SoFIA, November 2016

What can we learn from simple models of social interaction?

Understanding Mechanisms to Understand Data

Collective agreement or disagreement by imitation processes?

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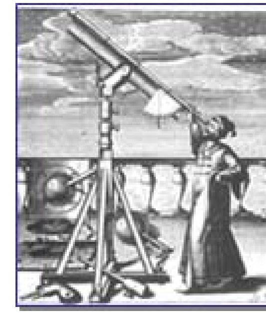
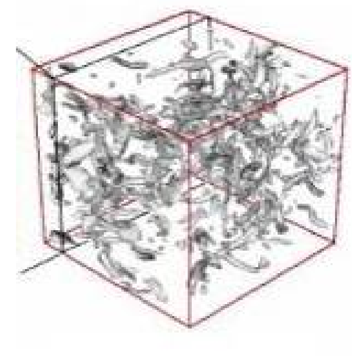
Fourth Paradigm, J. Gray, 2007

- Thousand years ago:
  science was **empirical**
  describing natural phenomena



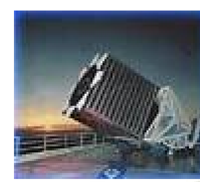
- Last few hundred years:
  theoretical branch
  using models, generalizations

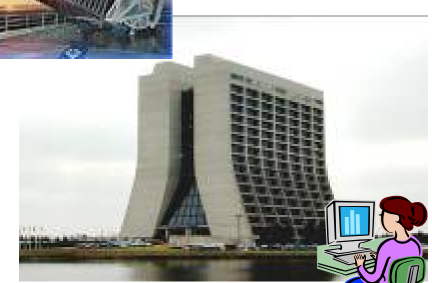
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - K\frac{c^2}{a^2}$$



- Last few decades:
  a **computational** branch
  simulating complex phenomena

- Today:
  data exploration (eScience)
  unify theory, experiment, and simulation
  Information/Knowledge stored in computer
  Scientist analyzes database / files
  using data management and statistics





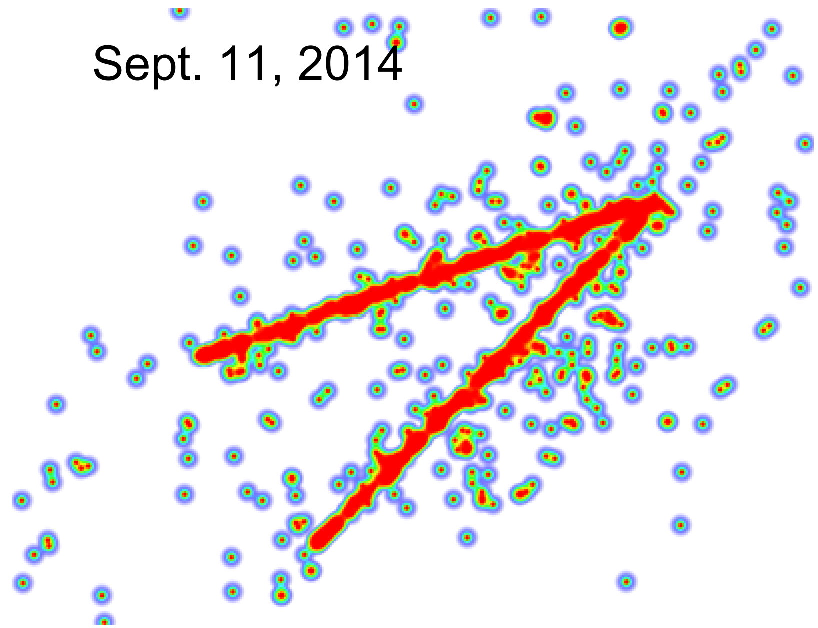
TWITTER DATA

http://ifisc.uib-csic.es/humanmobility/

Studying real time human mobility triggered by social events through on-line networks

