Online Social Networks and Media

Cascading Behavior in Networks

Chapter 19, from D. Easley and J. Kleinberg

Diffusion in Networks

How new behaviors, practices, opinions and technologies **spread from person to person through a social network** as people **influence** their friends to adopt new ideas

Information effect: choices made by others can provide indirect information about what they know

Old studies:

- Adoption of hybrid seed corn among farmers in Iowa
- Adoption of tetracycline by physicians in US

Basic observations:

- Characteristics of early adopters
- Decisions made in the context of social structure

Diffusion in Networks

Direct-benefit Effect: there are direct payoffs from copying the decisions of others

Spread of technologies such as the phone, email, etc

Common principles:

- ✓*Complexity* of people to understand and implement
- ✓*Observability*, so that people can become aware that others are using it
- ✓*Trialability*, so that people can mitigate its risks by adopting it gradually and incrementally
- ✓*Compatibility* with the social system that is entering (homophily?)

Modeling Diffusion through a Network

An *individual* level model of *direct-benefit effects* in networks due to S. Morris

The benefits of adopting a new behavior increase as more and more of the social network neighbors adopt it

A Coordination Game

Two players (nodes), *u* and *w* linked by an edge
Two possible behaviors (strategies): A and B

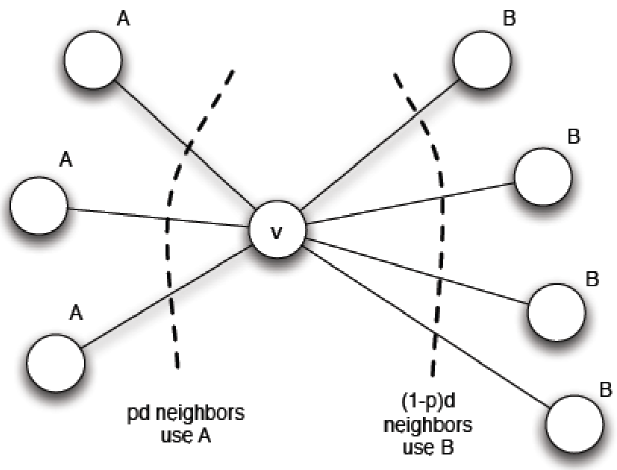
- If both *u* and *w* adapt A, get payoff $a > 0$
- If both *u* and *w* adapt B, get payoff $b > 0$
- If opposite behaviors, than each get a payoff 0

		w: A	w: B
v	A	a, a	$0, 0$
	B	$0, 0$	b, b

Modeling Diffusion through a Network

u plays a copy of the game with each of its neighbors, its payoff is the sum of the payoffs in the games played on each edge

Say some of its neighbors adopt A and some B, what should *u* do to maximize its payoff?



Threshold $q = b/(a+b)$ for preferring A
(at least q of the neighbors follow A)

Modeling Diffusion through a Network: Cascading Behavior

Two obvious equlibria, which ones?

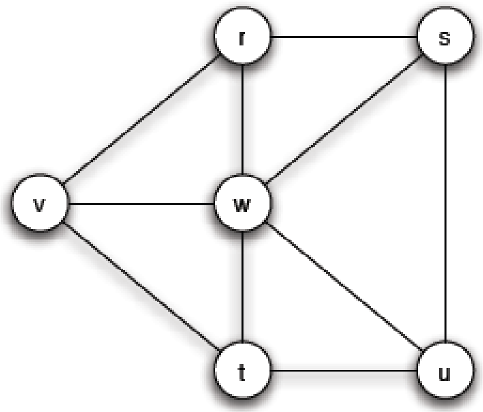
Suppose that initially everyone is using B as a default behavior
A small set of "initial adopters" decide to use A

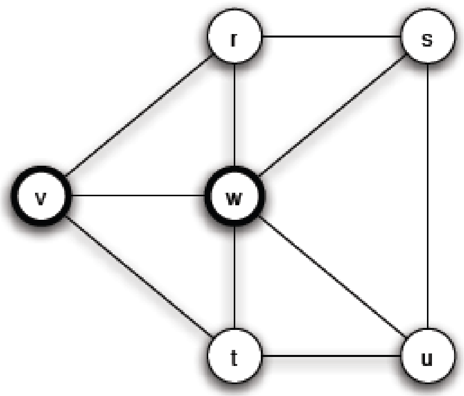
- ✓ When will this result in everyone eventually switching to A?
- ✓ If this does not happen, what causes the spread of A to stop?

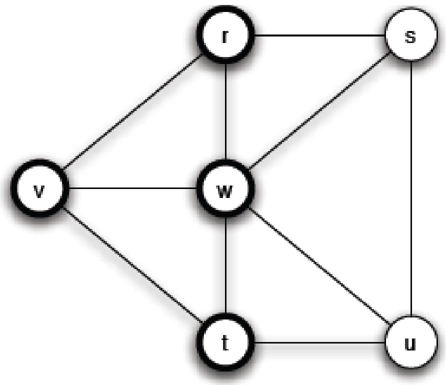
Observation: strictly progressive sequence of switches from A to B

