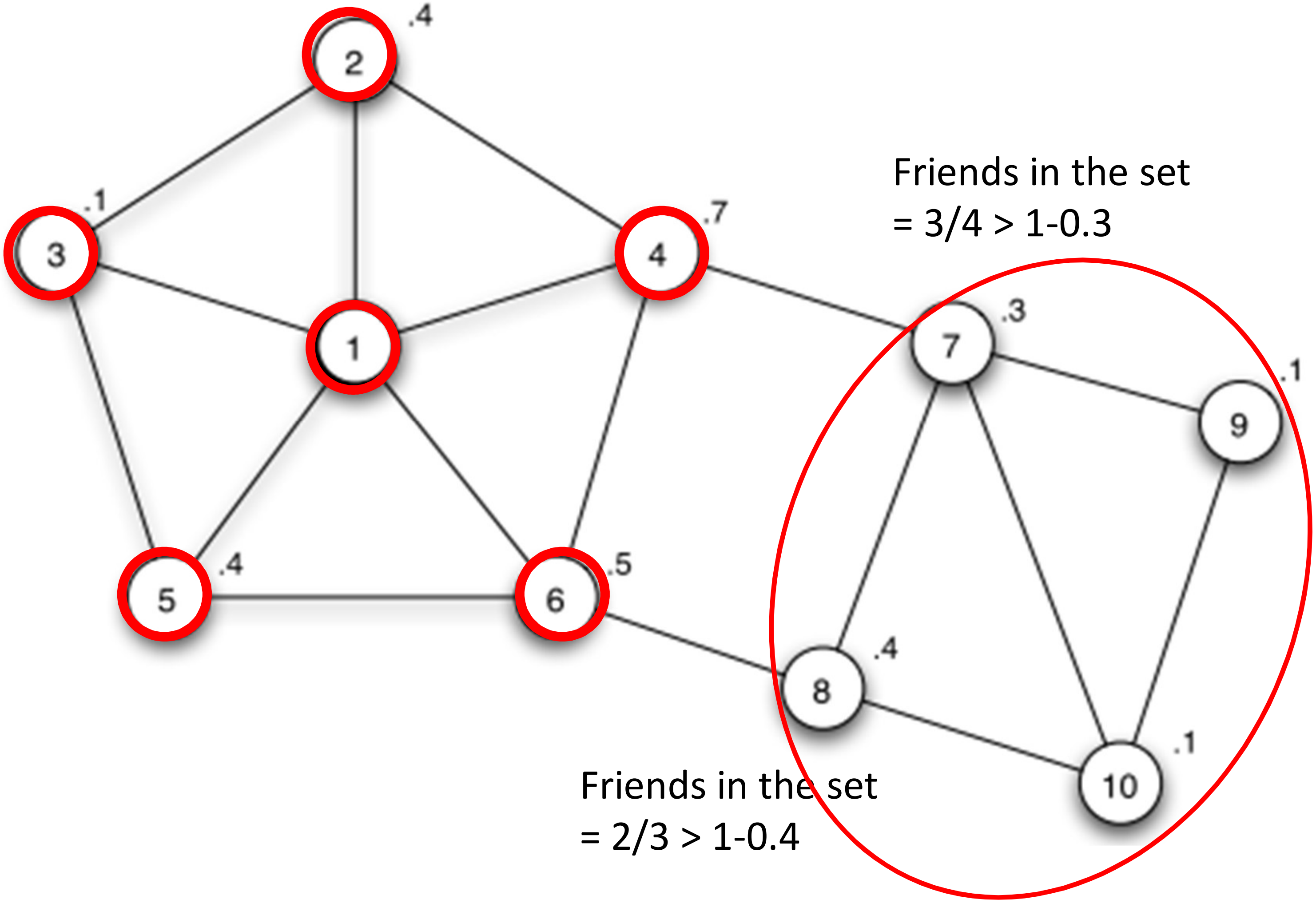


Example of heterogeneous thresholds



- Given a set of node thresholds
- A blocking cluster in the network is a set of nodes for which each node v has more than a $1 - q_v$ fraction of its friends also in the set.
- It can be shown that a set of initial adopters will cause a complete cascade — with a given set of node thresholds — if and only if the remaining network does not contain a blocking cluster.