September 11, 2013

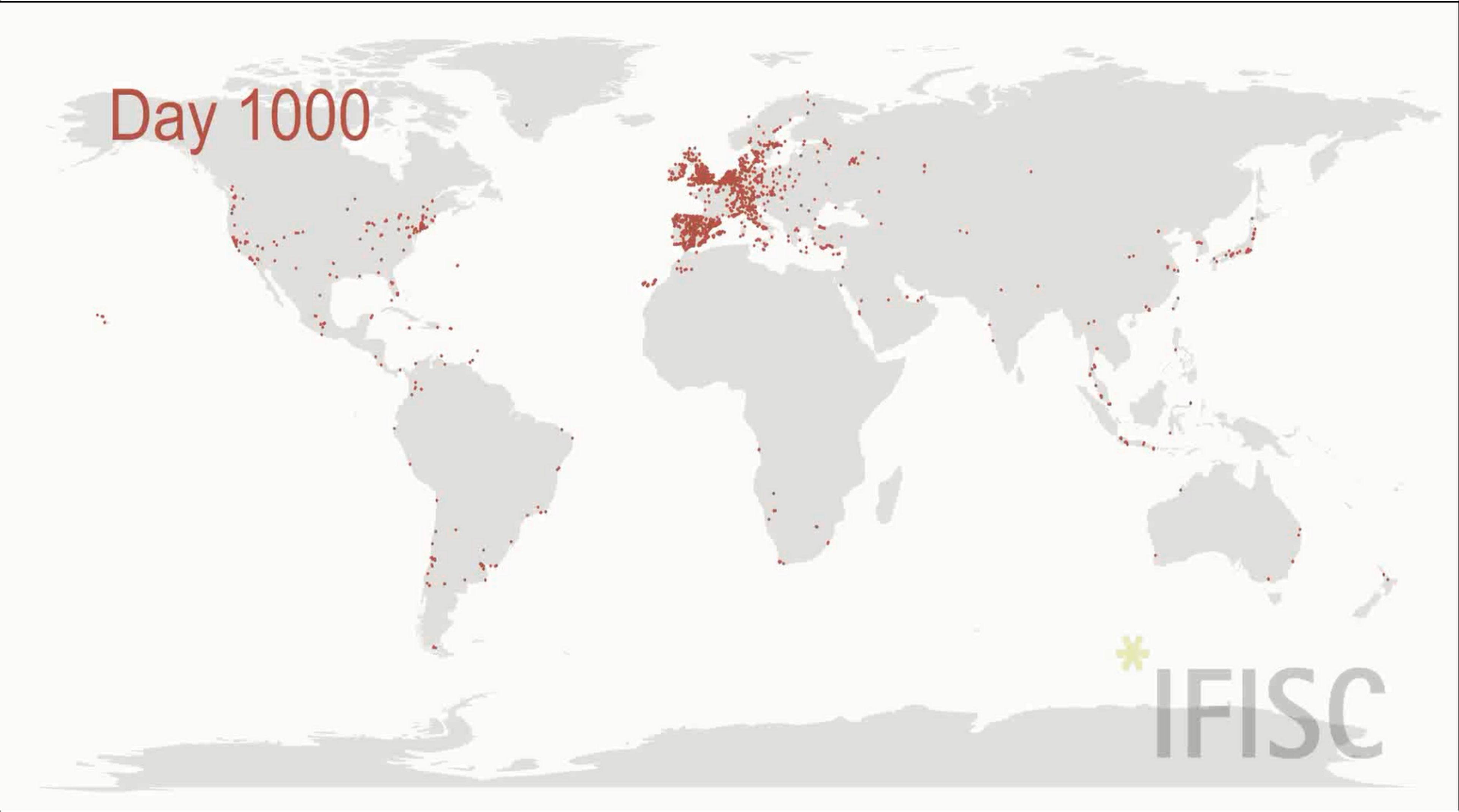
September 11, 2014



http://ifisc.uib-csic.es/humanmobility/

Twitter, Mobility and City Influence

*M.Lenormand, et al J. Royal Soc. Interface **12**, (2015)*



Day 1:Mallorca

Data Science

-Opportunity and Challenge

-Data → Information → Knowledge

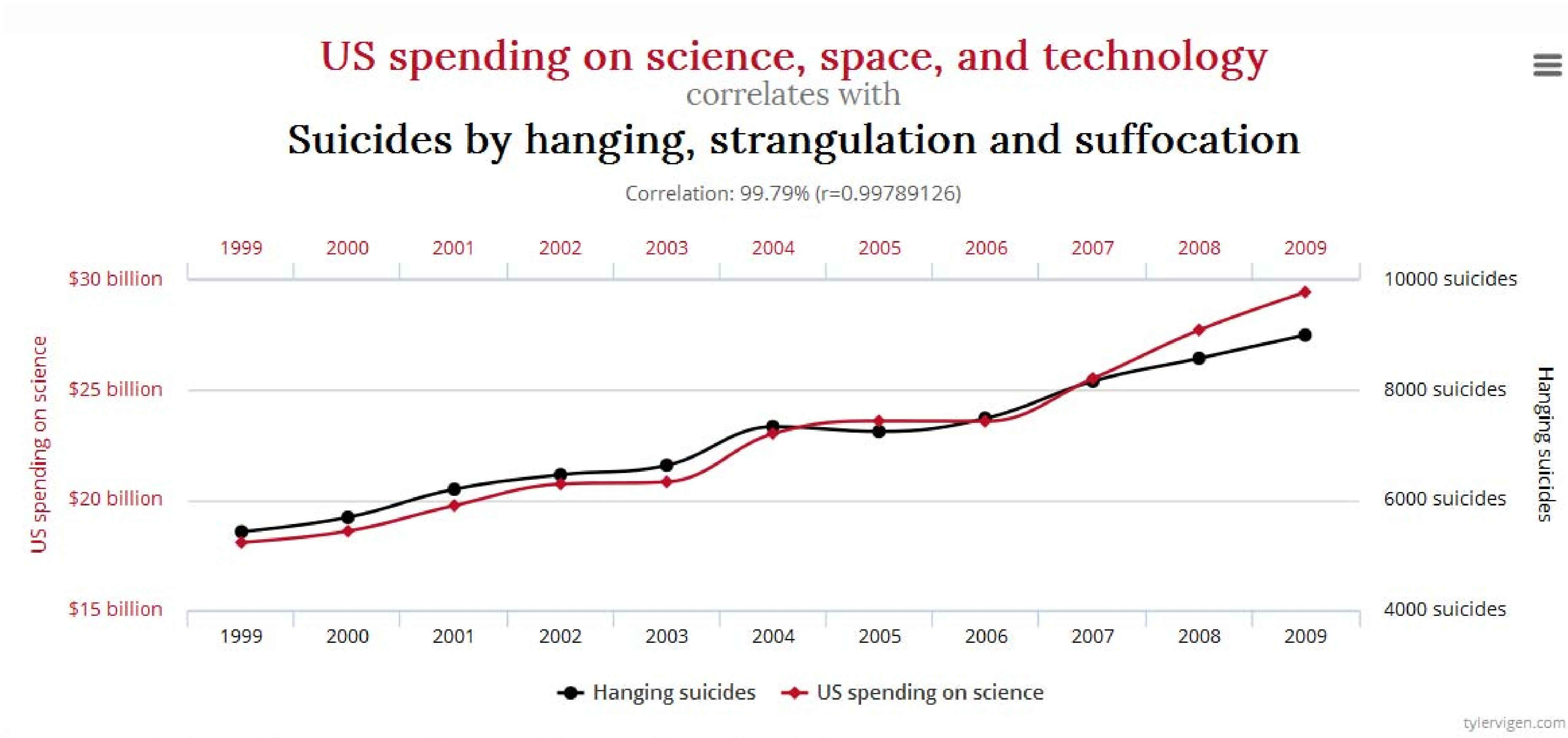
-What do we understand when we know everything?:

On the face of this 'data deluge', it has been argued we are witnessing the end of theory and that the scientific method is becoming obsolete:
"The new availability of huge amounts of data, along with the statistical tools to crunch these numbers, offers a whole new way of understanding the world. Correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all."