Modeling Diffusion through a Network: Cascading Behavior

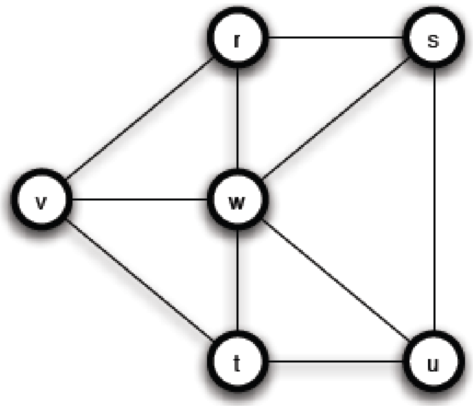
$a = 3$, $b = 2$, $q = 2/5$







Step 1

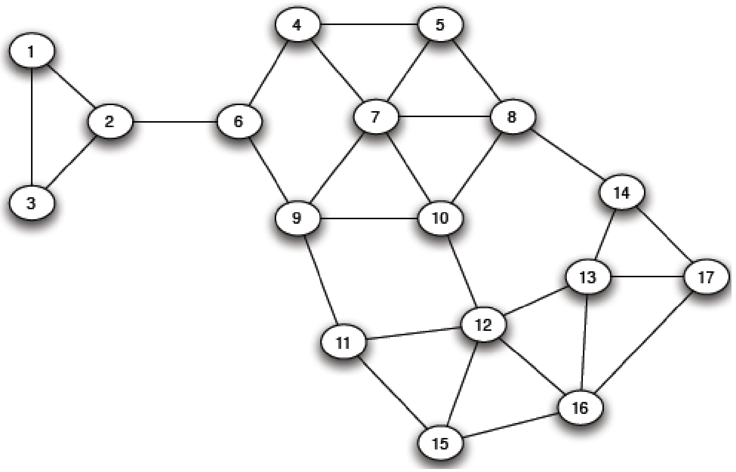


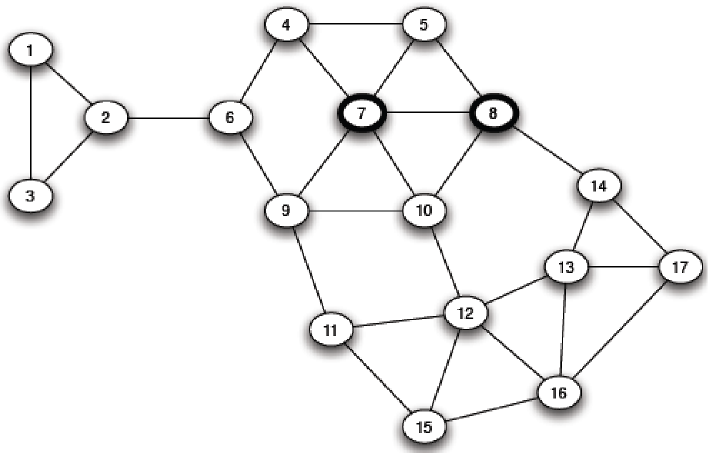
Step 2

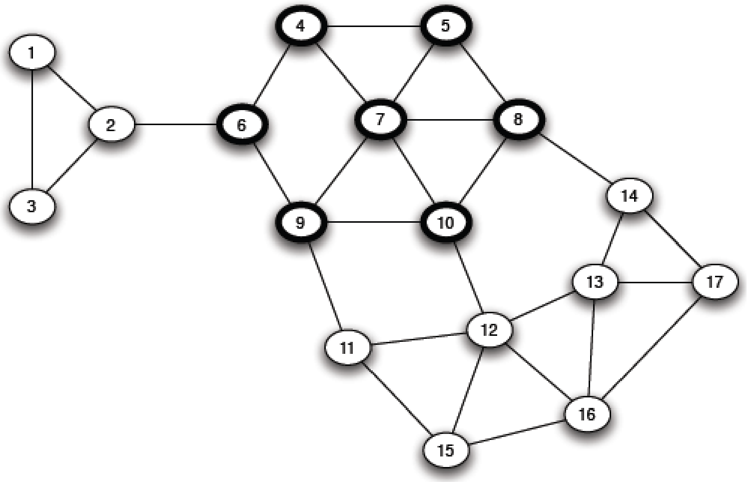
Chain reaction

Modeling Diffusion through a Network: Cascading Behavior

$a = 3, b = 2, q = 2/5$







Step 3

Modeling Diffusion through a Network: Cascading Behavior

Chain reaction of switches to A -> a cascade of adoptions of A

1. Consider a set of initial adopters who start with a new behavior A, while every other node starts with behavior B.
2. Nodes then repeatedly evaluate the decision to switch from B to A using a threshold of q.
3. 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.

Modeling Diffusion through a Network: Cascading Behavior and "Viral Marketing"

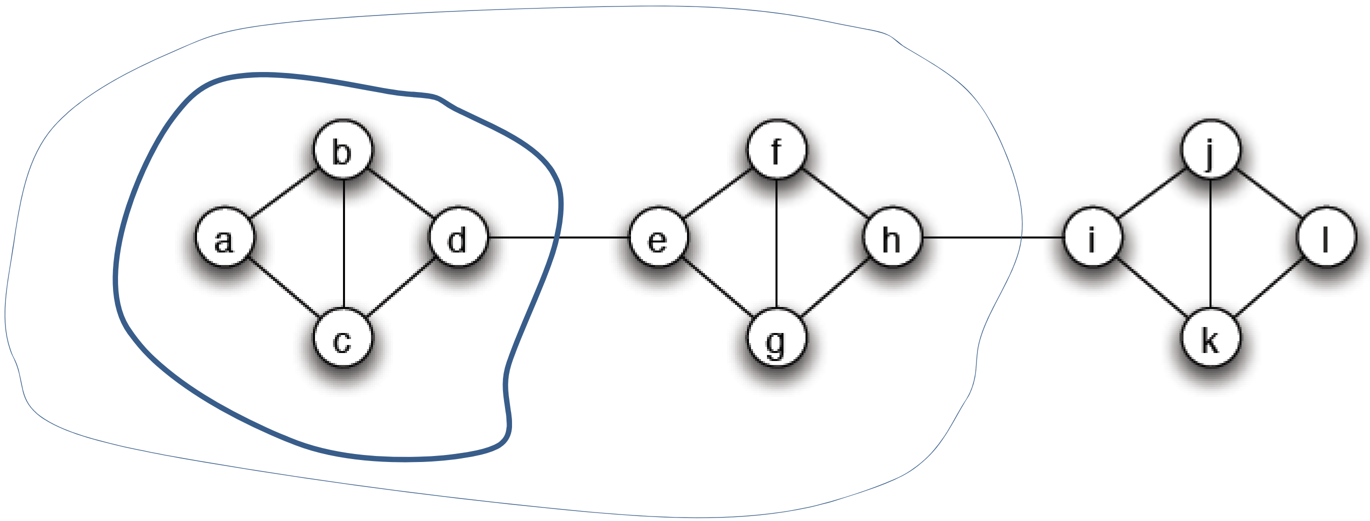
Tightly-knit communities in the network can work to hinder the spread of an innovation
(examples, age groups and life-styles in social networking sites, Mac users, political opinions)

Strategies

- Improve the quality of A (increase the payoff *a*)
- Convince a small number of *key people* to switch to A

