Introduction to Network Statistics

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Online Workshop
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  - **R**
  - RStudio
  - statnet package
  - datafiles for the class
- Basic SNA Measures
  - centrality measures
  - graph correlation
  - reciprocity
  - transitivity
- Hypothesis testing
  - for Node level indices
    - General permutation tests
    - Quadratic Assignment Procedure
    - Network Autocorrelation Models
  - for Graph level indices
    - Conditional Uniform Graph (CUG) Models

Hypothesis Testing

Relating Node level indices to covariates

- Node Level Indices: centrality measures, brokerage, constraint

Relating Node level indices to covariates

- Node Level Indices: centrality measures, brokerage, constraint
- Node Covariates: measures of power, career advancement, gender – really anything you want to study that varies at the node level

Emergent Multi-Organizational Networks (EMON) Dataset

- 7 case studies of EMONs in the context of search and rescue activities from Drabek et. al. (1981)

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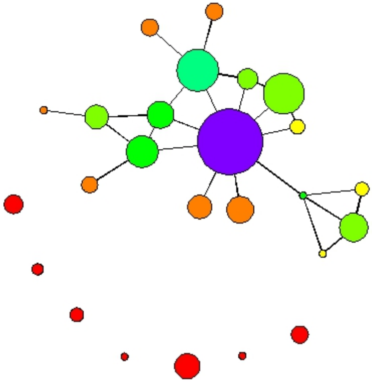
- 7 case studies of EMONs in the context of search and rescue activities from Drabek et. al. (1981)
- Ties between organizations are self-reported levels of communication coded from 1 to 4 with 1 as most frequent

Emergent Multi-Organizational Networks (EMON) Dataset

Attribute Data

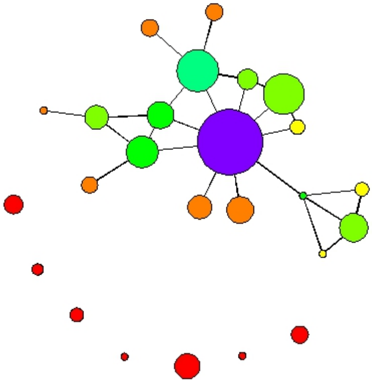
- Command Rank Score (CRS): mean rank (reversed) for prominence in the command structure
- Decision Rank Score (DRS): mean rank (reversed) for prominence in decision making process
- Paid Staff: number of paid employees
- Volunteer Staff: number of volunteer staff
- Sponsorship: organization type (City, County, State, Federal, or Private)

Correlation between DRS and Degree?



Correlation between DRS and Degree?

- Subsample of Mutually Reported "Continuous Communication" in Texas EMON



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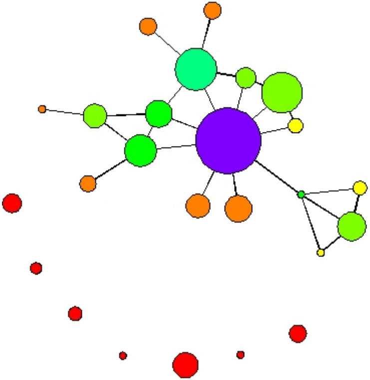

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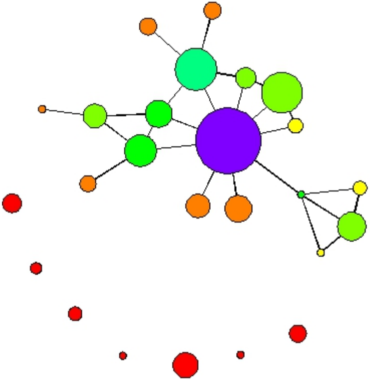

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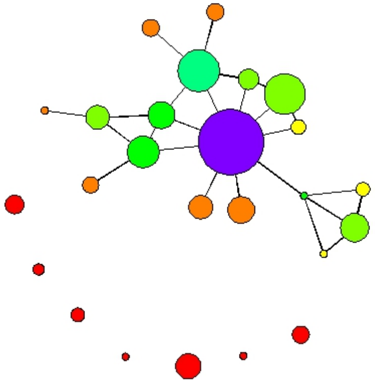
- Empirical corelation $\rho = 0.86$



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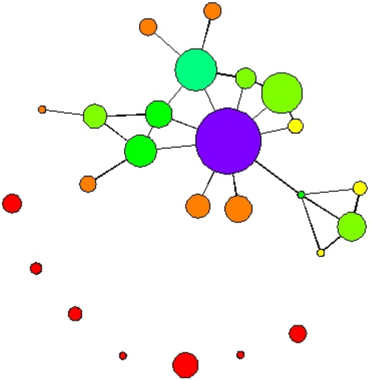

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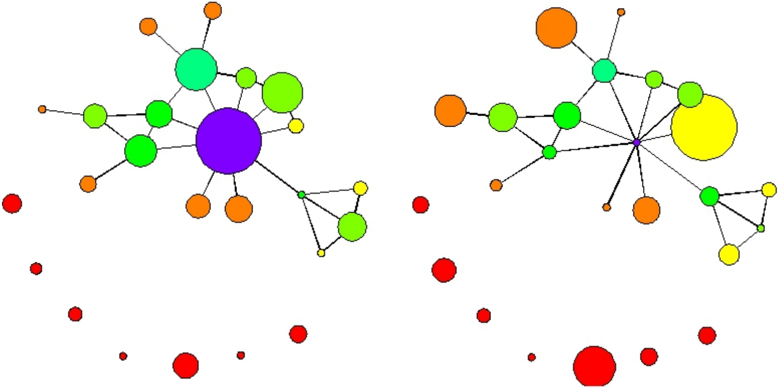

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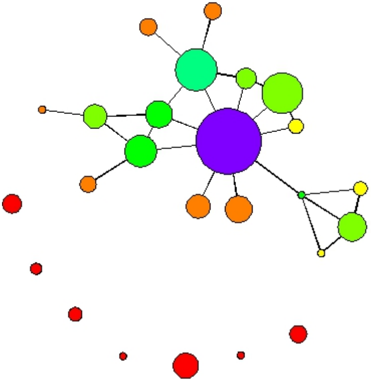

