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Latent Space Models for Temporal Networks

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References

- **This talk based on work (with Rajesh Venkatachalapathy) submitted to NetSci 2019.**
- **A fuller manuscript (with Rajesh) is in progress.**
- **Peres et. al. "Mobile Geometric Graphs" (2010)**
- **Holme, P. "Modern Temporal Network Theory: A Colloquium"**

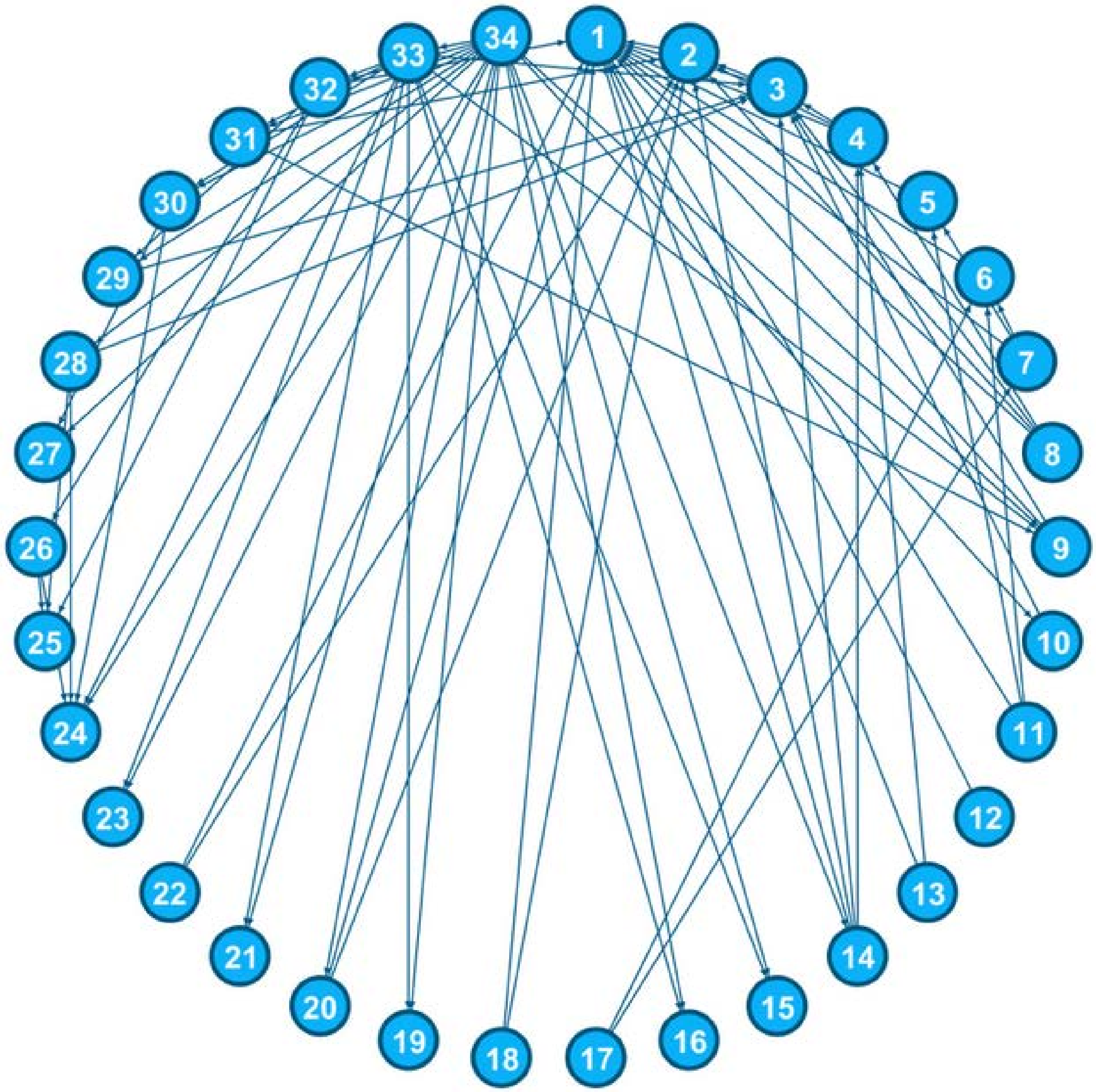
(2015)

