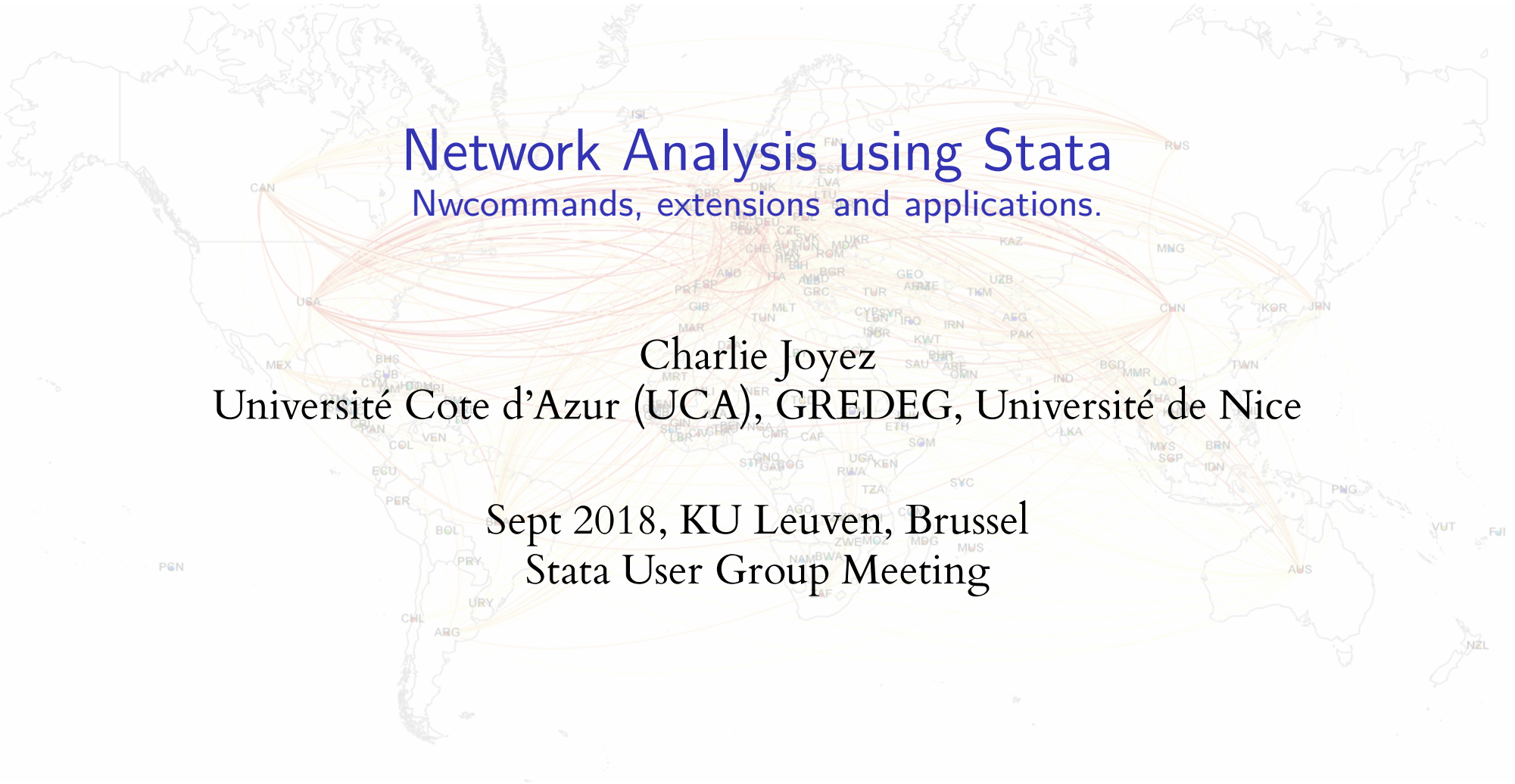

Network Analysis using Stata

Nwcommands, extensions and applications.

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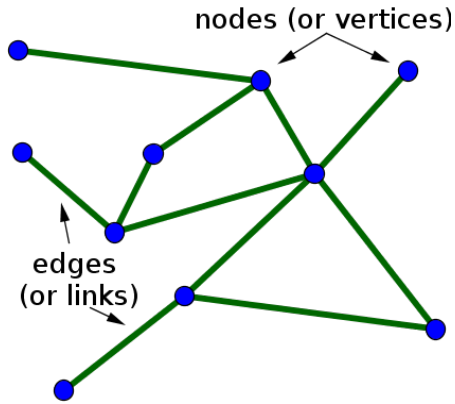
Stata User Group Meeting

Motivation

Networks are everywhere. flexible mathematical object



- Complex systems, interactions, interdependence's.
- Two type of use in (Social) Sciences
  - Theoretical modeling with complex micro-foundations
  - Empirical analysis of existing networks.
    - Booming in several fields with data availability and computing capabilities.
    - Increasing interest (See Stata news january 2018 (33-1))

Objective

How to easily proceed to network analysis using Stata?

