Network Analysis:

The Hidden Structures behind the Webs We Weave

17-213 / 17-668

Edges vs. Social Ties

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2-min Quiz, on Canvas

Quick Recap – Last Tuesday's Lecture

Graph component and dyad shortest path both use breadth-first search (BFS)

Random network models: Useful baseline model

- *N* (# nodes), *p* (tie probability) → *L* (# edges) and <*k*> (mean degree)
- Critical point at which a giant component forms → <*k*> > 1
- Average path length grows slower than the growth of a network ~ ln(N)
    - Hence the small-world

Social Ties are “Messy”

Edge vs. Social Tie

An edge in a graph is devoid of “meaning” or “content”

Its very utility comes from context-free abstraction

Edge vs. Social Tie

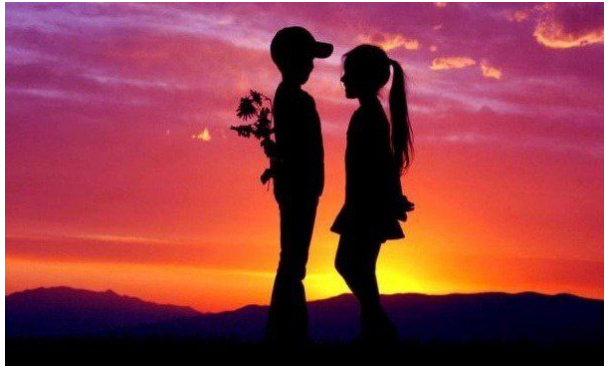
An edge in a graph is devoid of “meaning” or “content”

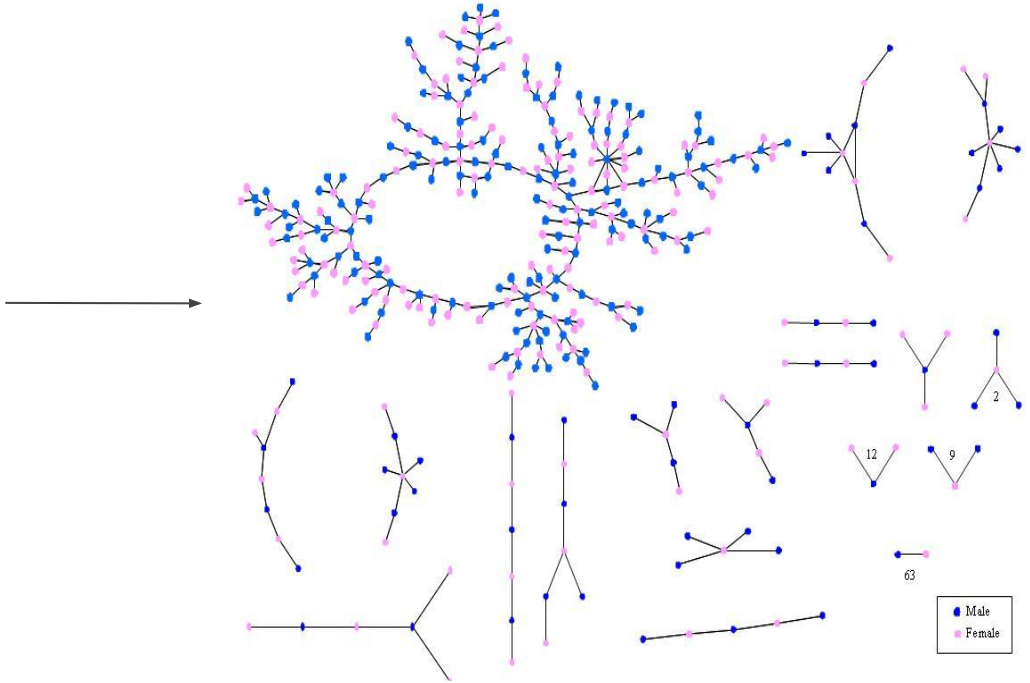
Its very utility comes from context-free abstraction

A social tie in a network is a hefty baggage: carries emotion, meaning, norms, expectations, trust, competition, social roles, and a history

Edge vs. Social Tie

Yet, the messy, variegated content in that baggage can surprisingly constrain or enable the emergence of certain graph structures

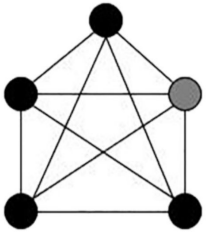




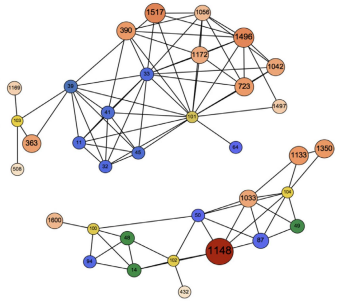
Edge vs. Social Tie

The inverse is also true: a graph structure can also constrain or enable certain characteristics in social ties

closed structure



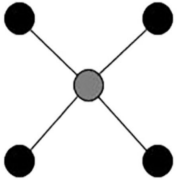
Monitoring, loyalty



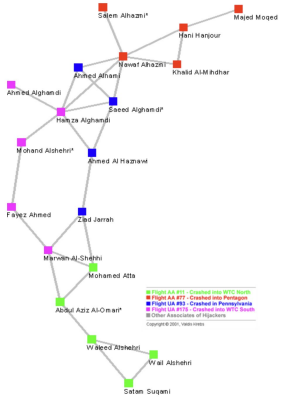
Mafia network

Agreste et al. 2016

open structure



Easily fragmentable,
Low risk of annihilation



Terrorist network

Krebs 2002

Social Ties and Social Support

People activate particular social ties for particular resources or support

Strong vs. weak ties
- Strong ties generally provide wide range of support

Physical contacts (e.g., neighbors)
- Provide small/large services (e.g., borrowing sugar, giving a ride to the station)
- Limited emotional and financial support