Outline

- **Homophily and latent space**
- **Random geometric graphs and Brownian motion**
- **Mobile geometric graphs**
- **Implementation**
- **Observations**
- **Current and future work**

0. Social Networks

- **Maps of relationships between actors**
- **What do the actors tell us about the networks?**
- **What do the networks tell us about the actors?**



A social network (Wikipedia)

1. Homophily

“Birds of a feather flock together”

- **Actors with common attributes are more likely to form ties**
- **Ties between actors may indicate common attributes**
- **Typically expressed in an informal way**

- **Latin prefix, Greek Suffix**
- **Idiophily?**

2. Latent Space

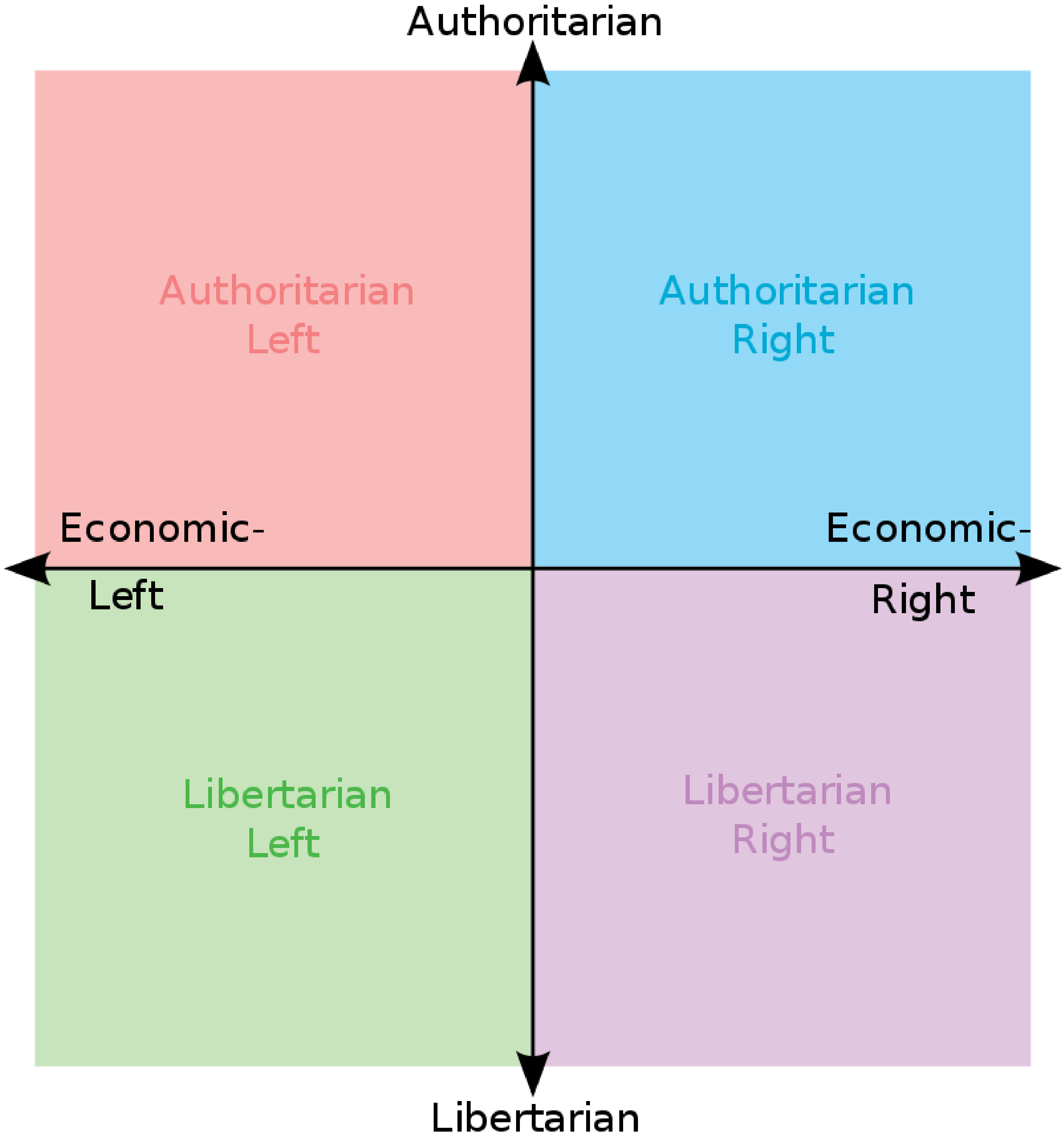
- **Can we state something more formal?**