- Node level and network wide analysis

Outline

nwcommands - Presentation

- Developed (maintained) by Thomas Grund - Univ. College Dublin
  - http://nwcommands.org
  - `install nwcommands-ado, from(http://www.nwcommands.org)`
- Entire suite of commands, close to Stata commands (nw prefix)
  - declare, use, save network data
  - Manipulate (keep, drop, permute, etc.) nodes or entire networks
  - Compute network metrics
    - At the node level (centrality, etc)
    - At the entire network level (density, overall clustering coeff).

Declare Data

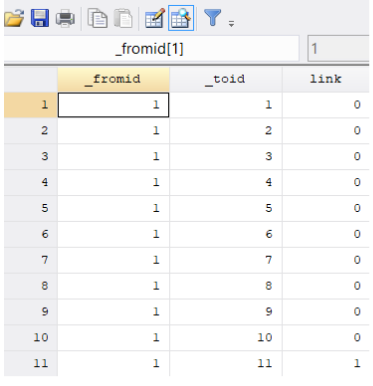
- From a Mata Matrix (Adjacency matrix)
  - `mata A=(0,10,1 \5,0,0 \0,2,0)`

    `mata A`

```
. mata A
        1    2    3
    +-------------------+
  1 |   0   10    1     |
  2 |   5    0    0     |
  3 |   0    2    0     |
    +-------------------+
```

    `nwset, mat(A) name(netA)`

- From an edge list



_fromid[1] 1

	_fromid	_toid	link
1	1	1	0
2	1	2	0
3	1	3	0
4	1	4	0
5	1	5	0
6	1	6	0
7	1	7	0
8	1	8	0
9	1	9	0
10	1	10	0
11	1	11	1

  - `nwfromedge _fromid _toid link, name(Net1) undirected`

Node-level metrics

- **`nwdegree`**
  - `_degree`: Number of direct neighbors
  - $d_i = \sum_j m_{i,j}$, $M = A$: /A Unweighted adjacency matrix
  - returns Freeman (1979) index

$$C_x = \frac{\sum_{i=1}^{N} C_x(p_*) - C_x(p_i)}{\max \sum_{i=1}^{N} C_x(p_*) - C_x(p_i)}$$

- **`nwdegree, valued`**
  - `_strength`: Sum of edges weights
  - $s_i = \sum_j a_{ij}$

- Other node centrality metrics : Betweeness & closeness, Katz, Eigenvector.

Network-wide information

- **`tnwsummarize`**

```
. nwsummarize
```

```
   Network name:  test
   Network id:  1
   Directed: true
   Nodes: 6
   Arcs: 14
   Minimum value:  0
   Maximum value:  1
   Density:  .4666666666666667
```

- **`nwgeodesic`**
  - Longest past, diameter, avg shortest path (unweighted)
- **`nwclustering`** Overall clustering coefficient (nb triads / nb possible triads)

Outline

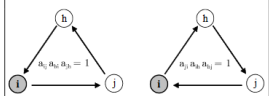
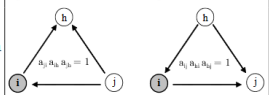
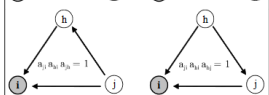
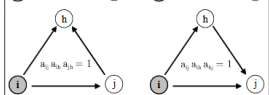
Node-level metrics 1/2

- Average Nearest Neighbors Degree (Strength)
  - `nwannd` : Average nearest neighbor degree.
    -
```
mata
neighbor = mymat:>0
Z=st_data(.,"_degree")
mata:  totdegreemat = neighbor*Z
mata:  ANNDmat=totdegreemat:/Z
end mata
```
- nwdisparity (Barthélemy et al., 2005) : distribution of edge's weight (concentration)
  $disparity_i = \sum_j (w_{ij}/s_i)^2$
- nw_harmonic centrality (suited for disconnected graphs)
  - $H(x) = \sum_{y \neq x} \frac{1}{d(y,x)}$