Kinship ties (e.g., parents, siblings)
- Emotional and/or financial support

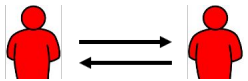
Abstraction: Social Ties as Edges

Reciprocity

The job of the network analyst: Apply or develop adequate abstract graph representations for a social tie. Example:

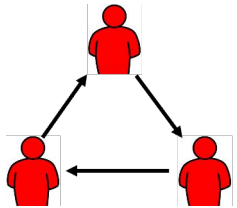
Reciprocity: The general social tendency to maintain **balance** in social exchange

- Dyadic:
  - *i* gives *j* resource *x* with value *v1* at time *t0*
  - *j* reciprocates with resource *y* with similar value *v2* at *t1*

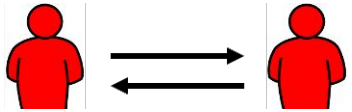


- Chain:
  - Pay it forward (e.g., parental care)

- Triadic:
  - *i* gives to *j* (without expectation of direct reciprocation)
  - *j* gives to *k*
  - *k* gives to *i*



Measuring Reciprocity: Dyad Level

Examples: 

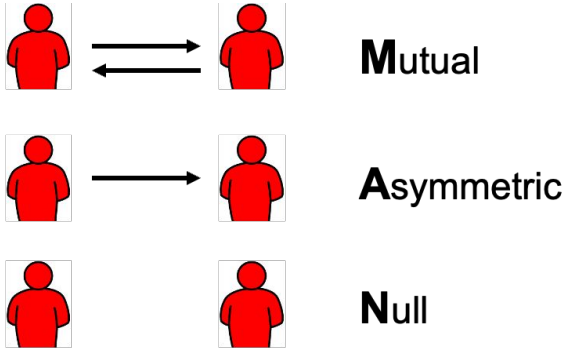
- How well balanced are the values of exchange between A and B?
  - |v1-v2|/2
  - |v1-v2|/(v1+v2)

- How well balanced are the times to reciprocation?
  - $\Delta t_{i \to j} - \Delta t_{j \to i}$

Measuring Reciprocity: Network Level

Dyad Census

- Frequency of all dyadic isomorphism classes in a network
- A useful quantitative description of an observed network



This approach makes it difficult to compare reciprocal tendencies between different networks

Measuring Reciprocity: Network Level

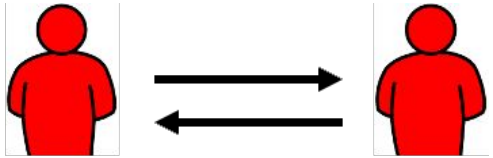
Index for Mutuality

- The **observed** numbers of *M*, *A*, *N* dyads are viewed as realizations of a **probabilistic** process governed by social forces

- Example: Societies with strong norms of reciprocity should have higher probability of mutual dyads

- Index of mutuality expresses such forces

"You bought me a coffee last time, now it's my turn"



Edges and Dyads

Index for Mutuality (ρ)

Core intuition: How much does the number of mutual dyads in the **observed network** (e.g., Japan's social network) deviate from the number of mutual dyads in a comparable **random** network?

Estimate a parameter **ρ** which quantifies the extent of this deviation

In statistical terms: The **probability of mutual dyads**:

$$P(\, i \rightarrow j \; and \;\; j \rightarrow i \,)$$

Edges and Dyads

Index for Mutuality (ρ)

In statistical terms: We want to estimate the probability of mutual dyads:

Conditional probability: probability of i choosing j, multiplied by the conditional probability of j choosing i, when i chooses j

$$P(i \to j \text{ and } j \to i) = P(i \to j)P(j \to i \mid i \to j)$$

$$P(j \to i \mid i \to j) = P(j \to i) + \boldsymbol{\rho} P(j \nrightarrow i)$$

$\boldsymbol{\rho}$=0 → $P(j \to i)$ and $P(i \to j)$ are independent (no reciprocation)

$\boldsymbol{\rho}$=1 → $P(j \to i \mid i \to j) = 1$, so every nomination is reciprocated

Edges and Dyads

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Estimate a parameter **ρ** which quantifies the extent of this deviation

ρ can be estimated from data and be used to compare networks of different size and density (e.g., Japan vs. US Twitter networks)

Edges and Dyads

Index for Mutuality (ρ)

In a completely random graph where every node has arcs to *k* random nodes, The expected number of *M* dyads is:

$$E(M) = \frac{N(N-1)}{2}\frac{k^2}{(N-1)^2} = \frac{Nk^2}{2(N-1)}$$

Edges and Dyads

Index for Mutuality (ρ)

$$P(i \to j \text{ and } j \to i) = P(i \to j)P(j \to i | i \to j)$$

$$P(i \to j | j \to i) = P(j \to i) + \rho P(j \nrightarrow i)$$

$$P(i \to j \text{ and } j \to i) = P(i \to j)[P(j \to i) + \rho P(j \nrightarrow i)]$$

$$E(M|\rho) = \frac{N(N-1)}{2} P(i \to j \text{ and } j \to i)$$

Measuring Reciprocity: Dyad Level

Intuition: How well balanced is the exchange between A and B?