- **Combinations & intensities of attributes assign the actors to coordinates in a *latent space***

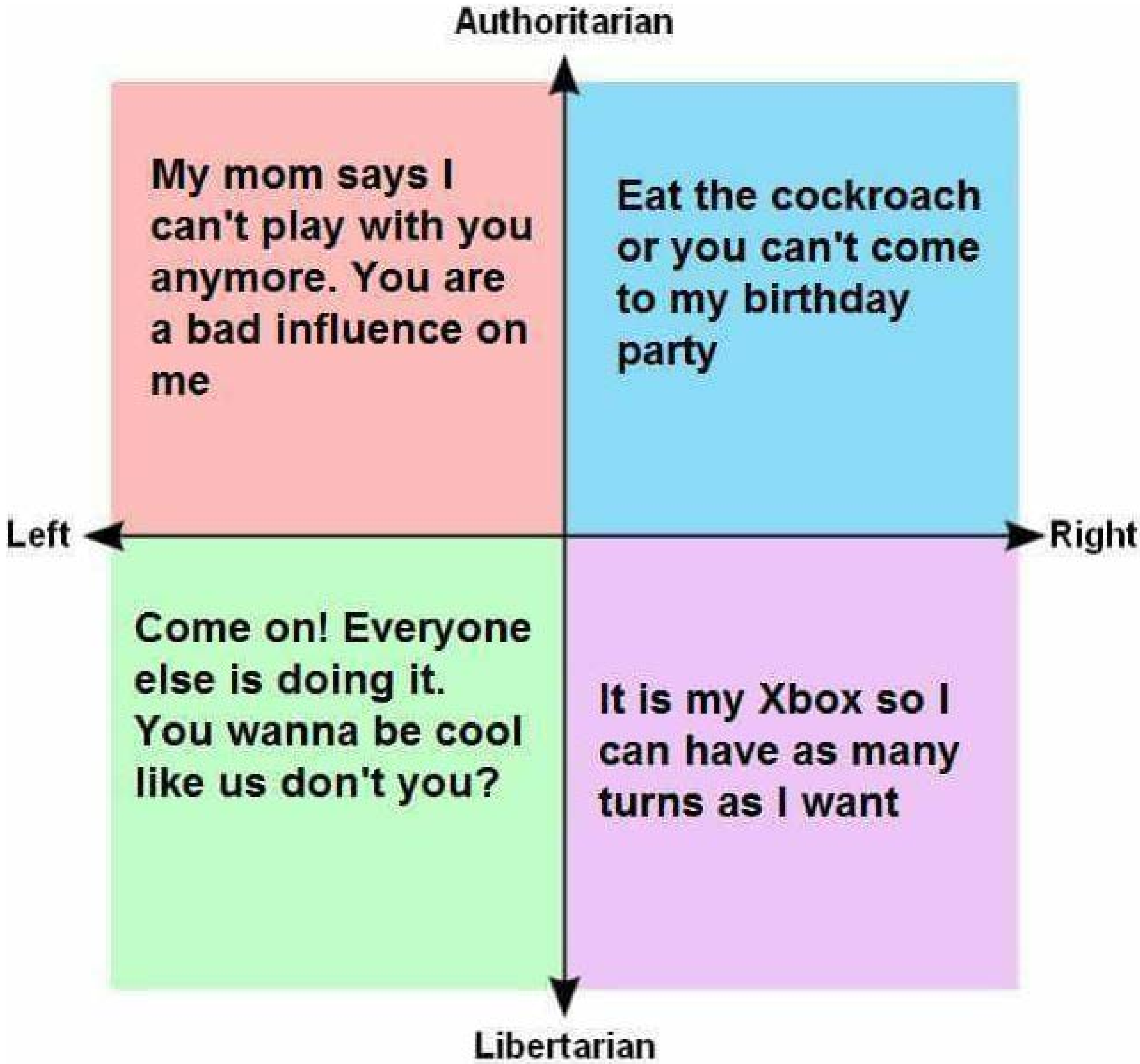
- **More attributes in common, or attributes with similar intensities, mean the actors are closer together in this space.**