C. Anderson (2008) The end of theory: The data deluge makes the scientific method obsolete. Wired Magazine.

It is nice to know that the computer understands the problem. But I would like to understand it too (E. Wigner) http://www.tylervigen.com/

SPURIOUS CORRELATIONS



Science as the art of abstraction:

"What do you consider the largest map that would be really useful?" "About six inches to the mile." "Only six inches!" exclaimed Mein Herr. "We very soon got six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country, on the scale of a mile to the mile!" "Have you used it much?" I enquired. "It has never been spread out, yet," said Mein Herr: "The farmers objected: they said it would cover the whole country, and shut out the sunlight! So now we use the country itself, as its own map, and I assure you it does nearly as well (From Lewis Carroll)

Questions and answers:

Computers are useless: They only provide answers! (Pablo Picasso)

What can we learn from models of simple social behavior?

Purpose of simple model:

-Isolate a mechanism and determine collective level consequences

-Establish cause-effect relations

-Checking common sense concepts

Mechanism of IMITATION:

Herding Behavior

Voter Model: Imitation Dynamics

Clifford and Sudbury, Biometrika (1973)
Holley and Ligget, Ann. Probability (1975)

Two options:

Interaction: copy the state of one of your neighbors at random

Question: When and how agreement is reached by imitation?

First lesson: Choice of variables

Average number of nodes in one of the states is conserved

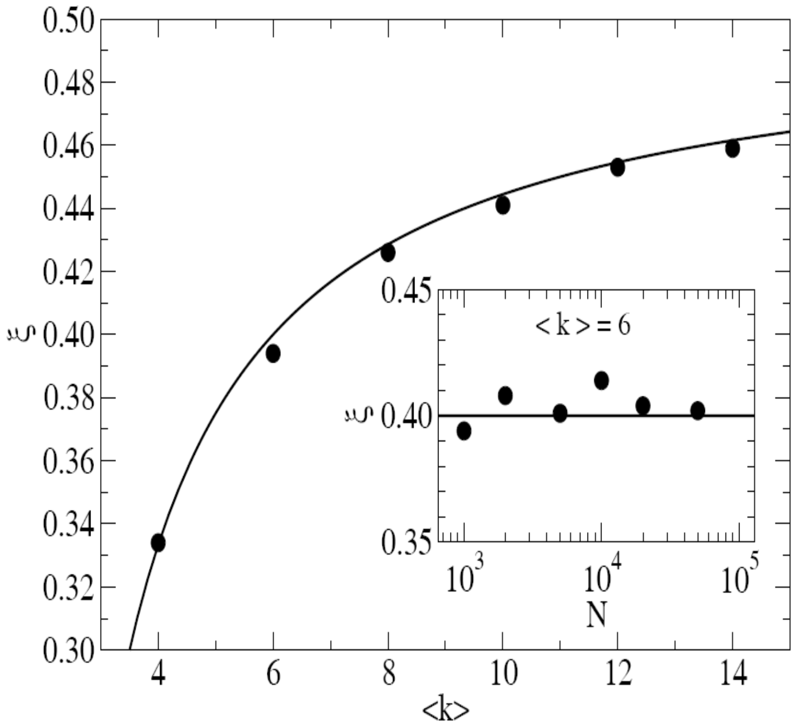
Local variable: ρ Average number of active links (interface density)