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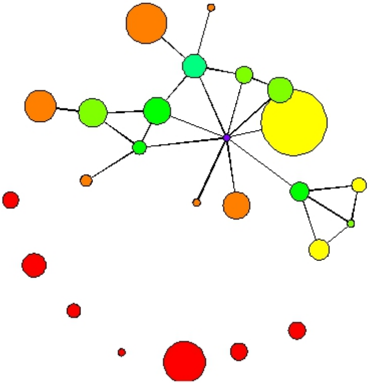

$\rho = -0.07$

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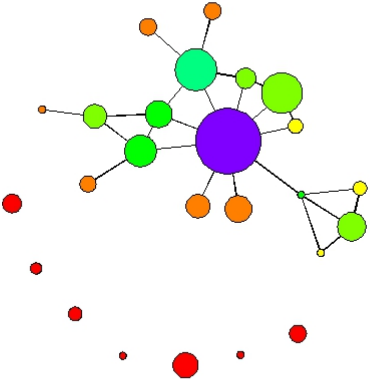

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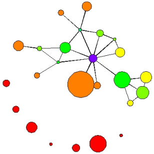

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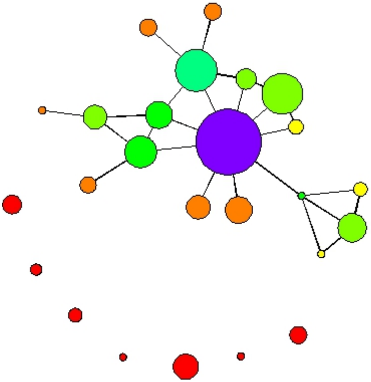

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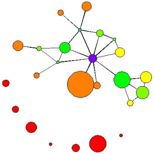

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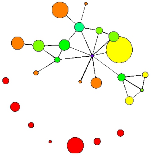

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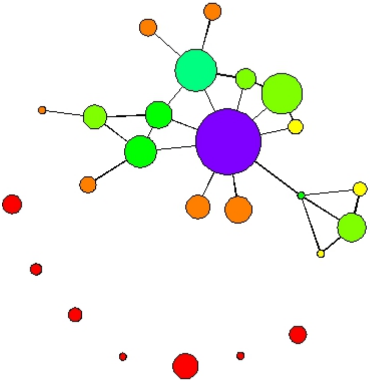

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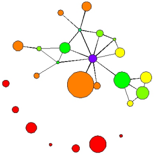

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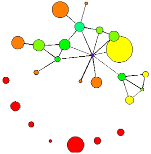

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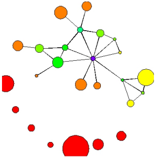
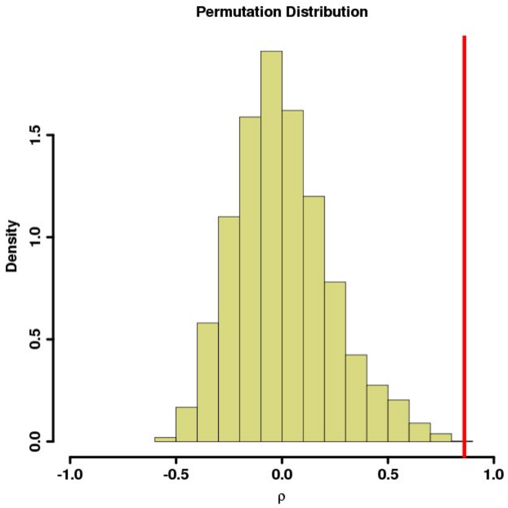


$\rho = -0.39$

Correlation between DRS and Degree?



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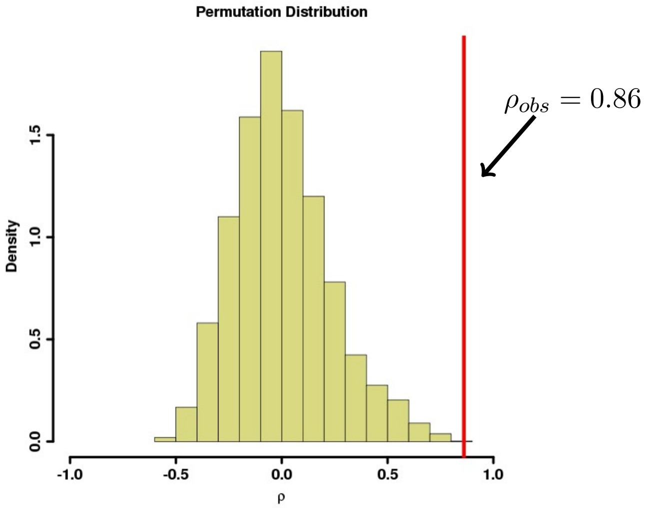

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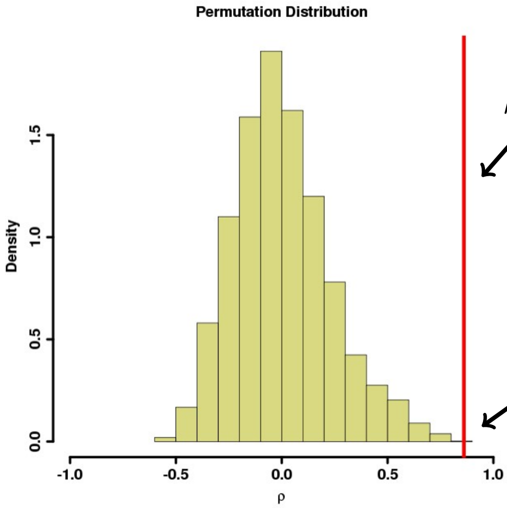
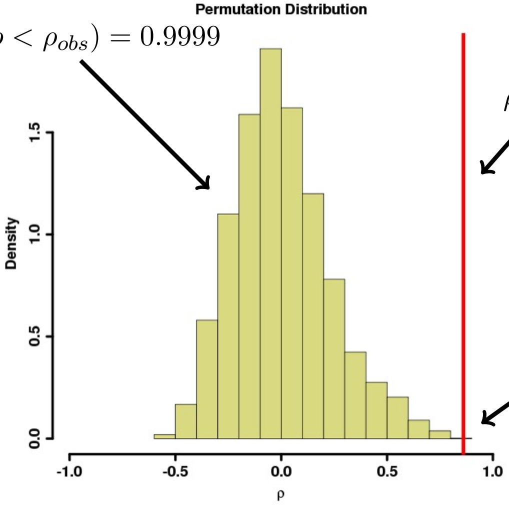


$\rho_{obs} = 0.86$

$Pr(\rho \geq \rho_{obs})$
$= 3e-5$

Correlation between DRS and Degree?