- **Tobler's Law: Everything is related to everything else, but near things are more related than distant things.**

- **(Q. Are there *any* networks that do *not* correspond to a latent space?)**



Wikipedia: The political compass



Tag yourself

3. Homophily in Latent Space

The graph at right is described by an $n \times n$ adjacency matrix **A**, where n = n *10* inc("n"); figure[2].size(get("n")); figure[1].load([0, matriculate(figure[2].data, get("m"))]); dec("n"); figure[2].size(get("n")); figure[1].load([0, matriculate(figure[2].data, get("m"))]); , whose entries

A_{ij} = \begin{cases} f(d_{ij}) &\text{if } f(d_{ij}) > m \\ 0 &\text{otherwise} \end{cases} \text{ where } f(d_{ij}) = x
["\\dfrac{1}{1 + e^{0.5(5 - d_{ij})}}", "\\dfrac{1}{1 + e^{0.5(5 - d_{ij})}}", "1 - \\dfrac{d_{ij}}{2}",] 0 get("X")[get("Xi")]

var X = get("X"); inc("Xi"); set("x", X[get("Xi")]); update("blurb_dij"); distanceFunction = distances[get("Xi")]; figure[1].load([0, matriculate(figure[2].data, get("m"))]); var X = get("X"); dec("Xi"); var Xi = get("Xi"); set("x", X[get("Xi")]); update("blurb_dij"); distanceFunction = distances[get("Xi")]; figure[1].load([0, matriculate(figure[2].data, get("m"))]); ,

$blurb$ *["d_{ij} \\text{ is the } \\href{http://en.wikipedia.org/wiki/Euclidean_distance}{Euclidean} \\text{ distance between } \ i \\text{ and } j", "d_{ij} \\text{ is the } \\href{http://en.wikipedia.org/wiki/Manhattan_distance}{Manhattan} \\text{ distance between } \ i \\text{ and } j", "d_{ij} \ \\text{ is the } \\href{http://en.wikipedia.org/wiki/Hamming_distance}{Hamming} \\text{ distance between } \ \\text{"}x_{i}y_{i} \\text{\" and "} \ x_{j}y_{j} \\text{"}",] get("blurbs")[get("Xi")]* set("blurb", get("blurbs")[get("Xi")]); , and m = m *0.35* inc("m"); figure[1].load([0, matriculate(figure[2].data, get("m"))]); dec("m"); figure[1].load([0, matriculate(figure[2].data, get("m"))]); is an arbitrary cutoff distance. If the edge weights are interpreted as probabilities of connections, then the matrix describes a distribution of possible graphs reflecting the same underlying social space.

Click and drag the points to change the graph.