Reciprocity: The general social tendency to maintain **balance** in social exchange

- Dyadic:
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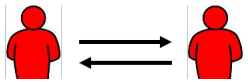
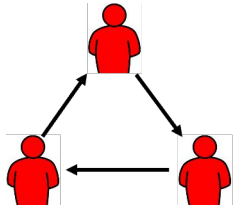


- Chain:
  - Pay it forward (e.g., parental care)

- Triadic:
  - A gives to B without expectation of direct reciprocation
  - B gives to C
  - C gives to A



Reciprocity

Cyworld Gift Exchange

Social Ties and Diffusion

Social Ties and Information Diffusion

Similar to social support, people selectively talk about certain topics to certain types of relationships

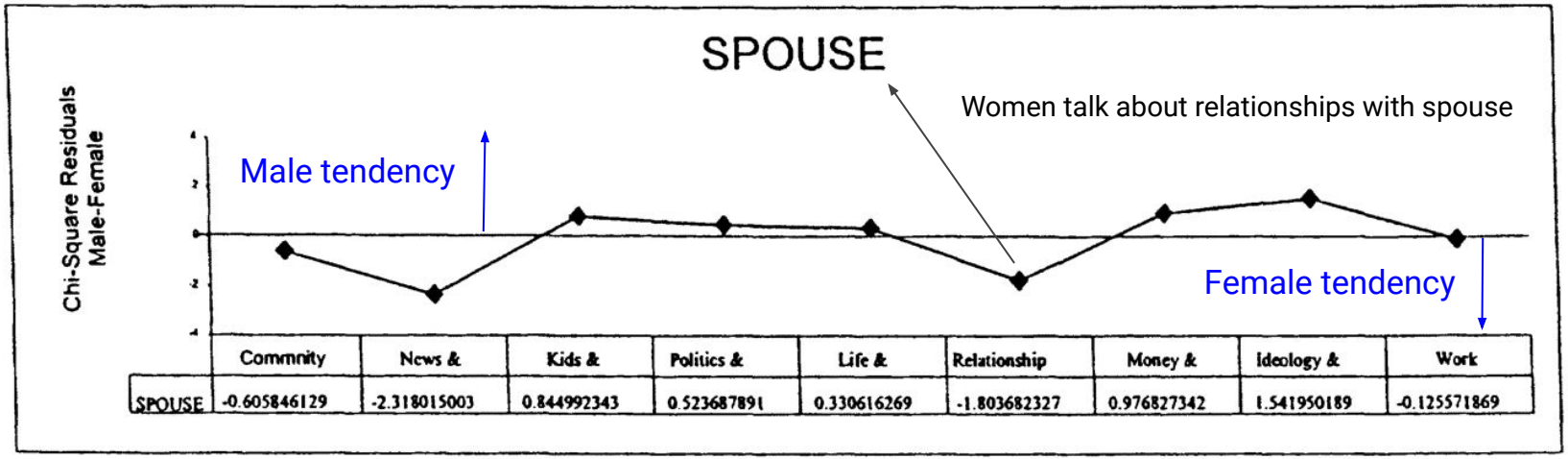
Examples:

- Sensitive topics (politics and religion) are usually discussed with close friends and family
- Generally, people discuss important matters with people they trust (i.e., confidants)
- Confidants potentially wield substantial influence on one's opinion
- At a more macro scale, studying opinion dynamics with confidant networks rather than an all-encompassing network might yield more insight

Social Ties and Information Diffusion

So, with **whom** do we discuss important matters? And **what** are those important matters?