Node-level metrics 2/2

Weighted / directed extension of existing commands

- **`nwcluster`** : directions and/or weighted generalization (Onnela et al., 2005)
- **`nw_wcc`** : Weighted Clustering Coefficients (Fagiolo, 2006)

Patterns	Graphs	t_i^*	T_i^*	CCs for BDNs	CCs for WDNs
Cycle		$(A)^3_{ii}$	$d_i^{in}d_i^{out} - d_i^{\leftrightarrow}$	$C_i^{cyc} = \frac{(A)^3_{ii}}{d_i^{in}d_i^{out} - d_i^{\leftrightarrow}}$	$\tilde{C}_i^{cyc} = \frac{(\hat{W})^3_{ii}}{d_i^{in}d_i^{out} - d_i^{\leftrightarrow}}$
Middleman		$(AA^TA)_{ii}$	$d_i^{in}d_i^{out} - d_i^{\leftrightarrow}$	$C_i^{mid} = \frac{(AA^TA)_{ii}}{d_i^{in}d_i^{out} - d_i^{\leftrightarrow}}$	$\tilde{C}_i^{mid} = \frac{(\hat{W}\hat{W}^T\hat{W})_{ii}}{d_i^{in}d_i^{out} - d_i^{\leftrightarrow}}$
In		$(A^TA^2)_{ii}$	$d_i^{in}(d_i^{in} - 1)$	$C_i^{in} = \frac{(A^TA^2)_{ii}}{d_i^{in}(d_i^{in}-1)}$	$\tilde{C}_i^{in} = \frac{(\hat{W}^T\hat{W}^2)_{ii}}{d_i^{in}(d_i^{in}-1)}$
Out		$(A^2A^T)_{ii}$	$d_i^{out}(d_i^{out} - 1)$	$C_i^{out} = \frac{(A^2A^T)_{ii}}{d_i^{out}(d_i^{out}-1)}$	$\tilde{C}_i^{out} = \frac{(\hat{W}^2\hat{W}^T)_{ii}}{d_i^{out}(d_i^{out}-1)}$
All (D)	All 8 graphs above	$\frac{(A+A^T)^3_{ii}}{2}$	$d_i^{tot}(d_i^{tot} - 1) - 2d_i^{\leftrightarrow}$	$C_i^D = \frac{(A+A^T)^3_{ii}}{2T_i^D}$	$\tilde{C}_i^D = \frac{(\hat{W}+\hat{W}^T)^3_{ii}}{2T_i^D}$

- **`nw_geodesic`** (weights as distance)

Network level

- **nwreciprocity** (Barrat et al., 2004)
  - ```
    mata
    s=sum(W)
    Z = W :* (W :< W') + W' :* (W' :< W) /*min of symmetrics
    elements = reciprocated ties*/
    E=sum(Z)
    r=E/s
    end mata
    ```
  - Compares reciprocity with N random draws (same size, density).
- **nwstrengthcent** : (Freeman, 1979) index based on Strength.
    ```

Declaration

- From neigbor lists (only existing ties). A variable may indicate the sequence.
  - **nw_fromneighbor** `nw_fromlist test,node(NODE) id(ID) direction(year)`

Initial data


Data Editor (Browse) - [Untitled]
File Edit View Data Tools
var5[4]

	ID	NODE	year
1	1	AUT	1
2	1	USA	2
3	2	USA	1
4	2	GBR	1
5	3	GBR	2
6	3	FRA	2
7	3	ESP	1
8	4	ESP	1
9	4	ITA	1
10	4	USA	2
11	4	USA	3
12	.	USA	3
13	4		3

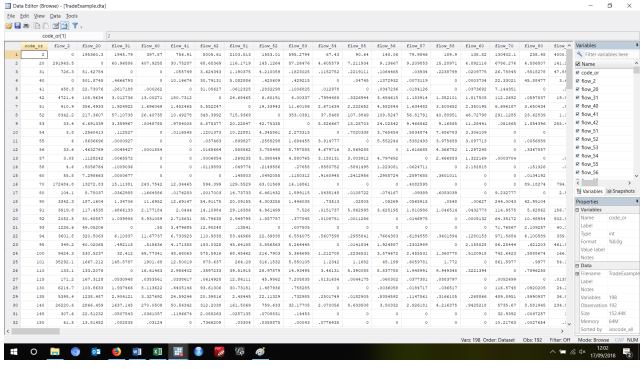
Final data

	NODE	_AUT	_ESP	_FRA	_GBR	_ITA	_USA
1	AUT	0	0	0	0	0	1
2	ESP	0	0	1	1	1	1
3	FRA	0	1	0	0	0	0
4	GBR	0	1	1	0	0	1
5	ITA	0	1	0	0	0	1
6	USA	0	1	0	1	1	0

Outline

Application to international economics

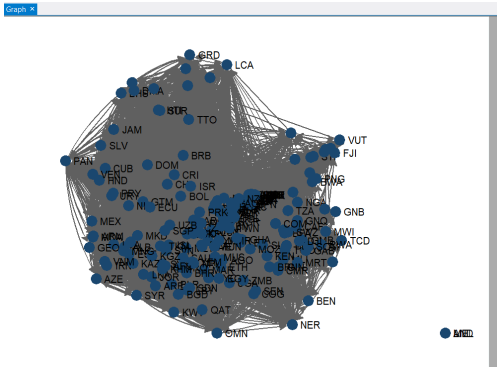
- World Trade Web on 2016



- Declare to be weighted directed network : 192*192 table