4. Latent Space Dynamics

- **We know attributes can change.**
- **This means the actors' positions in latent space change.**
- **There are *many* possible ways this could happen.**
- **In social contexts, we expect nontrivial dynamics.**

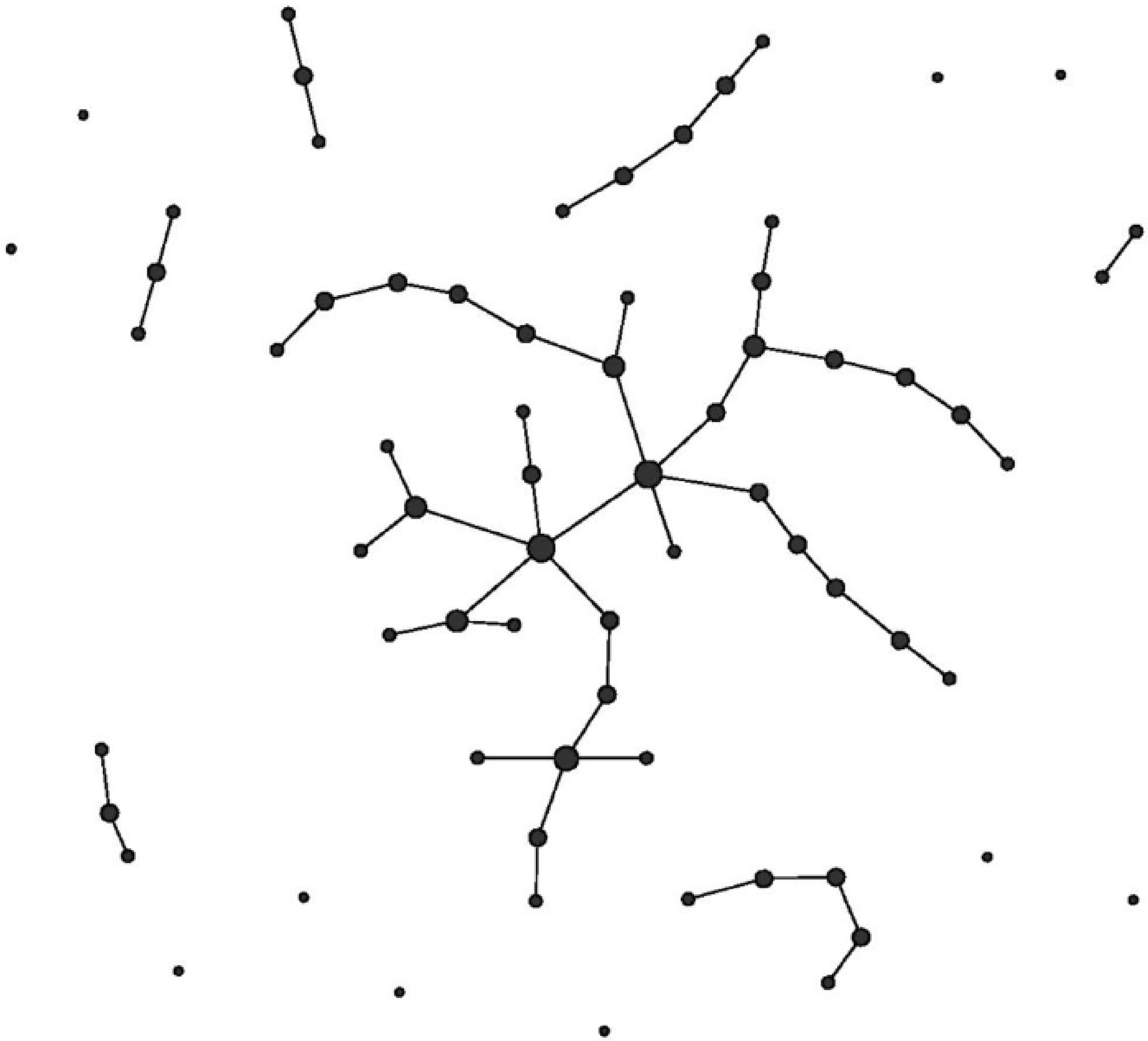
- **People influence each other and are influenced by social forces.**