Example of heterogeneous thresholds



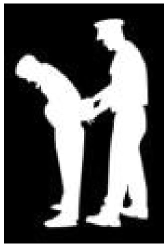
Friends in the set
= 3/4 > 1-0.3

Friends in the set
= 2/3 > 1-0.4

Knowledge, Thresholds, and Collective Action

Integrating network effects at both the population level and the local network level.

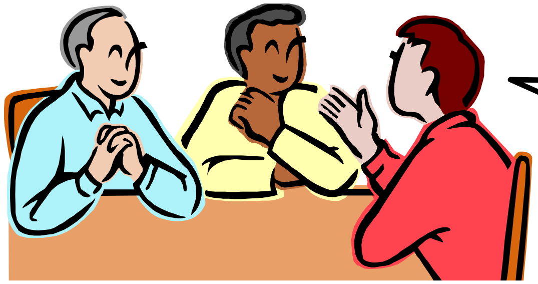
- There is a public demonstration against the government tomorrow.
  - – If an enormous number of people show up, the government will have to address the issue and everyone will benefit.
  - – If only a few hundred show up, the demonstrators will be arrested.
  - – What would you do ?



Knowledge, Thresholds, and Collective Action

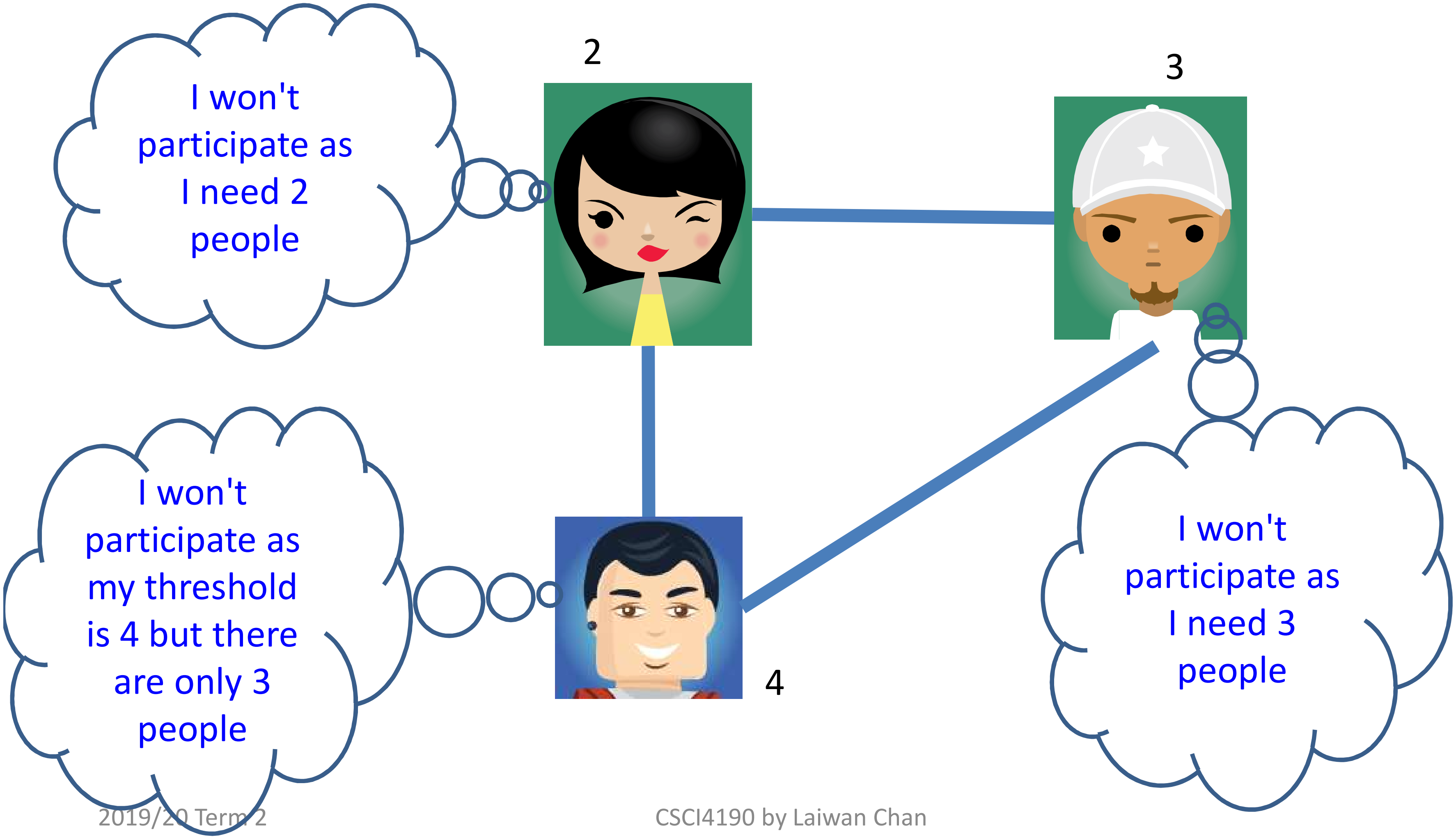
- We consider situations where coordination across a large segment of the population is important, and the underlying social network is serving to transmit information about people’s willingness to participate.
- ***Collective action* problem**: A positive payoff if a lot of people participate, a negative payoff if only a few participate (e.g. protest under a repressive regime).
- ***Pluralistic ignorance:*** People have wildly erroneous estimates about the prevalence of certain opinions in the population at large.