Cascades and Clusters

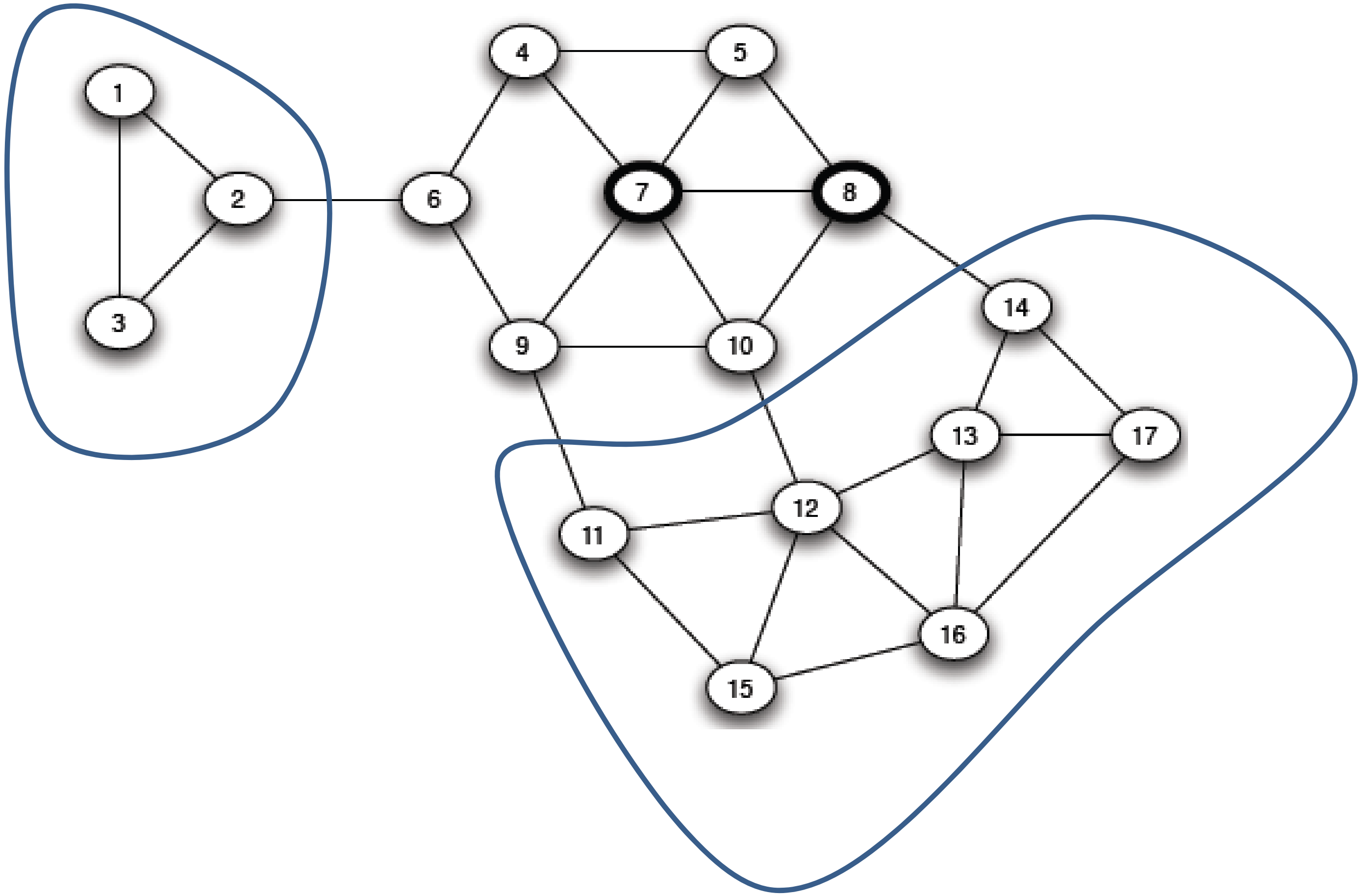
A cluster of density *p* is a set of nodes such that each node in the set has at least a *p* fraction of its neighbors in the set



Ok, but it does not imply that any two nodes in the same cluster necessarily have much in common

The union of any two cluster of density *p* is also a cluster of density *p*

Cascades and Clusters



Cascades and Clusters

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.

(i) (clusters as obstacles to cascades)

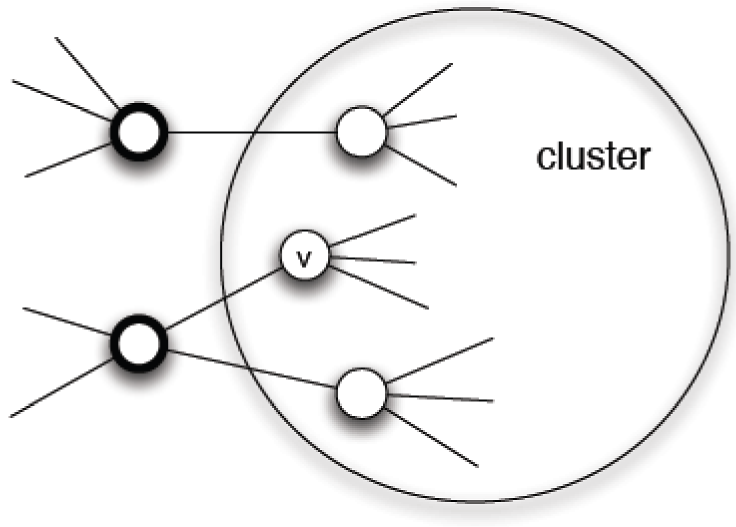
If the remaining network contains a cluster of density greater than $1 - q$, then the set of initial adopters will not cause a complete cascade.

(ii) (clusters are the only obstacles to cascades)

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 $1 - q$.

Cascades and Clusters

Proof of (i) (clusters as obstacles to cascades)

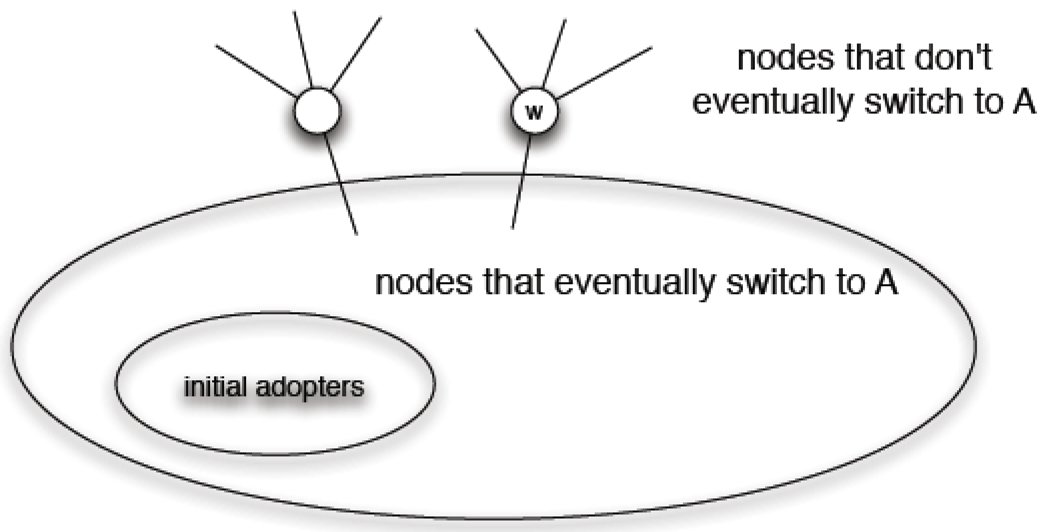


Proof by contradiction

Let v be the first node in the cluster that adopts A

Cascades and Clusters

Proof of (ii) (clusters are the only obstacles to cascades)