Paranormal Beliefs (2016-2018)	2016	2017	2018	Change 2016-2018
Ancient, advanced civilizations, such as Atlantis, once existed	39.6	55.0	56.9%	17.3%
Aliens have visited Earth in our ancient past	27.0	35.0	41.4%	14.4%
Places can be haunted by spirits	46.6	52.3	57.7%	11.1%
Aliens have come to Earth in modern times	24.7	26.2	35.1%	10.4%
Bigfoot is a real creature	13.5	16.2	20.7%	7.2%
Some people can move objects with their minds	19.1	25.0	26.2%	7.1%
Fortune tellers and psychics can foresee the future	14.1	19.4	17.2%	3.1%

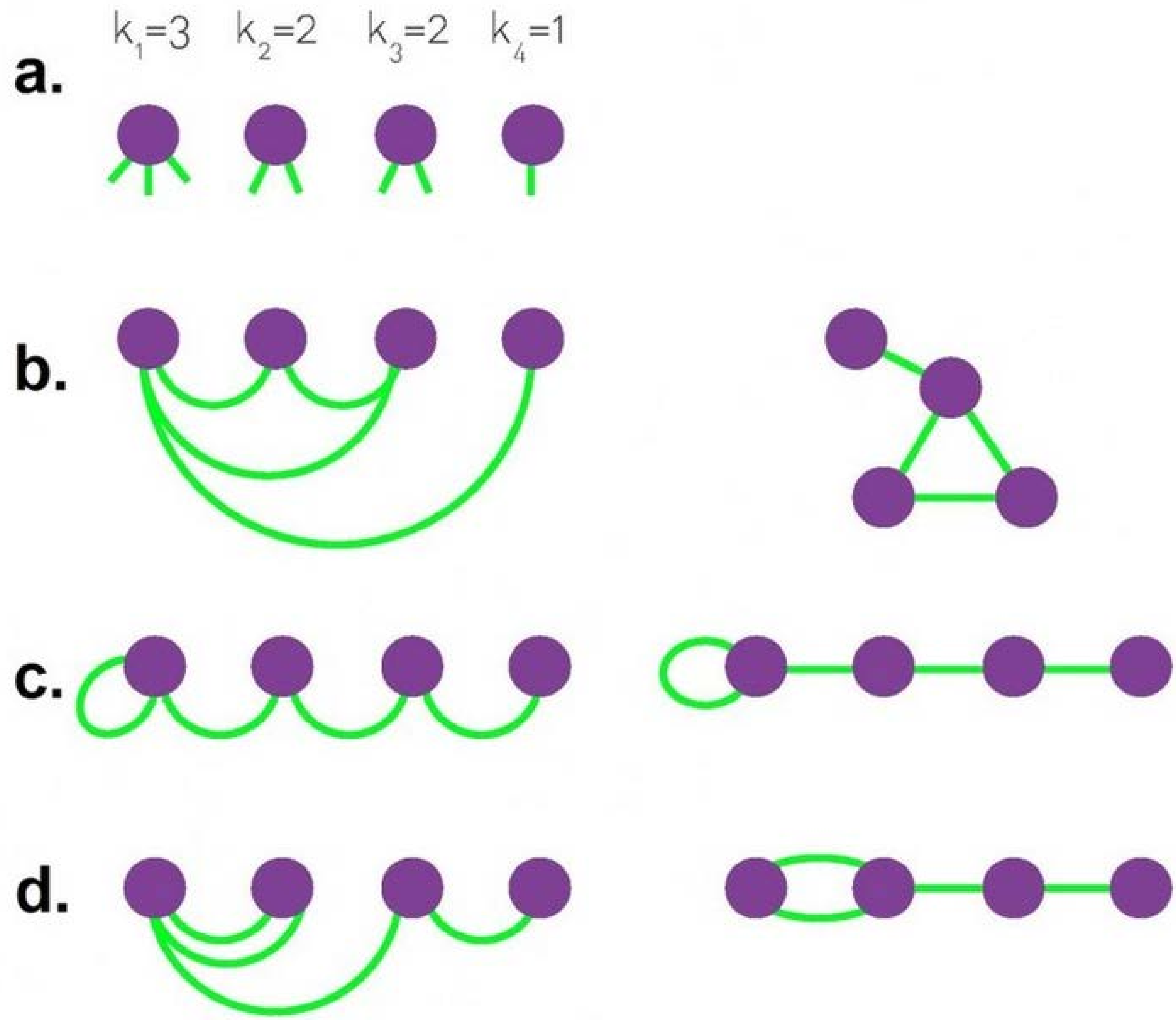
Chapman University Survey of American Fears