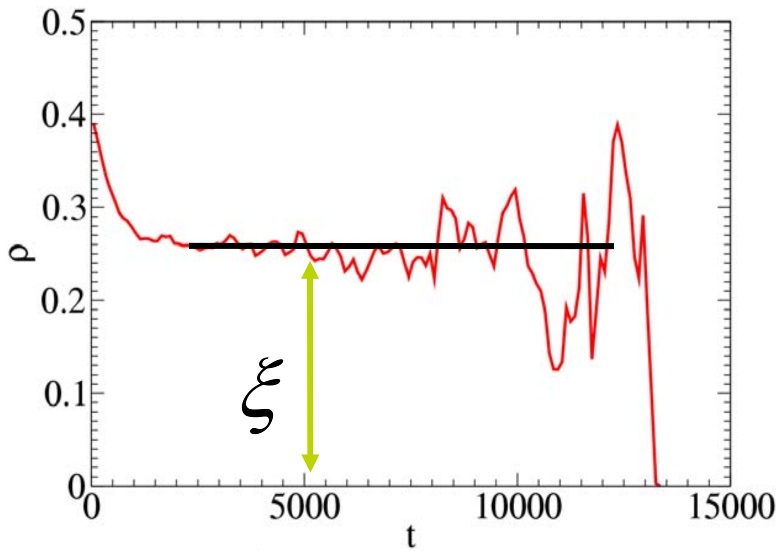
Role of topology of interactions

d>2, Random, Small World, Scale Free Networks,…

Long-lived, dynamically active, disordered states

Barabasi-Albert Scale Free Networks





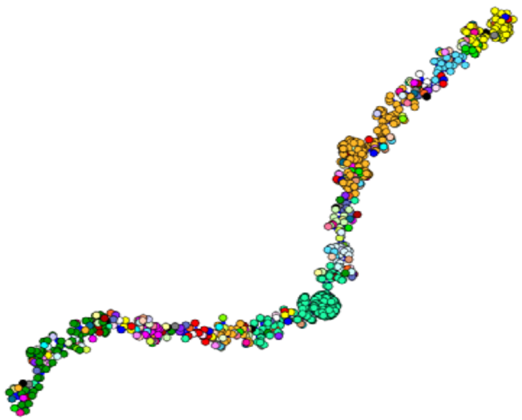
$l = \xi^{-1}$ *Characteristic size of ordered domain*

$$\xi = \frac{\langle k \rangle - 2}{2(\langle k \rangle - 1)}$$

Role of topology?: Dimensionality

1D Scale free net?