Panel a: Conversation Asymmetries for Talking with *Spouse*



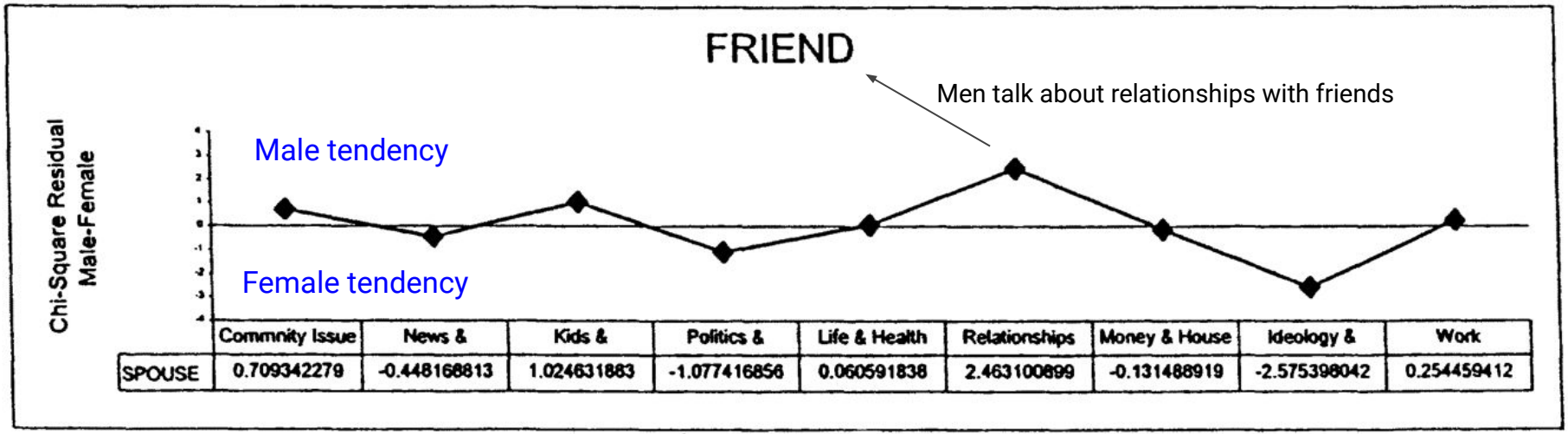
	Commnity	News &	Kids &	Politics &	Life &	Relationship	Money &	Ideology &	Work
SPOUSE	-0.605846129	-2.318015003	0.844992343	0.523687891	0.330616269	-1.803682327	0.976827342	1.541950189	-0.125571869

Bearman and Parigi 2004

Social Ties and Information Diffusion

So, with **whom** do we discuss important matters? And **what** are those important matters?

Panel b: Conversation Asymmetries for Talking with *Friend*



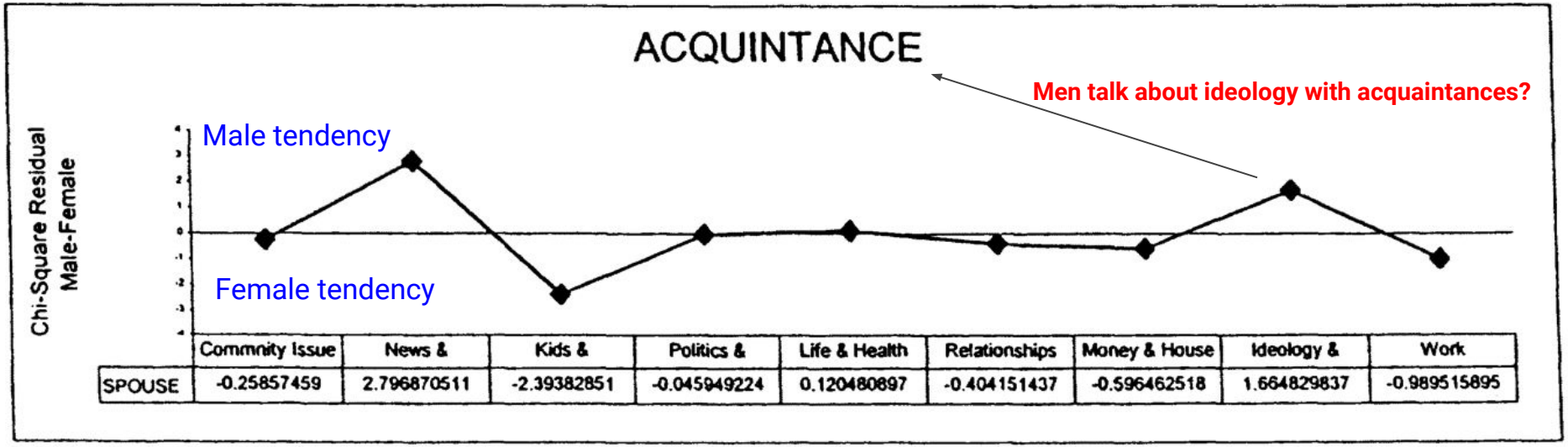
	Commnity Issue	News &	Kids &	Politics &	Life & Health	Relationships	Money & House	Ideology &	Work
SPOUSE	0.709342279	-0.448168813	1.024631883	-1.077416856	0.060591838	2.463100899	-0.131488919	-2.575398042	0.254459412

Bearman and Parigi 2004

Social Ties and Information Diffusion

So, with **whom** do we discuss important matters? And **what** are those important matters?

Panel d: Conversation Asymmetries for Talking with *Acquaintance*



	Commnity Issue	News &	Kids &	Politics &	Life & Health	Relationships	Money & House	Ideology &	Work
SPOUSE	-0.25857459	2.796870511	-2.39382851	-0.045949224	0.120480897	-0.404151437	-0.596462518	1.664829837	-0.989515895

Bearman and Parigi 2004

Social Ties and Information Diffusion

Men talk about ideology with acquaintances…

But, don't people discuss important, often private, topics with their trusted strong ties?