$Pr(\rho < \rho_{obs}) = 0.9999$

$\rho_{obs} = 0.86$

$Pr(\rho \geq \rho_{obs})$
$= 3e - 5$

Regression?

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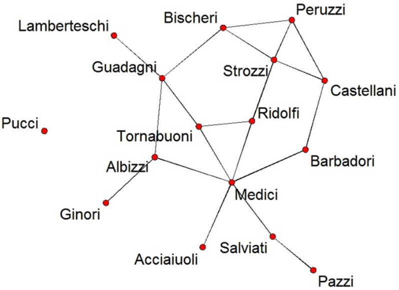
- Can use Node Level Indices as independent variables in a regression (Borgatti 2024 et al ch 14)
- Big assumption: ***position*** predicts the ***properties of those who hold them*** (Robins et al 2001, Parker et al 2022)
- Conditioning on NLI values, so dependence in accounted for ***assuming no error in the network***

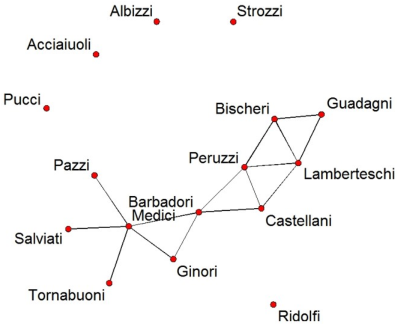
Code Time

Sections 1-2.3

Quadratic Assignment Procedure

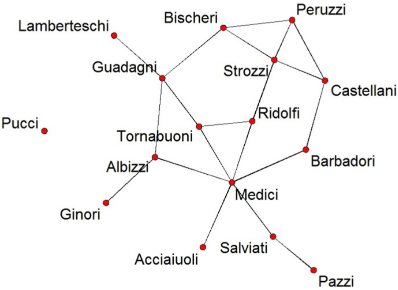


Marriage

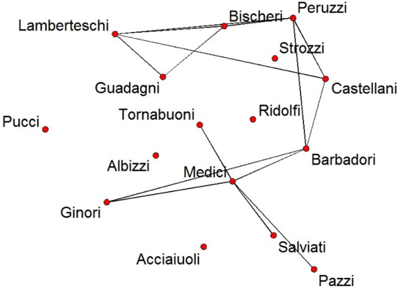


Business

Quadratic Assignment Proceedure



Marriage



Business

Graph Correlation

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- Simple way of comparing graphs on the same vertex set by element

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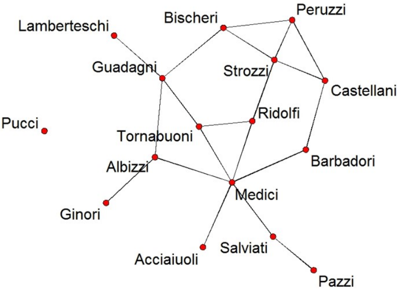
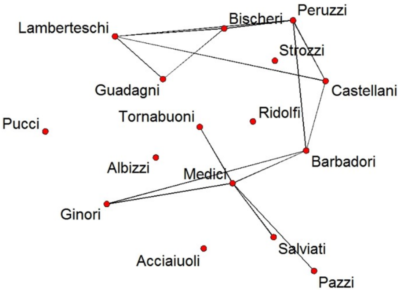
- $gcor\left(\begin{bmatrix}1 & 1\\1 & 0\end{bmatrix}, \begin{bmatrix}1 & 1\\2 & 2\end{bmatrix}\right) = cor([1,1,1,0],[1,1,2,2])$

Do business ties coincide with marriages?



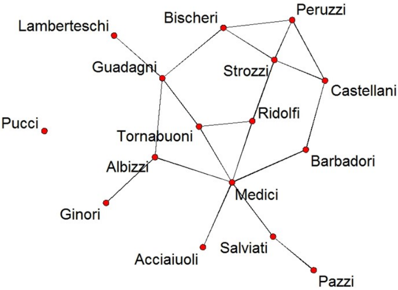


Marriage

Business

$$\rho = 0.372$$

Do business ties coincide with marriages?



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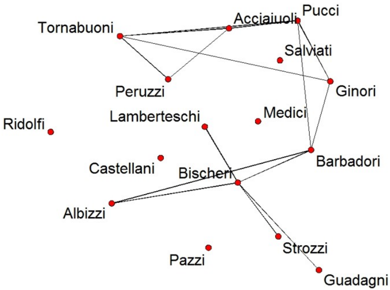

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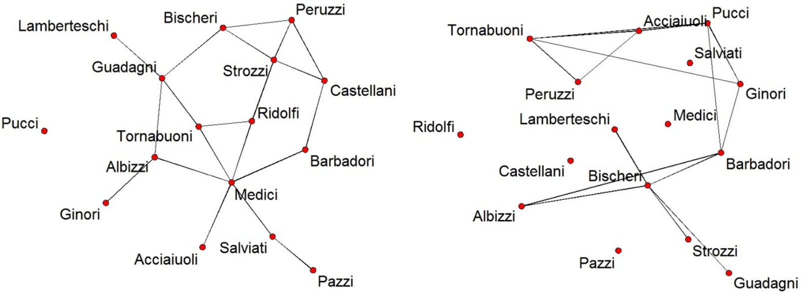
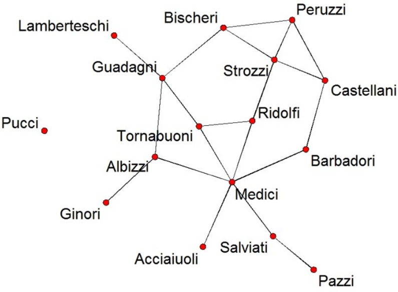


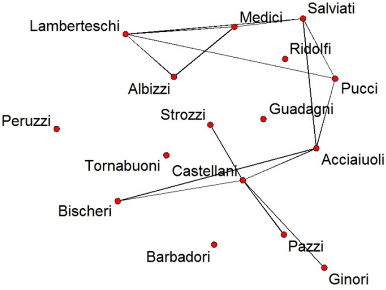
Marriage | Business

$$\rho = 0.169$$

Do business ties coincide with marriages?