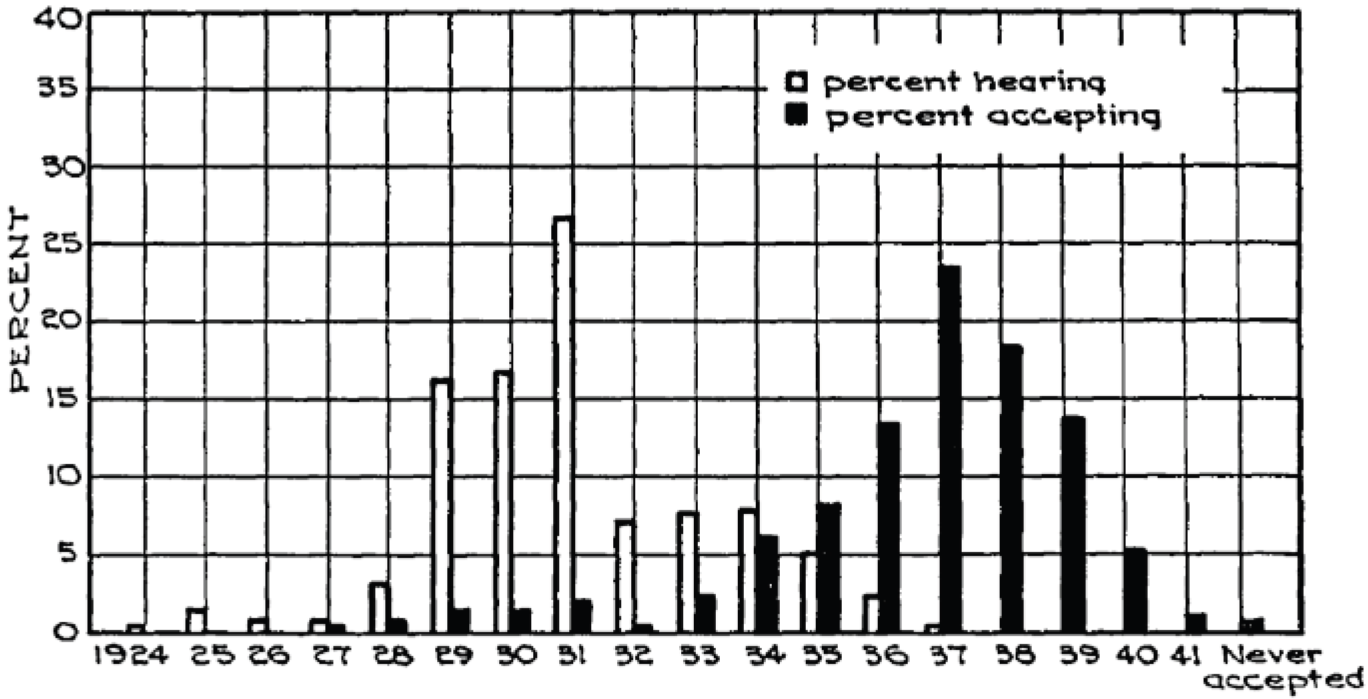


Let *S* be the set of nodes using B at the end of the process

Show that S is a cluster of density > 1 - *q*

Diffusion, Thresholds and the Role of Weak Ties

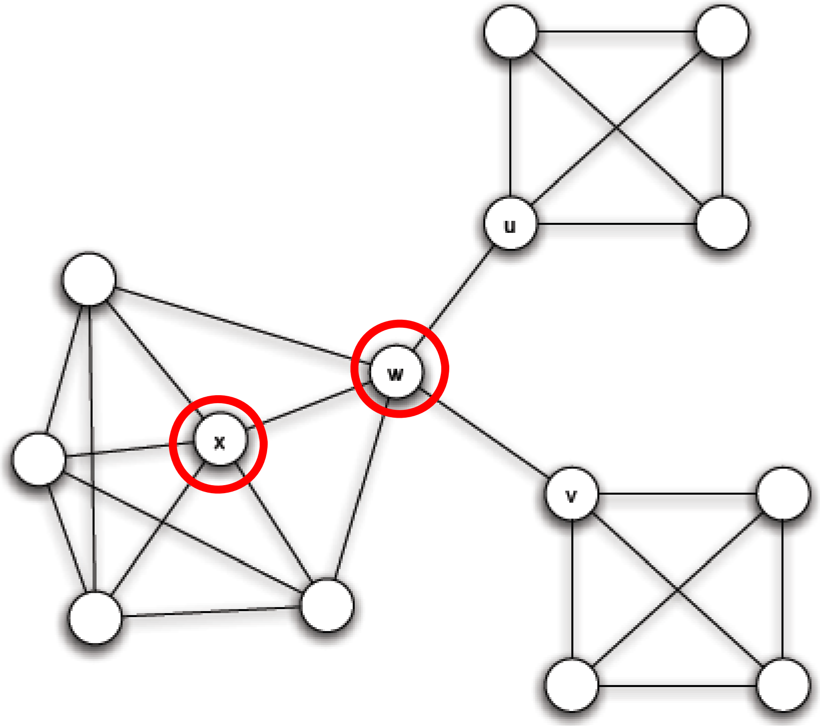
A crucial difference between learning a new idea and actually deciding to accept it



Diffusion, Thresholds and the Role of Weak Ties

Relation to weak ties and local bridges

$q = 1/2$



Bridges convey awareness but weak at transmitting costly to adopt behaviors

Extensions of the Basic Cascade Model:
Heterogeneous Thresholds

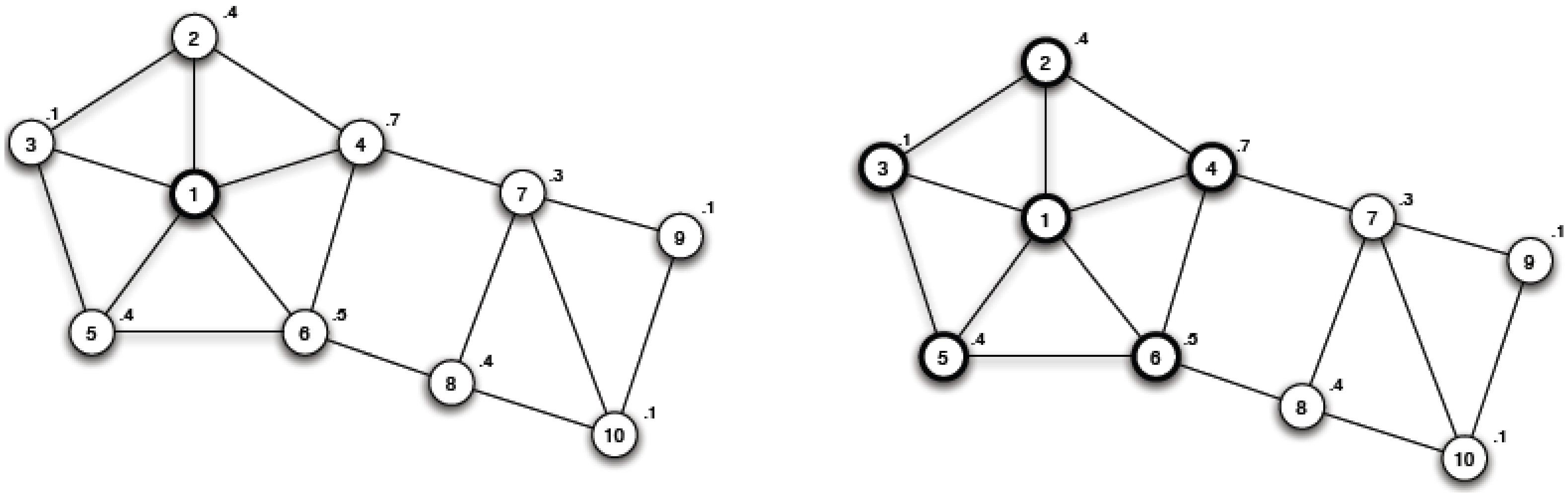
Each person values behaviors A and B differently:

- If both *u* and *w* adapt A, *u* gets a payoff $a_u > 0$ and *w* a payoff $a_w > 0$
- If both *u* and *w* adapt B, u gets a payoff $b_u > 0$ and w a payoff $b_w > 0$
- If opposite behaviors, than each gets a payoff 0

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

Each node u has its own personal threshold $q_u \geq b_u/(a_u + b_u)$

Extensions of the Basic Cascade Model:
Heterogeneous Thresholds



✓Not just the power of influential people, but also the extent to which they have access to easily influenceable people

✓What about the role of clusters?
A *blocking cluster* in the network is a set of nodes for which each node *u* has more that $1 - q_u$ fraction of its friends also in the set.

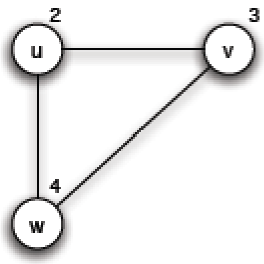
Knowledge, Thresholds and Collective Action:
Collective Action and Pluralistic Ignorance

A collective action problem: an activity produces benefits only if enough people participate

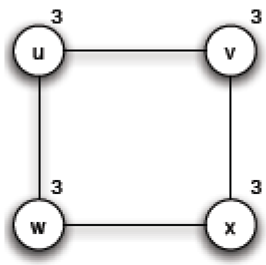
Pluralistic ignorance: a situation in which people have wildly erroneous estimates about the prevalence of certain opinions in the population at large

Knowledge, Thresholds and Collective Action:
A model for the effect of knowledge on collective actions

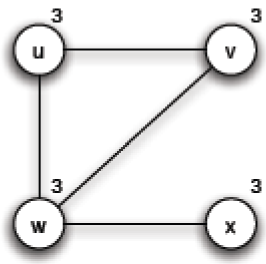
- Each person has a personal threshold which encodes her willingness to participate
- A threshold of *k* means that she will participate if at least *k* people in total (including herself) will participate
- Each person in the network knows the thresholds of her neighbors in the network



- w will never join, since there are only 3 people
- v
- u



- Is it safe for u to join?



- Is it safe for u to join? (common knowledge)

Knowledge, Thresholds and Collective Action:
Common Knowledge and Social Institutions

- Not just transmit a message, but also make the listeners or readers *aware that many others have gotten the message* as well

- Social networks do not simply allow or interaction and flow of information, but these processes in turn allow individuals to base decisions *on what other knows* and *on how they expect others to behave as a result*

The Cascade Capacity

Given a network, what is the *largest threshold* at which *any "small" set* of initial adopters can cause a *complete cascade*?

Cascade capacity of the network

Infinite network in which each node has a finite number of neighbors
Small means finite set of nodes

The Cascade Capacity: Cascades on Infinite Networks

- Initially, **a finite set S** of nodes has behavior A and all others adopt B

- Time runs forwards in steps, t = 1, 2, 3, …

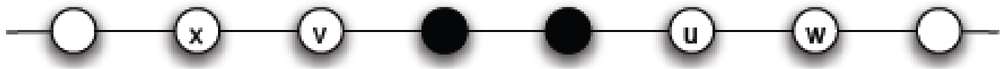
- In each step t, each node other than those in S uses the decision rule with threshold q to decide whether to adopt behavior A or B

- The set S causes a complete cascade if, starting from S as the early adopters of A, every node in the network eventually switched permanently to A.

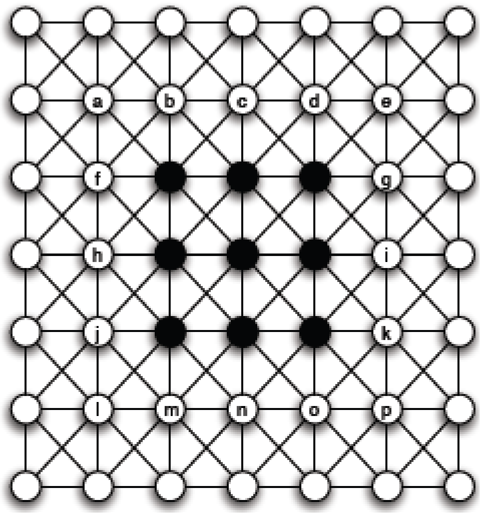
The cascade capacity of the network is the largest value of the threshold q for which some finite set of early adopters can cause a complete cascade.

The Cascade Capacity: Cascades on Infinite Networks

An infinite path



Spreads if ≤ 1/2



An infinite grid

Spreads if ≤ 3/8

✓An intrinsic property of the network
✓Even if A better, for *q* strictly between 3/8 and ½, A cannot win

The Cascade Capacity: Cascades on Infinite Networks

How large can a cascade capacity be?

At least 1/2, but is there any network with a higher cascade capacity?

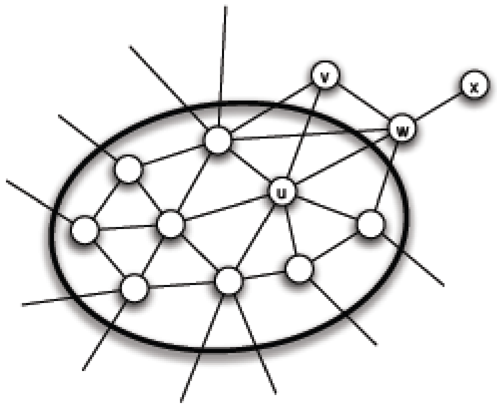
Will mean that an inferior technology can displace a superior one, even when the inferior technology starts at only a small set of initial adopters.