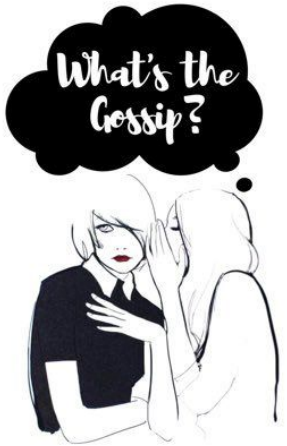
Answer: Not necessarily. "People may often confide in people they do not even consider confidants (Small 2017)."

Social Ties and Information Diffusion

Why?

Strong ties (e.g., friends and family) are interconnected (i.e., triadic closure)

- Sensitive/embarrassing information disclosed to a friend can quickly spread to other close friends in the same social circle



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Topic-alter dependency

- Strangers share very few social contexts, so people feel safe to disclose sensitive topics

Social Ties and Information Diffusion

So, will word about the exquisite cake from La Gourmandine spread like wildfire at the party?

Not necessarily, because **valued information** about scarce goods might spread through highly exclusive **strong ties**

Alternatively, gourmet cake as a topic might be discussed between cake lovers, but not with, say, people who are sensitive to gluten/dairy or who are indifferent → **topic-alter dependency**

Social Ties and Information Diffusion

Network science provides powerful tools for modeling information diffusion

Yet, if the ties are inadequate for the phenomenon under study, network analysis will be irrelevant

Hence, qualitative aspects of social ties (the “messy” content) must be carefully evaluated

- Types of social ties for constructing the network
- Strength of ties
- Topic-alter dependency

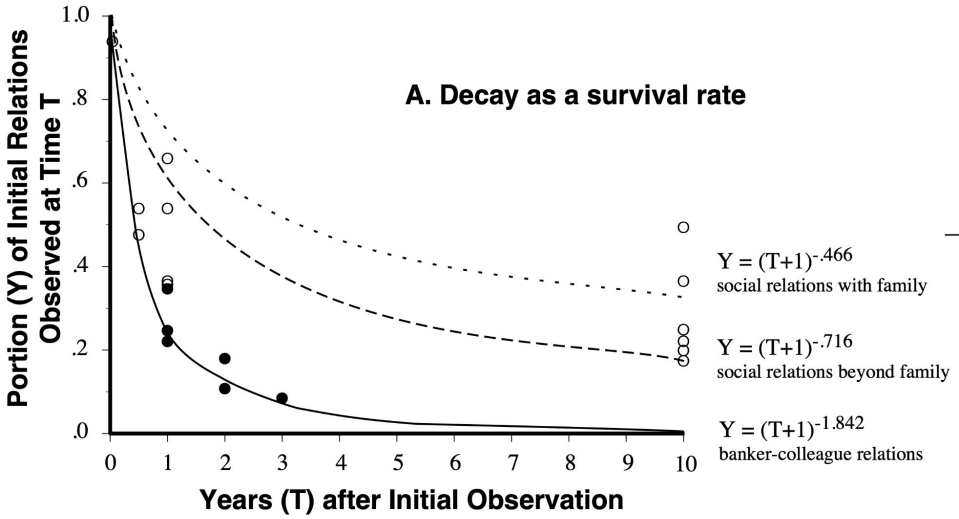
Edges

The Dynamics of Social Ties

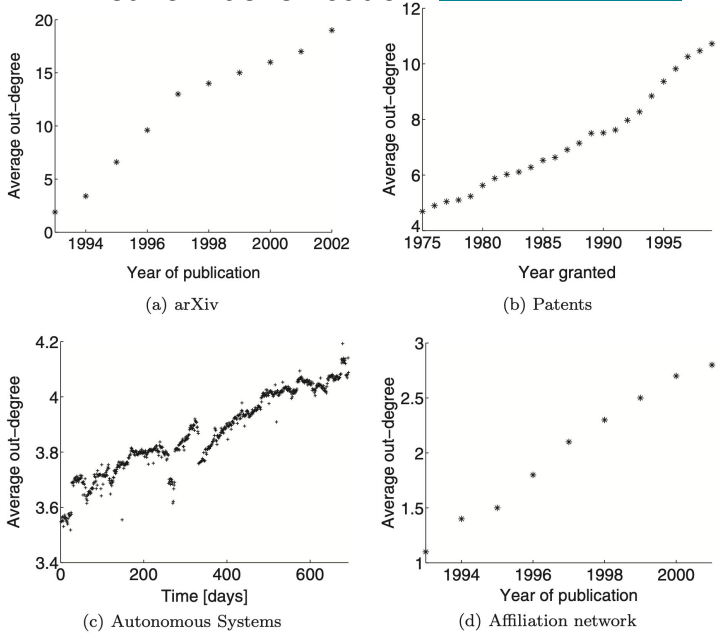
Persistence and Decay of Social Ties

People form relationships and those relationships can persist or subside over time

The evolution of a social network is closely related to such ebbs and flows of social ties



Network densification [Leskovec et al. 2007]