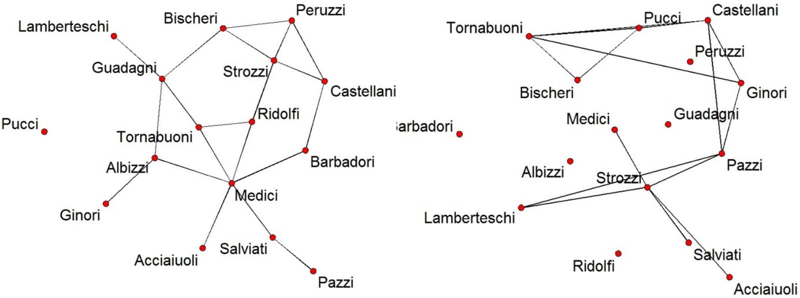
Marriage



Business

$$\rho = -0.034$$

Do business ties coincide with marriages?

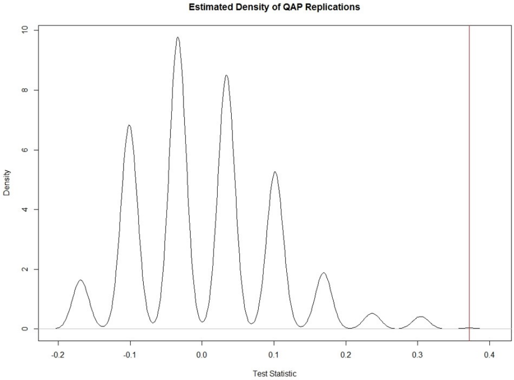


Marriage

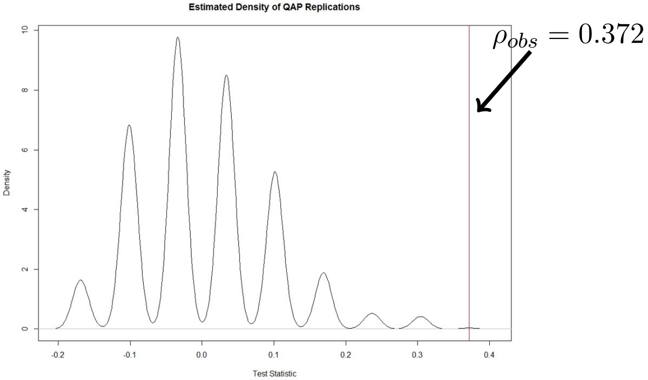
Business

$$\rho = -0.101$$

QAP Test


Estimated Density of QAP Replications
Density
Test Statistic
0
2
4
6
8
10
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4

QAP Test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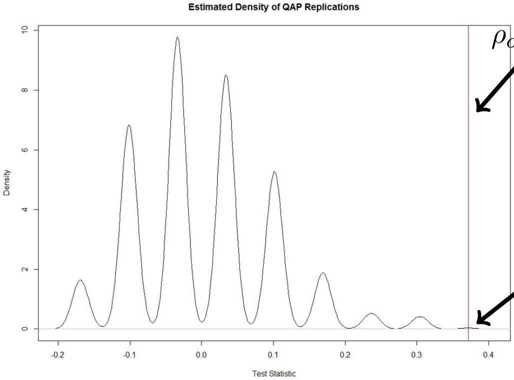

$\rho_{obs} = 0.372$

$Pr(\rho \geq \rho_{obs})$
$= .001$

QAP Test

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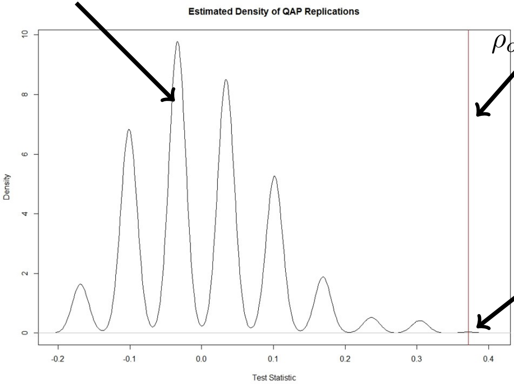
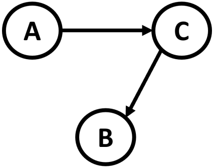


Why can't we use the same permutation test?

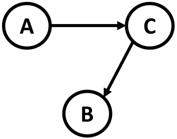
QAP Test



	A	B	C
A	-	0	1
B	0	-	0
C	0	1	-

$$\begin{bmatrix} - \\ 0 \\ 1 \\ 0 \\ - \\ 0 \\ 0 \\ 1 \\ - \end{bmatrix}$$

QAP Test



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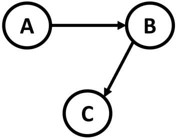

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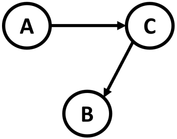

	A	B	C
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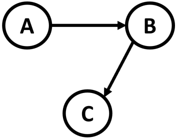
C	0	0	-



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  - Krackhardt 1988, Dekker et al 2007, Cranmer et al 2017

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  - Always takes matrix form, but may be based on vector data
  - eg. simple adjacency matrix, sender/receiver effects, attribute differences, elements held in common

Code Time

Sections 2.4-2.5

Network Autocorrelation Models

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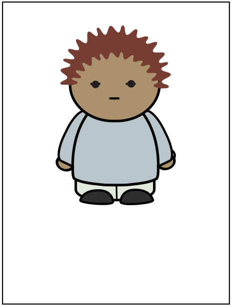
  - where Θ is the matrix for the Auto-Regressive weights
  - and ψ is the matrix for the Moving Average weights