A Model for the Effect of Knowledge on Collective Action

- 

I will show up for the protest if at least k people in total will show up.

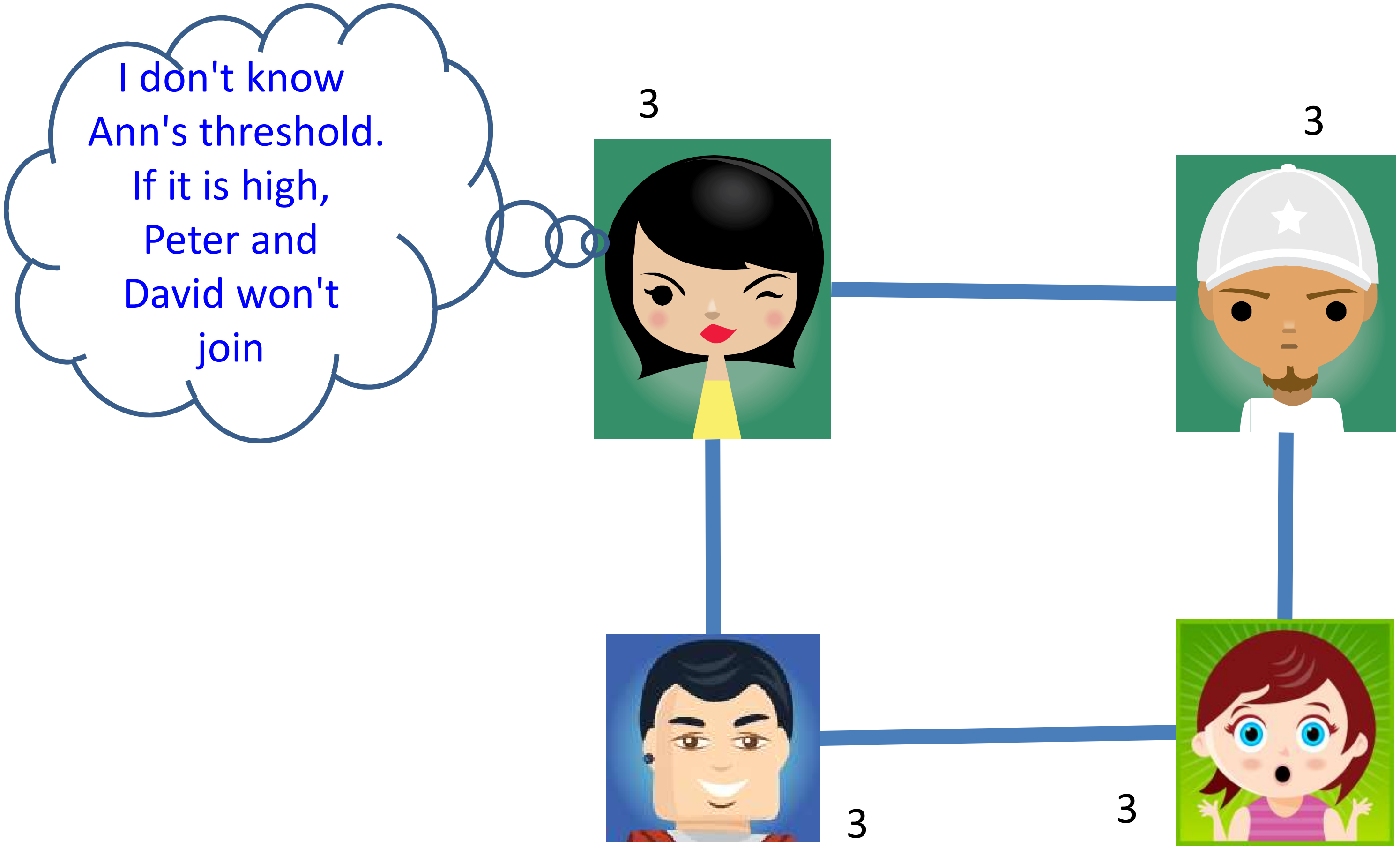
- Each person in the network knows the thresholds of all her neighbors in the network.
- Each does not know the thresholds of anyone else.
- What is likely to happen?