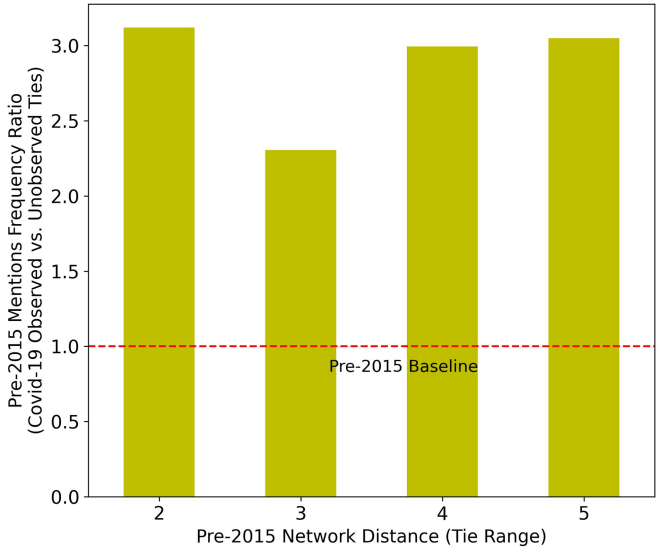


[Burt 2000]

Persistence and Decay of Social Ties

Strong ties also survive longer in social media (Park, Xu, and Carley)

Old “friends” on Twitter who discuss Covid-19 related topics interacted more frequently in the past, compared to old friends who do not discuss Covid-19 topics with each other



Interdependence and Persistent Social Ties

Then what factors influence how long a tie persists (commitment to a relationship)?

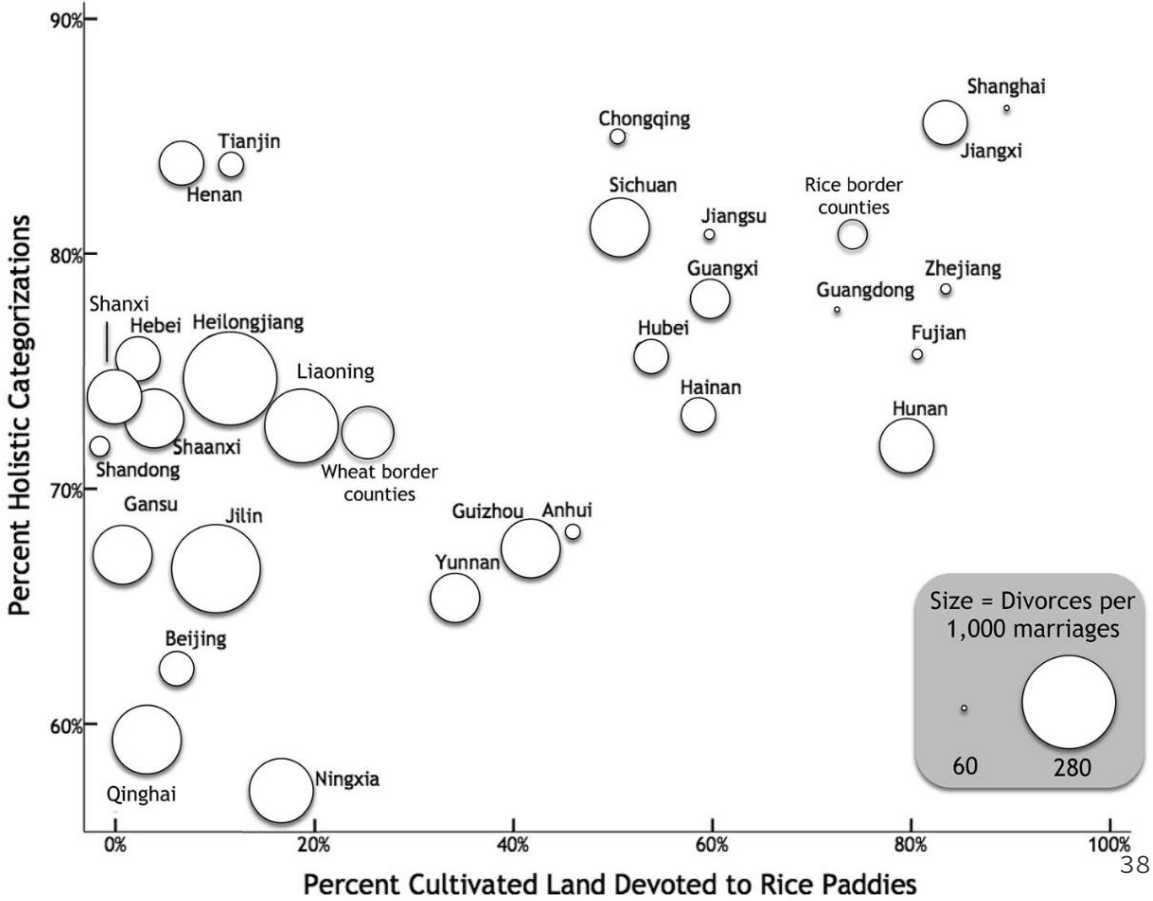
- Historically, more interdependent modes of production seems to have influenced people's thinking styles and social organization, including how people relate with one another

Rice farming requires highly interdependent, coordinated labor, compared to wheat farming