The Cascade Capacity: Cascades on Infinite Networks

Claim: There is no network in which the cascade capacity exceeds 1/2

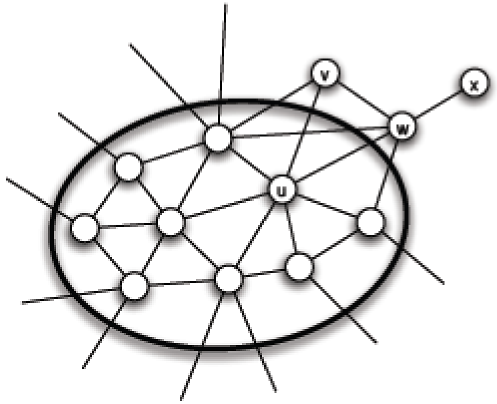
The Cascade Capacity: Cascades on Infinite Networks

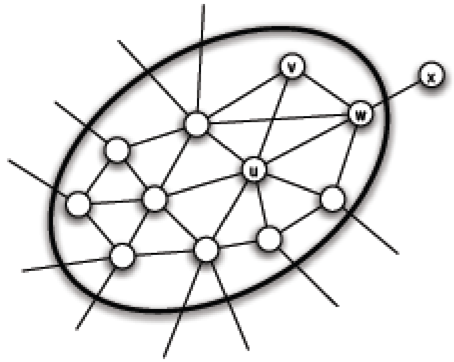
Interface: the set of A-B edges



Prove that in each step the size of the interface strictly decreases
Why is this enough?

The Cascade Capacity: Cascades on Infinite Networks





At some step, a number of nodes decide to switch from B to A

General Remark: In this simple model, a worse technology cannot displace a better and wide-spread one

Compatibility and its Role in Cascades

An extension where a single individual can sometimes choose a combination of two available behaviors

Coordination game with a bilingual option

- Two bilingual nodes can interact using the better of the two behaviors
- A bilingual and a monolingual node can only interact using the behavior of the monolingual node

		w		
		A	B	AB
v	A	a, a	$0, 0$	a, a
	B	$0, 0$	b, b	b, b
	AB	a, a	b, b	$(a, b)^+, (a, b)^+$

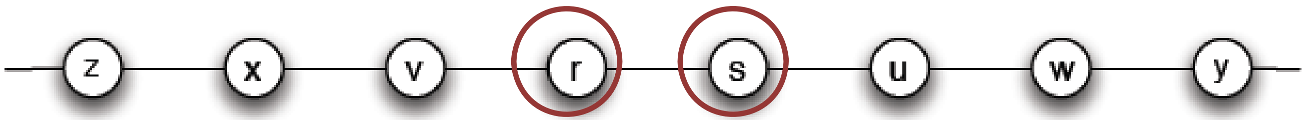
Is there a dominant strategy?

✓Cost **c** associated with the AB strategy

Compatibility and its Role in Cascades

Example (a = 2, b =3, c =1)

v \ w	A	B	AB
A	a, a	$0, 0$	a, a
B	$0, 0$	b, b	b, b
AB	a, a	b, b	$(a, b)^+, (a, b)^+$



Start B B B A A B B B

B: 0+b = 3
A: 0+a = 2
AB: b+a-c = 4 √

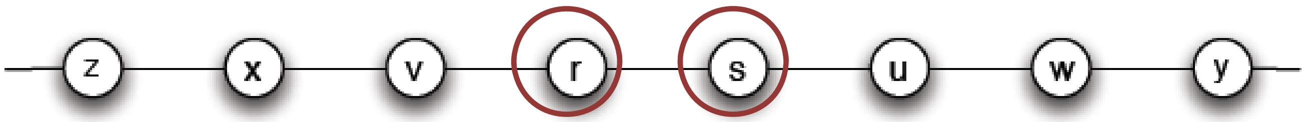
Step 1 B B AB A A AB B B

B: b+b = 6 √
A: 0+b = 3
AB: b+b-c = 5

Compatibility and its Role in Cascades

Example (a = **5**, b =3, c =1)

			w	
		A	B	AB
	A	a, a	$0, 0$	a, a
v	B	$0, 0$	b, b	b, b
	AB	a, a	b, b	$(a, b)^+, (a, b)^+$



	z	x	v	r	s	u	w	y
Start	B	B	B	A	A	B	B	B
Step 1	B	B	AB	A	A	AB	B	B
Step 2	B	AB	AB	A	A	AB	AB	B

B: 0+b = 3

A: 0+a = 5

AB: b+a-c = 7 √

Compatibility and its Role in Cascades

Example (*a* = 2, *b* =3, *c* =1)

v \ w	A	B	AB
A	a, a	$0, 0$	a, a
B	$0, 0$	b, b	b, b
AB	a, a	b, b	$(a, b)^+, (a, b)^+$

	z	x	v	r	s	u	w	y
Start	B	B	B	A	A	B	B	B
Step 1	B	B	AB	A	A	AB	B	B
Step 2	B	AB	AB	A	A	AB	AB	B
Step 3	AB	AB	A	A	A	A	AB	AB
Step 4	AB	A	A	A	A	A	A	AB

✓First, strategy AB spreads, then behind it, node switch permanently from AB to A
Strategy B becomes *vestigial*

Compatibility and its Role in Cascades

Given an infinite graph, for which payoff values of *a, b* and *c,* is it possible for a finite set of nodes to cause a complete cascade of adoptions of *A?*

Fixing $b = 1$

Given an infinite graph, for which payoff values of *a (how much better the new behavior A)* and *c (how compatible should it be with B),* is it possible for a finite set of nodes to cause a complete cascade of adoptions of *A?*

A does better when it has a higher payoff, but in general it has a particularly **hard time cascading when the level of compatibility is "intermediate"** – when the value of *c* is neither too high nor too low