The Classical Regression Model



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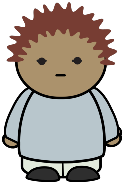
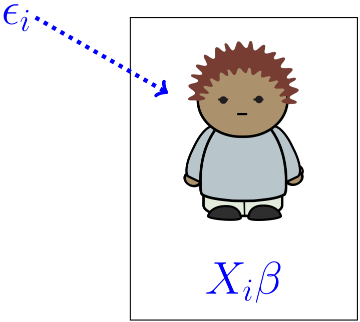
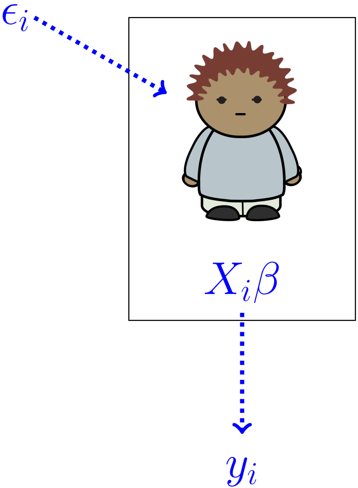


$$X_i\beta$$

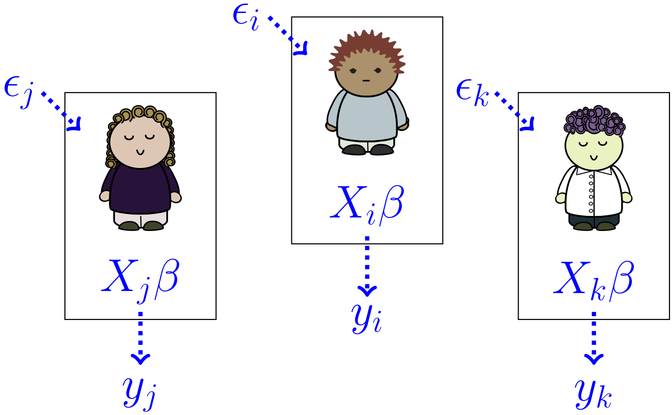
The Classical Regression Model



The Classical Regression Model



Adding Network AR Effects



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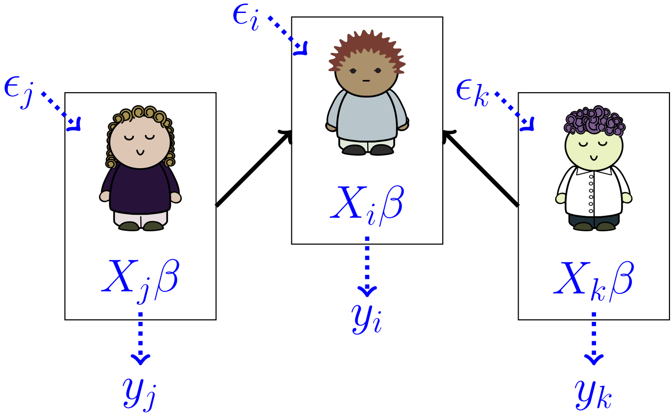

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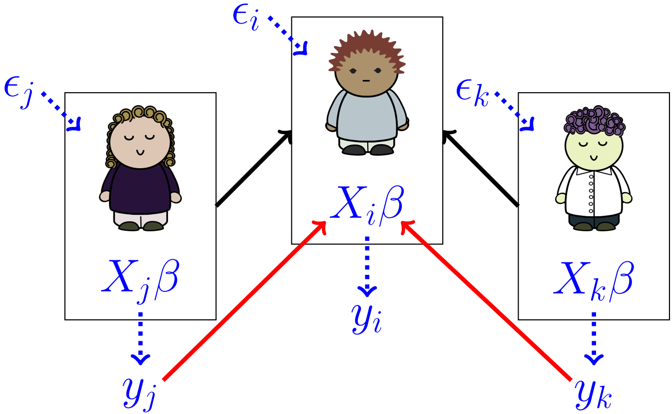
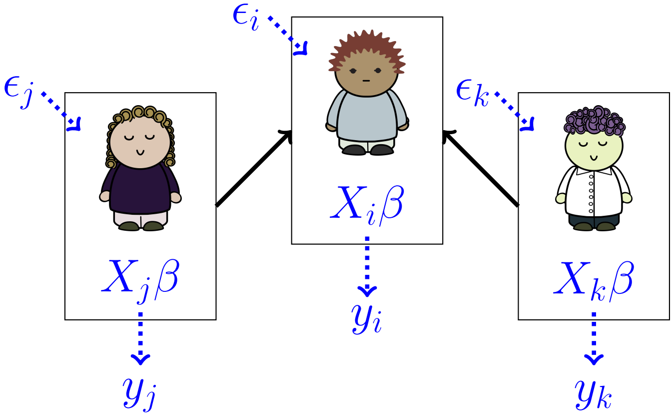


Adding Network MA Effects



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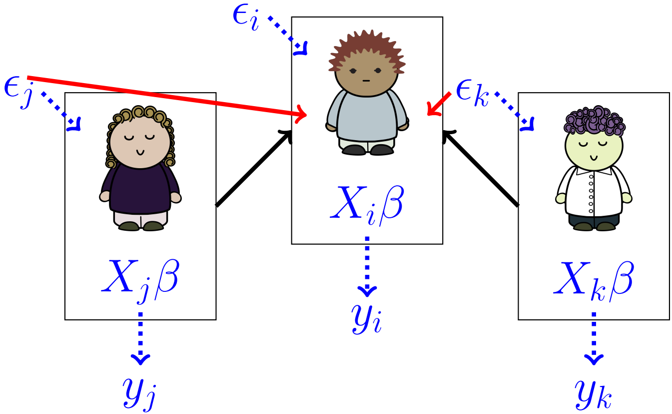
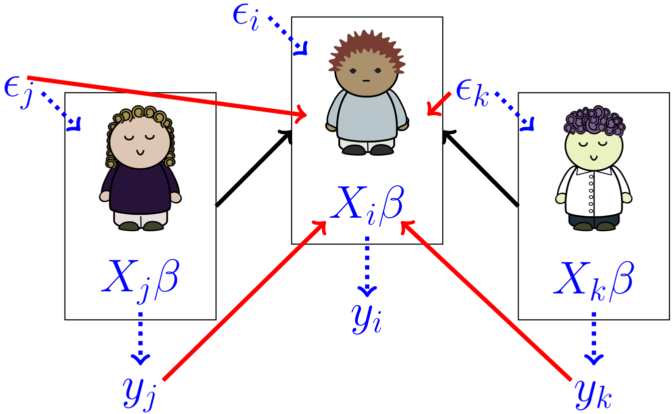
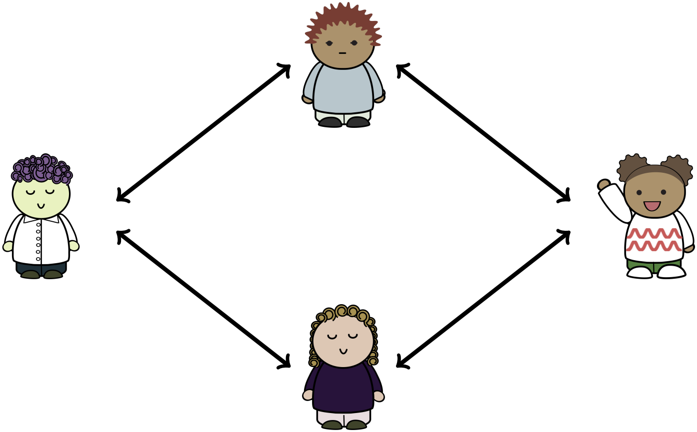