Interdependence and Persistent Social Ties

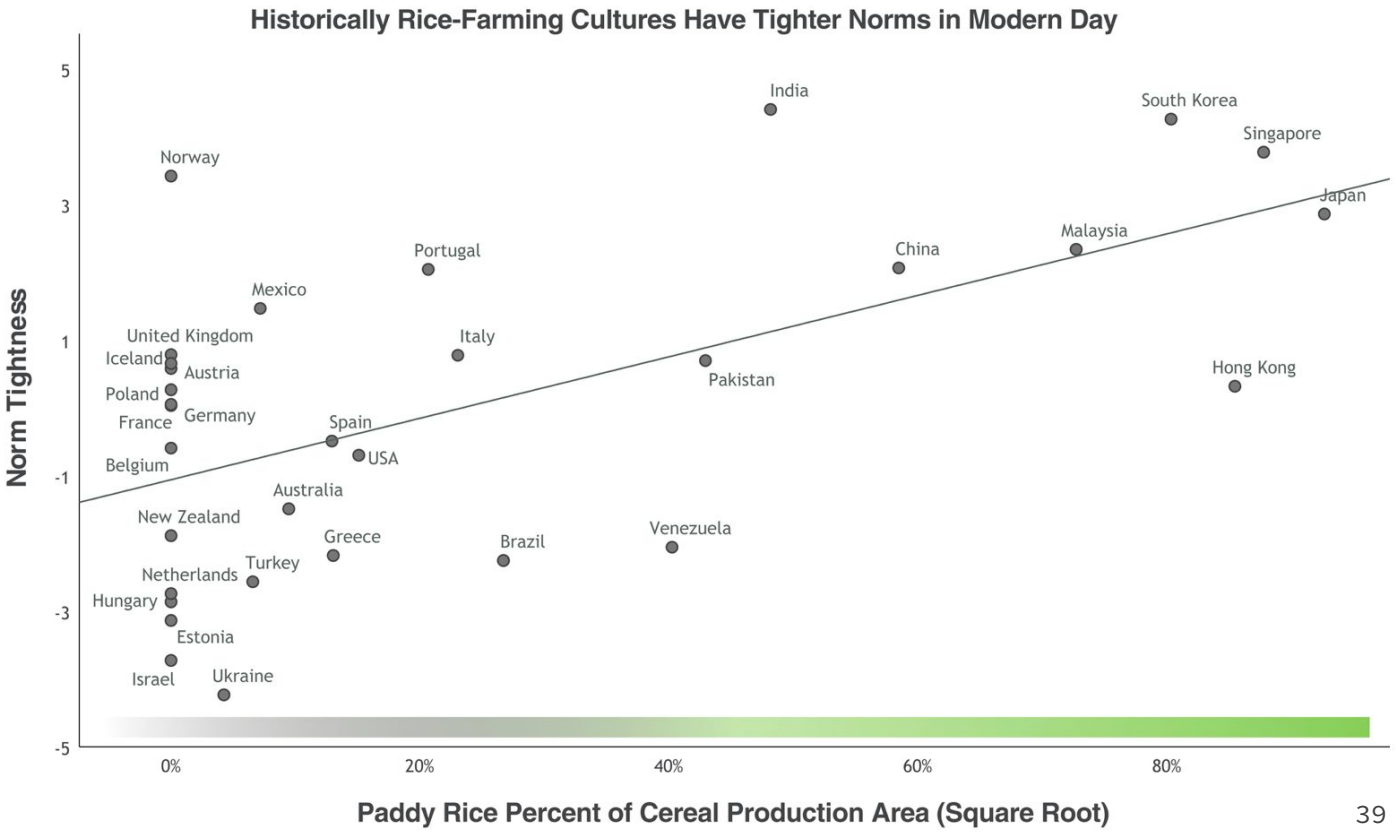
Even within a same country, the intensity of interdependent labor shows a correlation with holistic thinking styles

[Talhelm et al. 2014]



Interdependence and Persistent Social Ties

Even across countries, rice farming cultures have “tighter” norms – stronger group pressure on individual conformity



Talhelm et al. 2020

Uncertain Environments and Social Ties

These historical differences may have contributed to systematic differences in generalized trust and commitment to relationships

Survey of Japanese and American respondents

Q: “Do you think you can put your trust in most people, or do you think it’s always best to be on your guard?”

A: “People can be trusted” **47% American vs. 26% Japanese**

Uncertain Environments and Social Ties

Japanese society enforces stricter norms within groups, which provide security to their members

→ Strong trust for in-group members (norm violation is met with harsh sanctions)
→ Much weaker trust to outsiders/strangers (relatively weaker norms to ensure security)

In the extreme, if everyone distrusts outsiders, individually optimal choice is to rather stay in the community and increase commitment to existing ties

→ Strong ingroup trust: low transaction cost
→ Static relationships: high opportunity cost

Uncertain Environments and Social Ties

Individualist cultures (e.g., U.S.) where the environment forced self-sufficiency and lower interdependent modes of subsistence (think the wild west):

→ Necessary to learn to trust strangers

→ High transaction cost (due to thin trust)