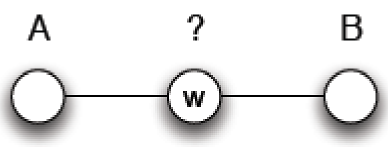
Compatibility and its Role in Cascades

Example: Infinite path

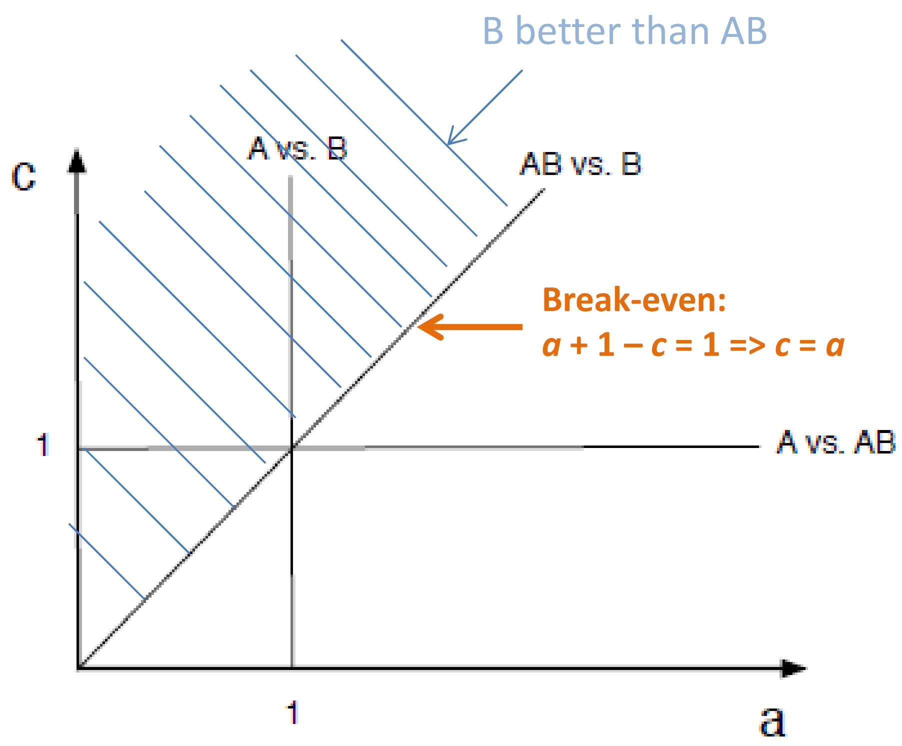
- Spreads when $q \leq 1/2$, $a \geq b$ (a better technology always spreads)

Assume that the set of initial adopters forms a contiguous interval of nodes on the path
Because of the symmetry, how strategy changes occur to the right of the initial adopters

Initially,

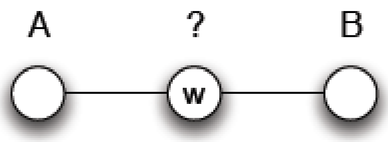


A: $0+a = a$
B: $0+b = 1$
AB: $a+b-c = a+1-c$



Compatibility and its Role in Cascades

Initially,



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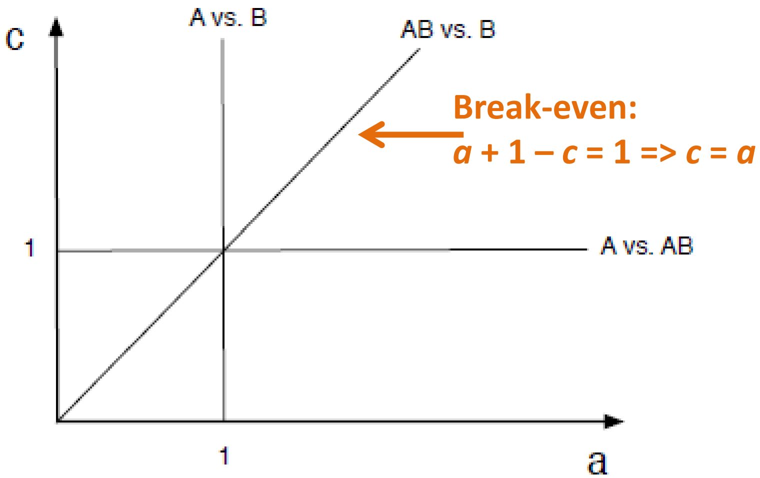
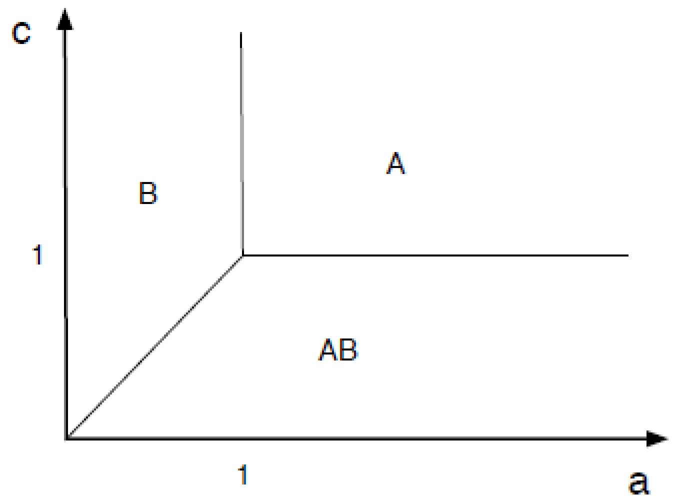
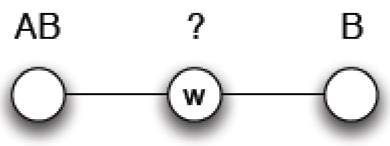