Network ARMA Model



Network ‘Resonance’



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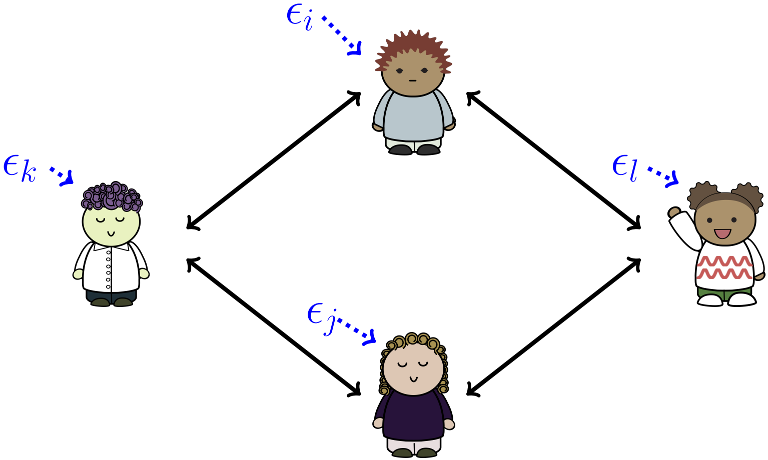

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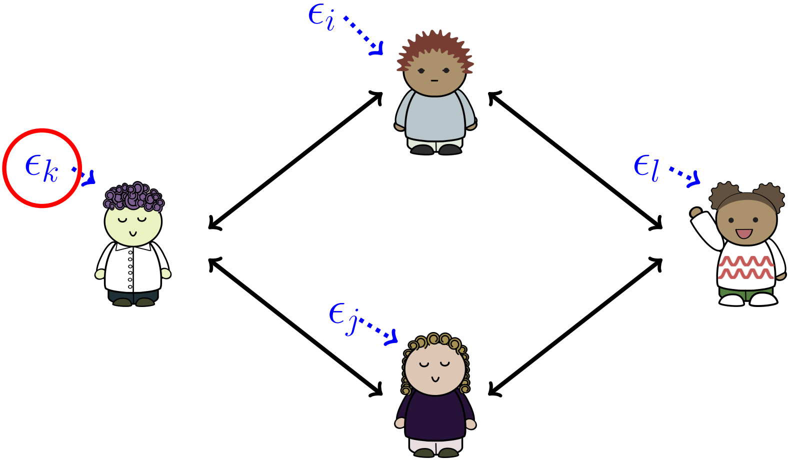

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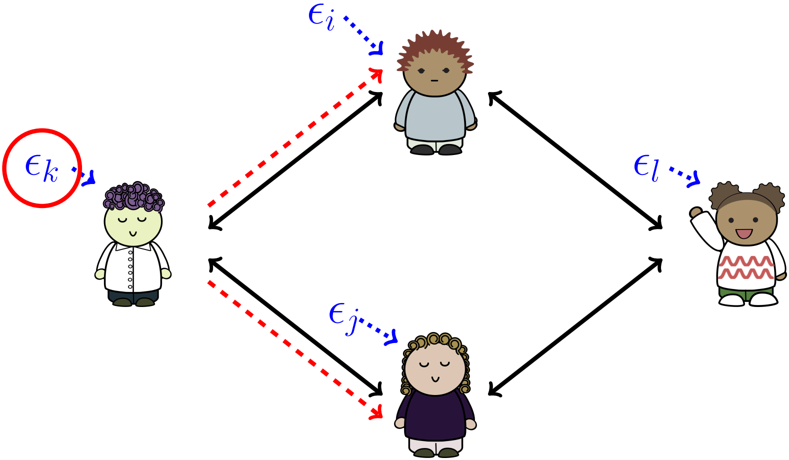

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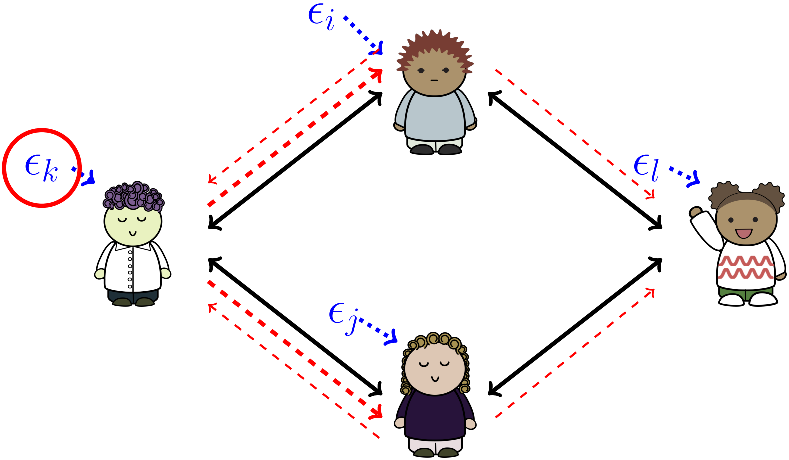

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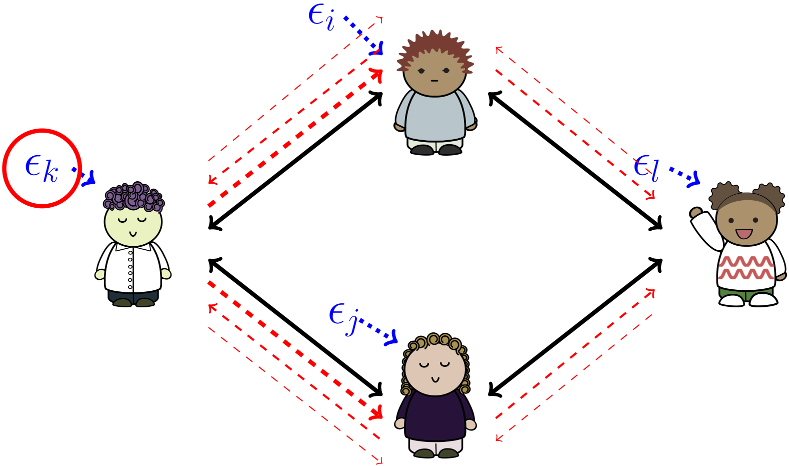