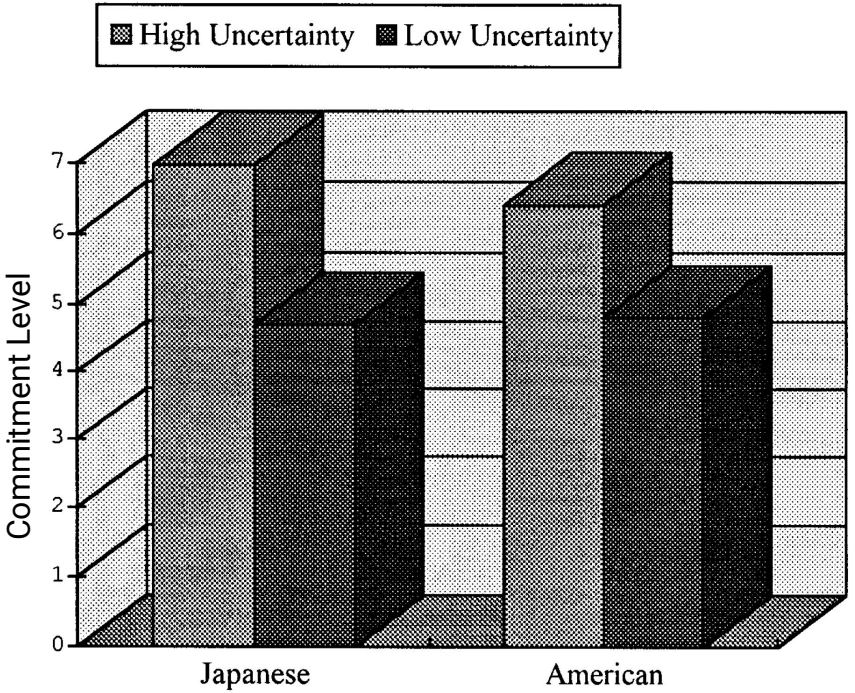
→ Low opportunity cost (possibility of discovering more beneficial interactions)

Uncertain Environments and Social Ties

In experimental settings where everyone transact with strangers (i.e., **no in-group security**), Japanese and the U.S. participants showed similar levels of commitment to their partners

Both groups form long-term, committed relationships when uncertainty is high.

(uncertainty = experimentally manipulated risk of being taken advantage of)



Yamagishi et al. 1998

Uncertain Environments and Social Ties

It is not so much a matter of culture:

It is more a matter of **structure**

- In a society where **in-group cohesion** is strong, general trust becomes less critical

It is also more a matter of circumstances

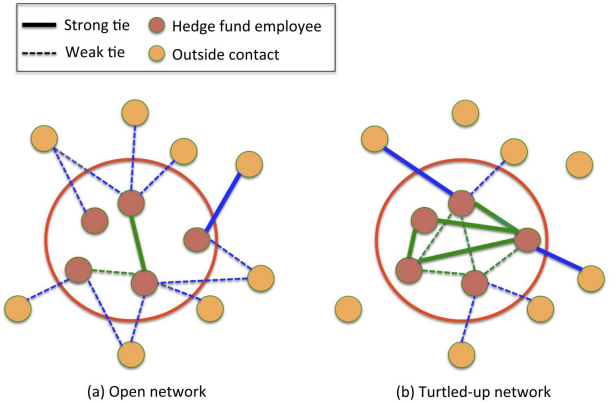
- Does the environment force interdependent modes of subsistence?
- Is there high uncertainty in the environment?

Uncertain Environments and Social Ties

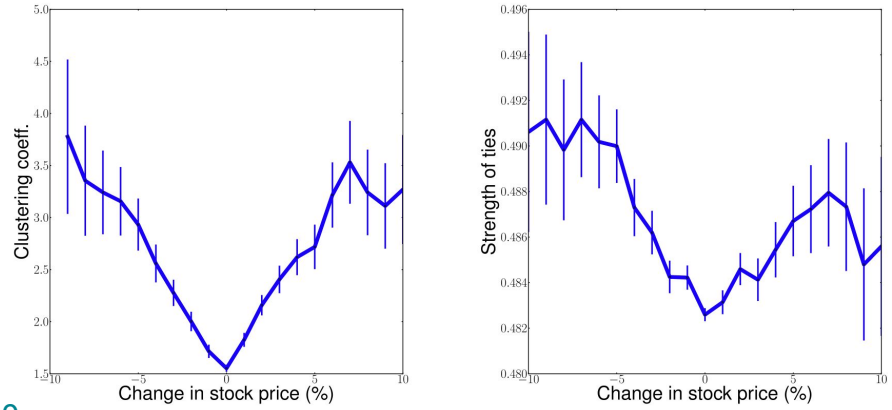
In real-world settings, people tend to shrink their communication ties to fewer, strong ties (“turtling up”)

A shock leads people to revert to their trusted ingroup (higher clustering and higher average tie strength)

This tendency grows more salient with the magnitude of the shock



(a) Open network (b) Turtled-up network



(a) Average clustering ($\nu(C_{s,d})$) (b) Strength of ties ($S_{s,d,.1}$)

[Romero et al. 2019]

Summary

An interpersonal tie influences and is influenced by the broader network structure

- Social support differs by type of relationship
- Topic-alter dependency can affect information diffusion
- Social tie can create a graph signature
- Reciprocity
- Dynamics of social ties hold implications for network structure