5. Null Models

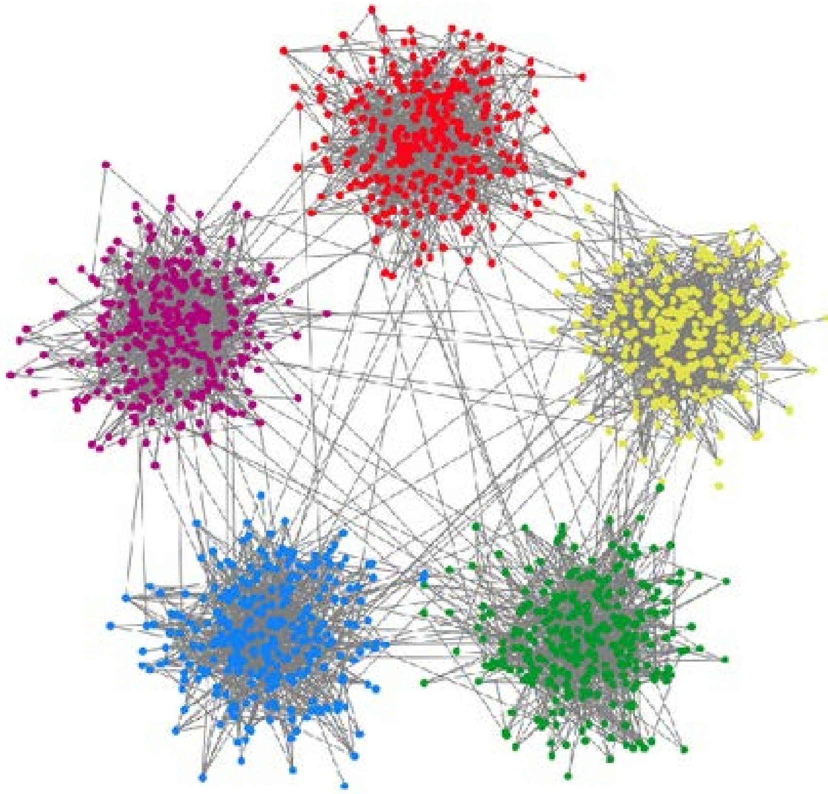
- **Network science has some big null models.**
- **Erdos-Renyi — random graphs**
- **Configuration models — random with fixed degree sequence**
- **Stochastic block models — random with some community structure**



Wikipedia: Erdos-Renyi model



Wikipedia: Configuration model



Emmanual Abbe: Stochastic block model

- **Good null models show what can be explained by chance.**
- **Random dynamics are useful for testing non-random alternatives.**
- **A good null model for latent space network dynamics will have random dynamics.**