Compatibility and its Role in Cascades

Then,



$a < 1$,

A: $0+a = a$

B: $b+b = 2$ √

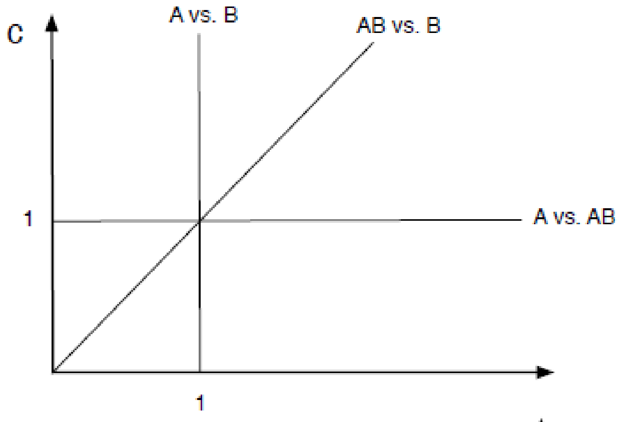
AB: $b+b-c = 2-c$

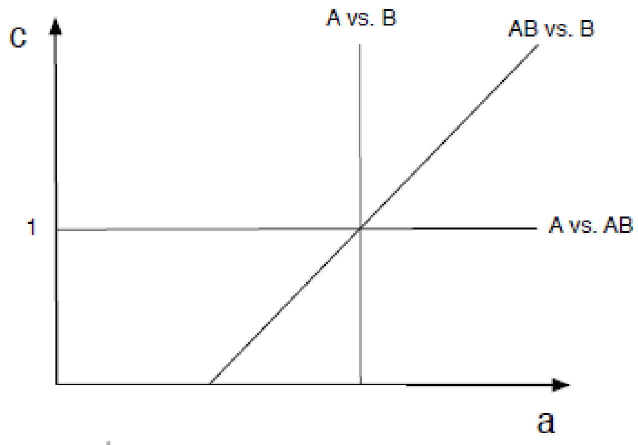
$a \geq 1$

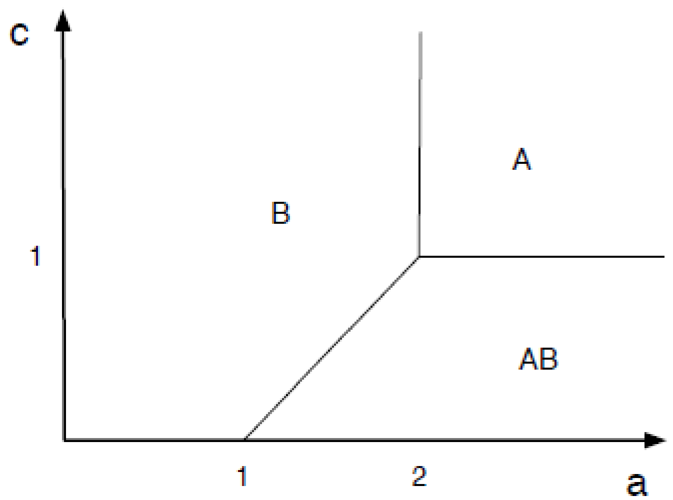
A: a

B: 2

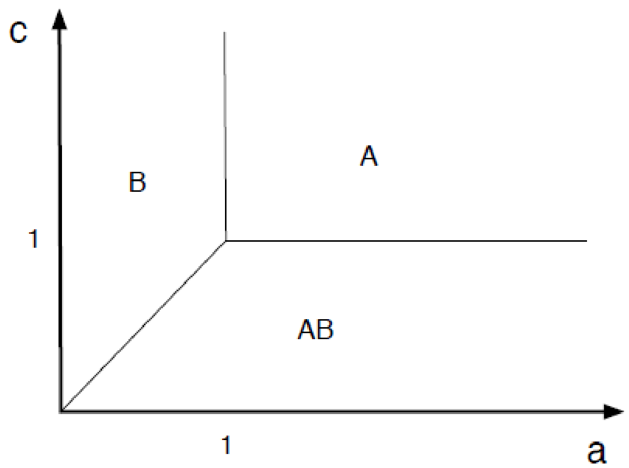
AB: $a+1-c$

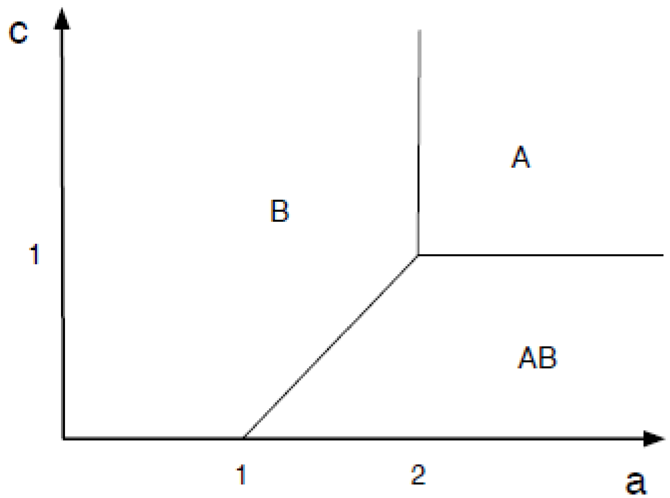


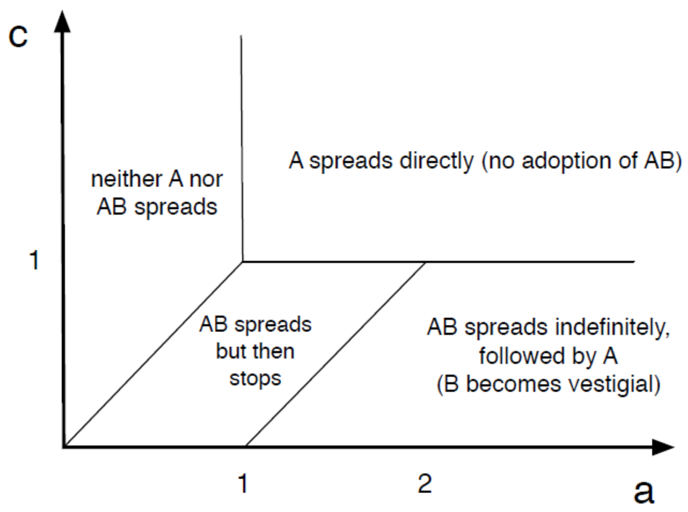




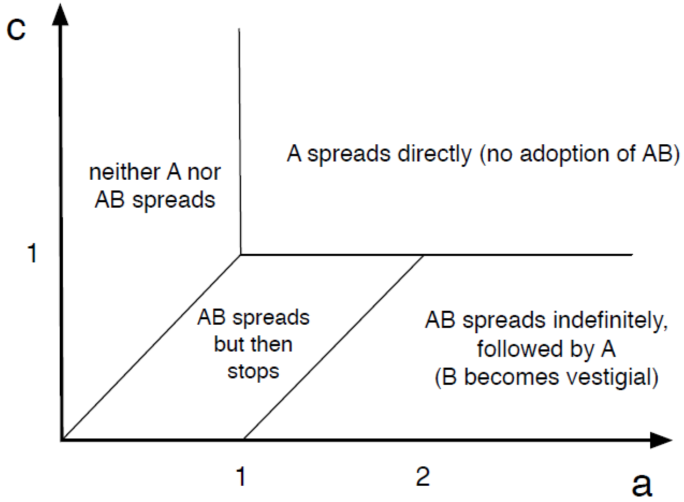
Compatibility and its Role in Cascades



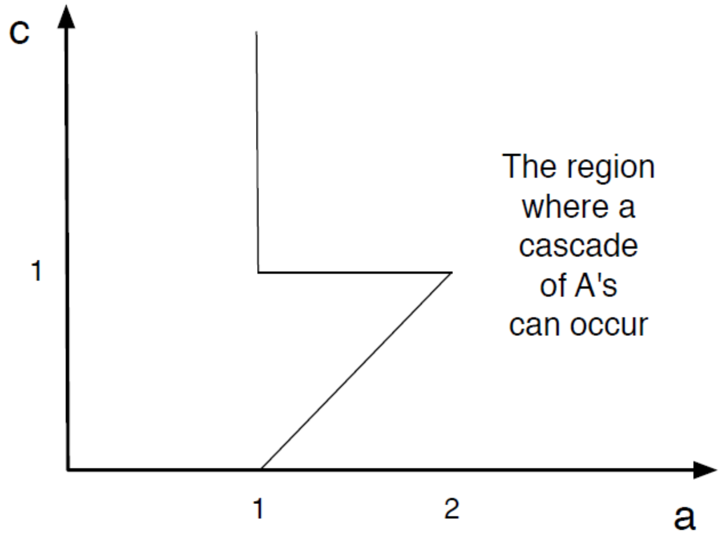




Compatibility and its Role in Cascades



What does the triangular cut-out means?



End of Chapter 19

- Diffusion as a network coordination game
- Payoff for adopting a behavior
- Cascades and the role of clusters
- The cascade capacity of a network
- "Bilingual" behavior