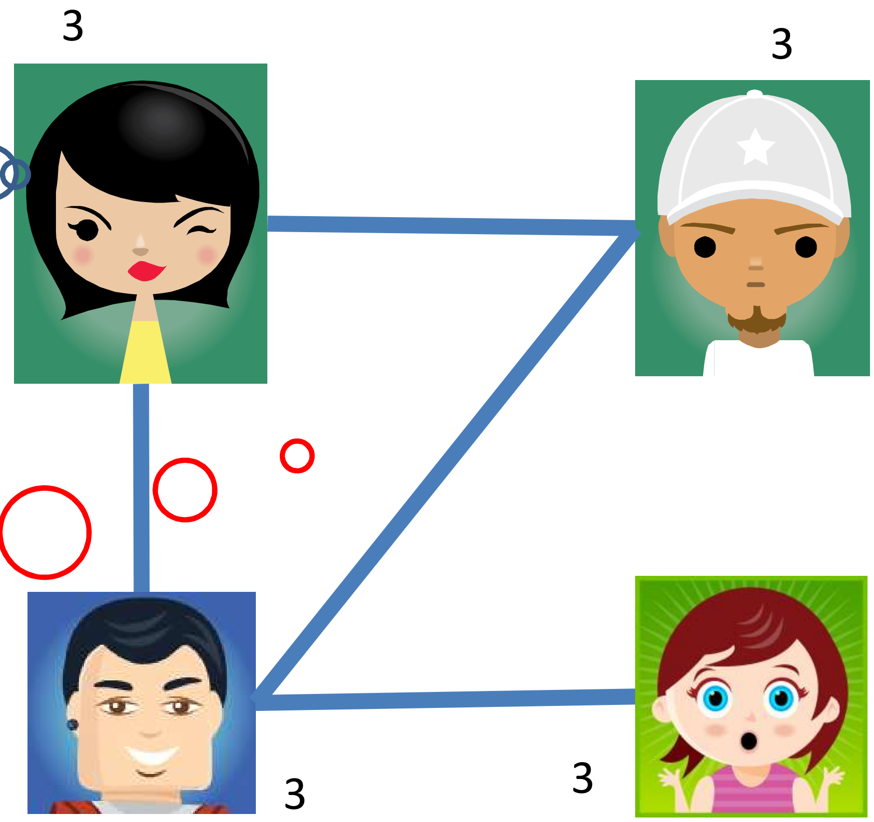
I won't participate as I need 2 people

I won't participate as I need 3 people

I won't participate as my threshold is 4 but there are only 3 people


I don't know Ann's threshold. If it is high, Peter and David won't join
3
3
3
3

All three of us have threshold of 3, so let's join !!!!!



Strong ties and tightly-knit communities give us common knowledge → collective actions

Common Knowledge and Social Institutions

- generators of common knowledge
  - A widely-publicized speech, or
  - an article in a high-circulation newspaper
  - freedom of the press and freedom of assembly
  - advertise products where there are strong network effects (telling each viewer that many other viewers were informed about the product)
- social networks
  - allow for interaction,
  - the flow of information,
  - allow individuals to base decisions on what others know, and on how they expect others to behave as a result.