```
mkmat flow_*, matrix(M)
mata A=st_matrix("M")
nwset , mat(A) name(TradeNet‘v’)
```

Application - 2



- Most central nodes?
  - Eigenvector centrality

Network name: **TradeNet_3**

Eigenvector centrality

Variable	Obs	Mean	Std. Dev.	Min	Max
_evcent	183	.0716463	.0182512	.0114232	.0927111

```
. rename _evcent evcent_unw

. nw_evcent
```

Network name: **TradeNet_3**

Eigenvector centrality

Variable	Obs	Mean	Std. Dev.	Min	Max
_evcent	183	.0246924	.0698673	5.23e-06	.5755326

```
. rename _evcent evcent_w

.
```

TZA	.039391	.0000414
UGA	.0506185	.0001651
UKR	.0907891	.0191053
URY	.0808169	.0013135
USA	.0924482	.5755326
UZB	.0913563	.1499816

Degree centralization 0.364

Strength Centralization 0.176

Application - 3

Econometrics of networks

- Use of network metrics (e.g. centrality indexes of nodes) into traditional analysis. (Hidalgo et al., 2007)
- Regress network structure (dyadic data)
  - Individuals in networks not iid
    - OLS biased unless FE or clustering
    - QAP : unit = dyadic value + random permutations of rows and columns.
  - `nwqap MNEnet_2011 GVCnet_2010 , mode(dist) type(reg) permutation(500)`

```
Permutation: 500 out of 500


Multiple Regression Quadratic Assignment Procedure

  Estimation           =  QAP
  Regression           =  reg
  Permutations         =  500
  Number of vertices   =  54
  Number of edges      =  1430
```

MNEnet_forGVC2011	Coef.	P-value
GVCnet_forMNE2010	.001906	0
_cons	37.52447	

Outline

Conclusion

- Network analysis made easy through Stata
  - easy to learn and contribute
  - suited to a wide range of issues

Next steps

  - generalize metrics to weighted, directed, unconnected graphs.
    - Fit to complex networks.
  - improve network graphs & plots vizualization
  - Incorporate nwcommands into Stata 16?
  - Promote network analysis to colleague/students already familiar with Stata.

Thank you

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Many thanks to **Thomas Grund** for its **nwcommands: Network Analysis with Stata**
Additional Stata commands used for this paper are available on my RePEc Ideas page or directy from SSC (e.g. `ssc install nwannd`)

References

Barrat, A., Barthelemy, M., Pastor-Satorras, R., and Vespignani, A. The architecture of complex weighted networks. *Proceedings of the National Academy of Sciences of the United States of America*, 101(11):3747–3752, 2004.

Barthélemy, M., Barrat, A., Pastor-Satorras, R., and Vespignani, A. Characterization and modeling of weighted networks. *Physica a: Statistical mechanics and its applications*, 346(1): 34–43, 2005.

Fagiolo, G. Directed or undirected? a new index to check for directionality of relations in socio-economic networks. *Economics Bulletin*, 3(34):1–12, 2006.

Freeman, L. C. Centrality in social networks conceptual clarification. *Social networks*, 1(3): 215–239, 1979.

Hidalgo, C. A., Klinger, B., Barabasi, A.-L., and Hausmann, R. The product space conditions the development of nations. Paper 0708.2090, arXiv.org, 2007. 00468.

Joyez, C. On the topological structure of multinationals network. *Physica A: Statistical Mechanics and its Applications*, 473:578 – 588, 2017.

Onnela, J.-P., Saramäki, J., Kertész, J., and Kaski, K. Intensity and coherence of motifs in weighted complex networks. *Physical Review E*, 71(6):065103, 2005.