- **This will make it easier to spot networks that don't.**

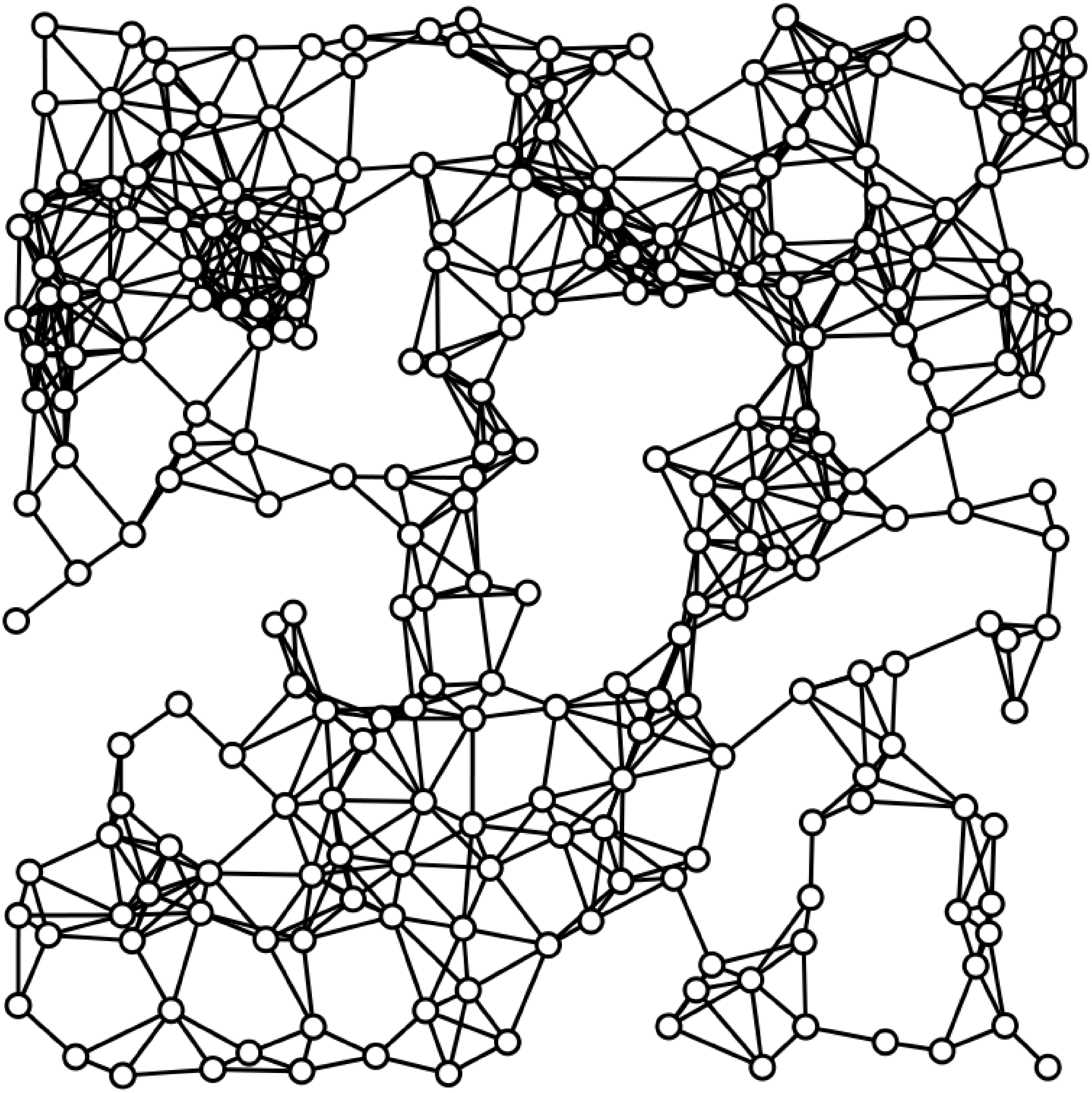
6. Temporal Networks

- **We typically understand static networks to be ‘snapshots’ of dynamic networks.**
- **Real networks are *temporal*.**
- **Static networks can be instantaneous snapshots or aggregate over a window of time.**
- **What is a null model for temporal networks?**
- **Random, but time dependent**

Building Blocks

6. Random Geometric Graphs

- **Graphs**
- **Geometric**
- **Random**



Wikipedia: Random geometric graph

- **Nodes are placed using some *point process***
- **(say, uniformly at random)**
- **Nodes within some radius of one another are connected.**
- **Studied in the context of wireless networks.**

7. Brownian Motion

- **Move a normally distributed distance in either direction.**
- **Like a particle in a fluid.**
- **Shows up in physics, statistics, quantitative finance, etc.**
- **Preserves the intensity of point processes.**

8. Mobile Geometric Graphs

- **Random geometric graphs with Brownian motion**
- **Brownian motion adds time dependence while preserving randomness**
- **Very little studied**
- **Existing work focuses on the mathematical statistics of their communication properties.**

Contd