Inference with the Network Autocorrelation Model

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- Standard errors based on the inverse information matrix at the MLE
- Compare models in the usual way (eg AIC, BIC)

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- Many suggestions given by Leenders 2002

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- Can include multiple weight matrices (as a list) for both AR and MA

Leenders 2002

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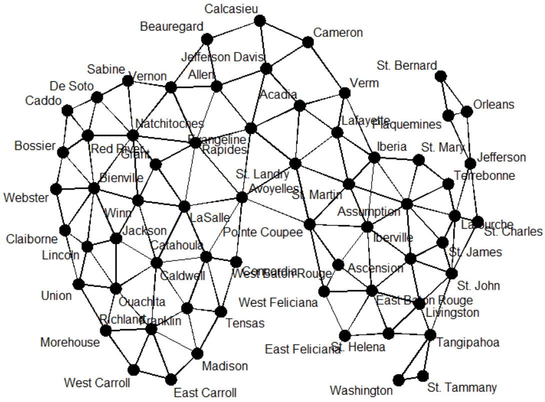

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- Weight matrix (ρ): simple contiguity network

Leenders 2002

Table 3
Network effects model for the Louisiana voting data

	OLS	$w_{ij}^{[1]}$	$w_{ij}^{[2]}$	$w_{ij}^{[6]}$	$w_{ij}^{[9]}$
ρ	–	0.31* (0.10)	0.07 (0.06)	0.12 (0.25)	0.04 (0.12)
Constant	21.03* (4.40)	13.87* (4.67)	19.83* (4.34)	16.78 (10.06)	19.80* (5.62)
B	0.01 (0.08)	−0.00 (0.07)	0.00 (0.08)	0.01 (0.08)	0.01 (0.08)
C	0.30* (0.04)	0.22* (0.05)	0.28* (0.04)	0.29* (0.05)	0.29 (0.05)
U	−0.11* (0.04)	−0.10* (0.04)	−0.11* (0.04)	−0.11* (0.04)	−0.11* (0.04)
BPE	0.39* (0.06)	0.30* (0.06)	0.37* (0.06)	0.38* (0.06)	0.38* (0.06)

* $P < 0.05$.

Table 4
Network disturbances model for the Louisiana voting data

	$w_{ij}^{[1]}$	$w_{ij}^{[2]}$	$w_{ij}^{[6]}$	$w_{ij}^{[9]}$
ρ	0.69* (0.10)	0.53* (0.13)	0.22 (0.42)	0.74* (0.15)
Constant	26.99* (4.50)	24.98* (4.22)	21.52* (4.30)	24.51* (5.06)
B	−0.11 (0.07)	−0.07 (0.07)	−0.00 (0.08)	−0.09 (0.08)
C	0.37* (0.05)	0.35* (0.04)	0.31* (0.04)	0.38* (0.04)
U	−0.07* (0.03)	0.08* (0.03)	−0.11* (0.04)	−0.10* (0.04)
BPE	0.24* (0.06)	0.30* (0.06)	0.38* (0.06)	0.29* (0.06)

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Leenders 2002

Table 5
Order of W matrices and autocorrelation models according to AIC

	Weight matrix	AIC	Order within model	Overall order
Network effects model	$w_{ij}^{[1]}$	439.12	1	3
	$w_{ij}^{[2]}$	445.52	2	5
	$w_{ij}^{[9]}$	446.78	4	8
	$w_{ij}^{[6]}$	446.44	3	6
Network disturbances model	$w_{ij}^{[1]}$	431.92	1	1
	$w_{ij}^{[2]}$	436.33	2	2
	$w_{ij}^{[9]}$	446.69	4	7
	$w_{ij}^{[6]}$	440.95	3	4
OLS	–	446.82	–	9

Code Time

Section 2.6

Baseline Models

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  - identify potentially constraining factors
  - compare observed properties to baseline model
  - useful even when baseline model is not 'realistic'

Types of Baseline Hypotheses

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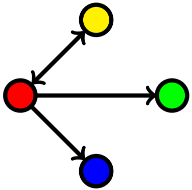
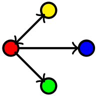
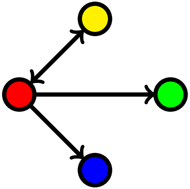


Empirical Network

Types of Baseline Hypotheses





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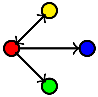

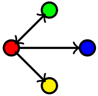

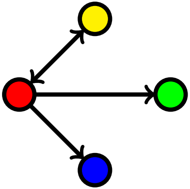

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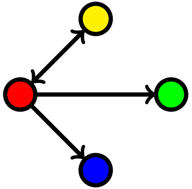

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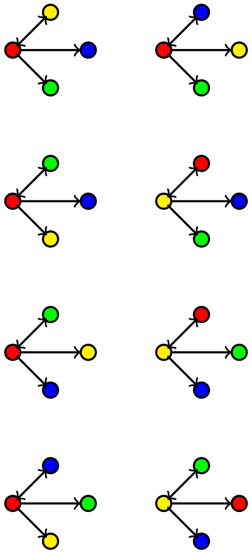

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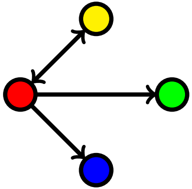

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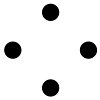

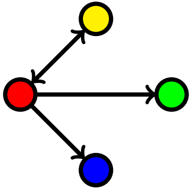

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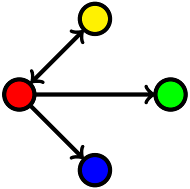

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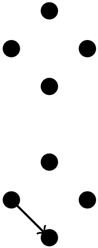

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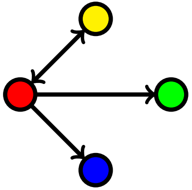

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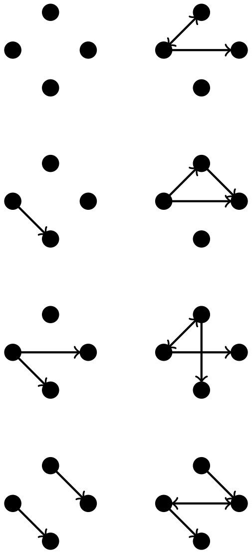

. . . etc

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- For each simulation, recalculate the test statistic
- Compare empirical value to null distribution, just as in standard statistical testing

Example

Transitivity in the Hurricane Frederic EMON

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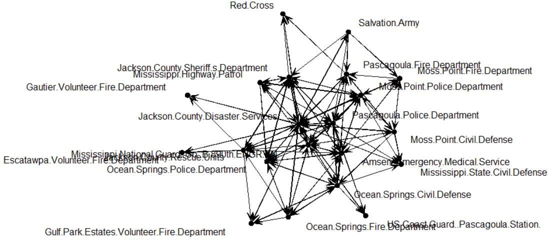
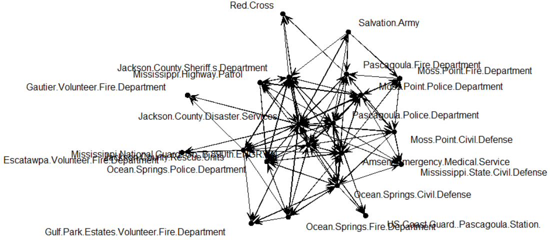


Example

Transitivity in the Hurricane Frederic EMON

- $\rho = 0.475$
- indicates that roughly half the time that $i \to j \to k$, $i \to k$



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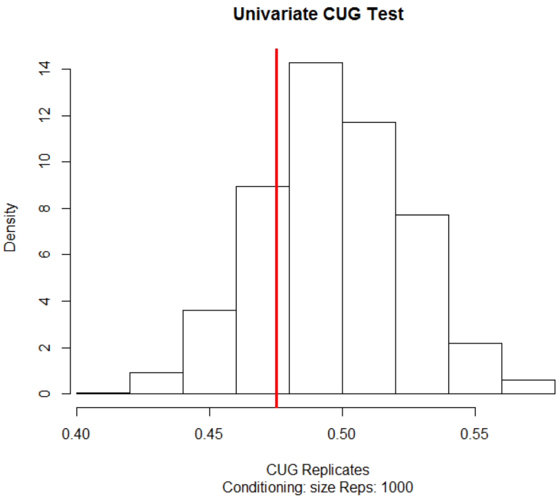
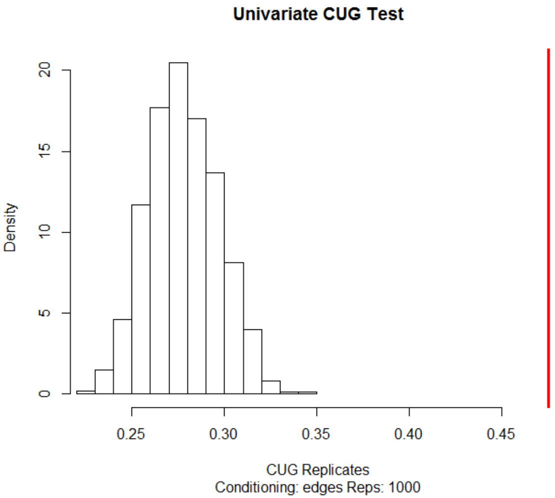

Univariate CUG Test
Density
0
2
4
6
8
10
12
14
0.40
0.45
0.50
0.55
CUG Replicates
Conditioning: size Reps: 1000

Example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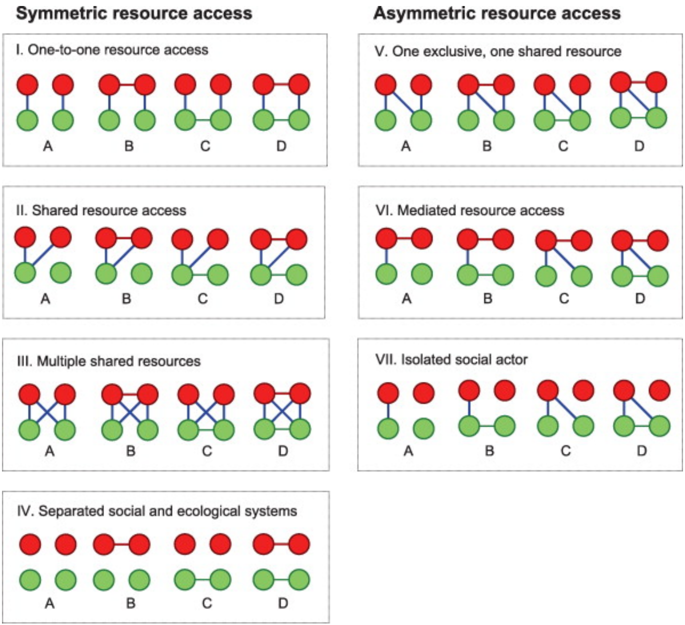
Bodin and Tengo

"Disentangling intangible social–ecological systems"

Bodin and Tengo



NetworkStats

LJasny

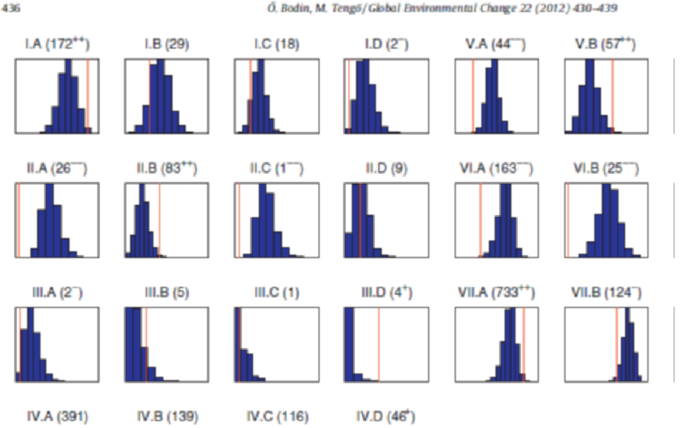
Node Level Permutation

Quadratic Assignment Procedure

Network Autocorrelation

Baseline Models

Bodin and Tengo



Summary

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- CUG tests (network is dependent variable)

Code Time

- the rest! whew!

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