Structured SF: ***SSF***

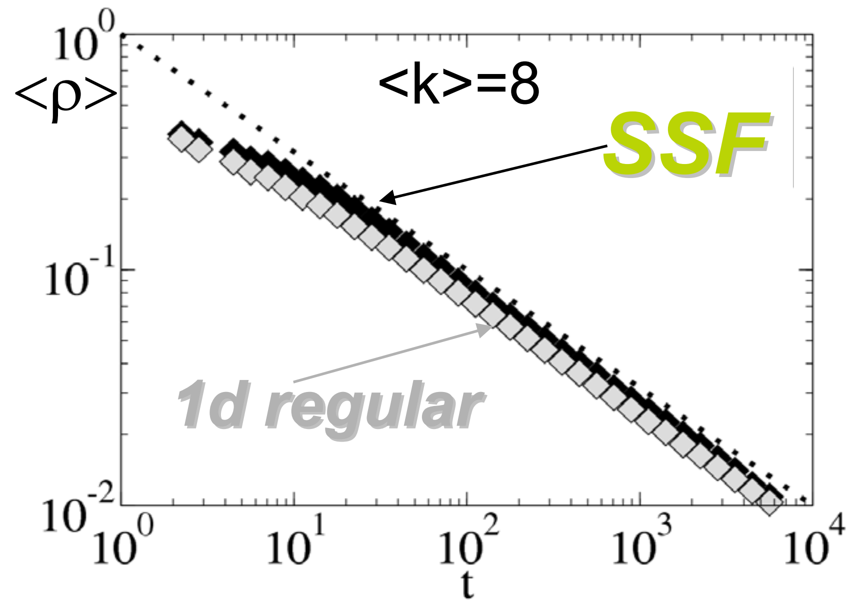


Scale free but
high clustering and 1d

P(k) $\sim$ ***k*** $^{-3}$

L $\sim$ ***N***   ***C*** $\sim$ ***N*** ^{0}

Klemm and Eguíluz,
Phys. Rev. E ***65***,*036123 (2002)*



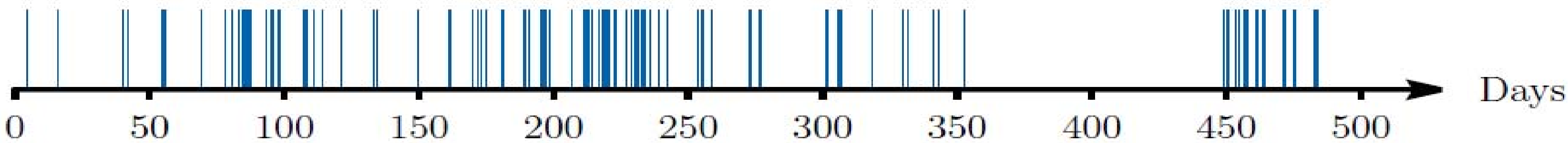
SSF $$<\rho>\sim t^{-1/2}$$ $$\tau_1 \approx N^2$$

Dimensionality *determines when imitation leads to growing agreement*

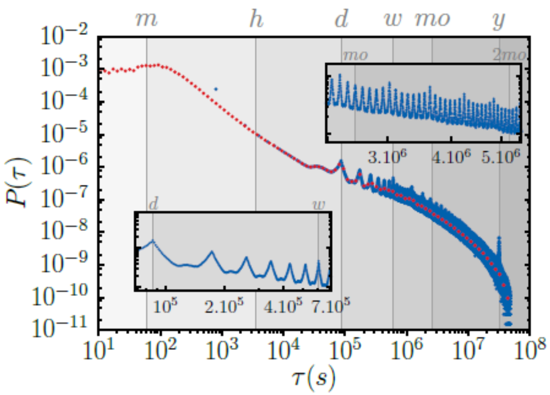
Degree *distribution or network* ***disorder*** ***are not relevant***

Human Activity Patterns

Fernandez-Gracia et al, PRE (2011);
Artime et al, ArXiv 1604.04155 (2016)



Bursty interaction pattern between two twitter users



P(τ)
Nonpoissonian

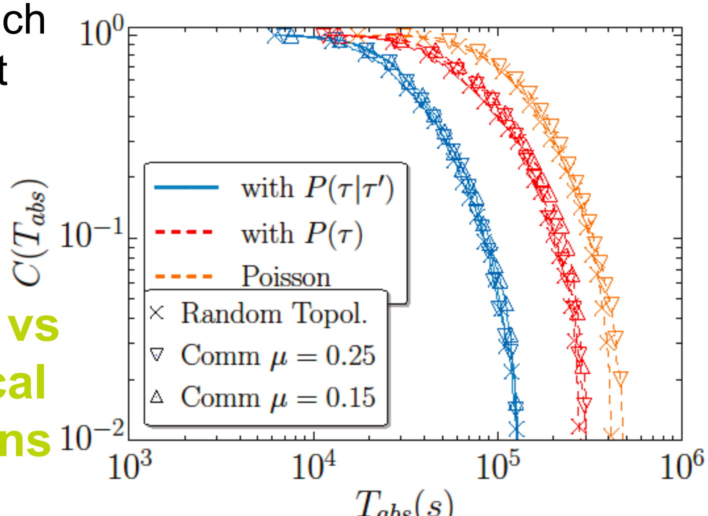
Temporal
Correlations
P(τ/τ´)

Question:

Role of the Timing of Interactions

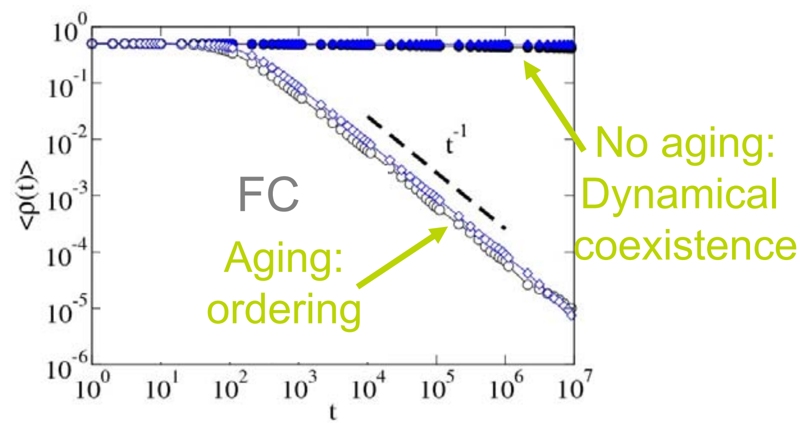
Updating processes

Times to reach agreement in finite systems



Temporal vs Topological correlations

Aging processes:



COEVOLUTION:

Dynamics **on** the network coupled with dynamics **of** the network

M. Zimmerman, et al Lecture Notes in Economics and Mathematical Systems 503, (2001)

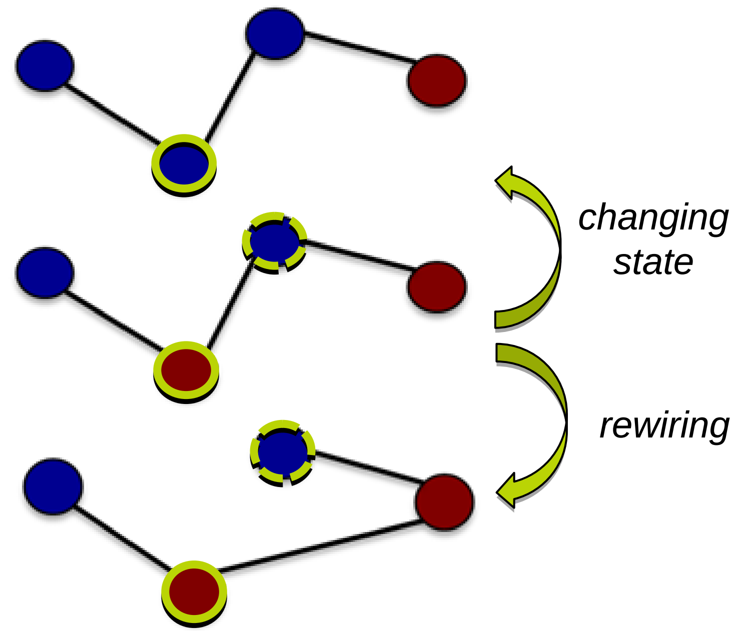
Social Imitation

Voter Model

Breaking and..

..establishing ties

Rewiring

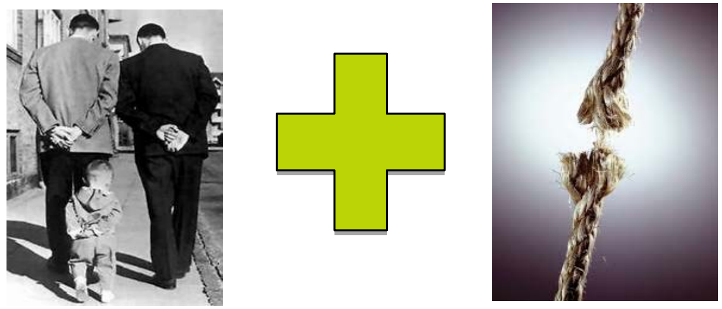


Coevolving voter model: Non-persistent ties

Coevolving Voter Model

F. Vázquez, et al, Phys. Rev. Lett. 100, 108702 (2008)

Imitation

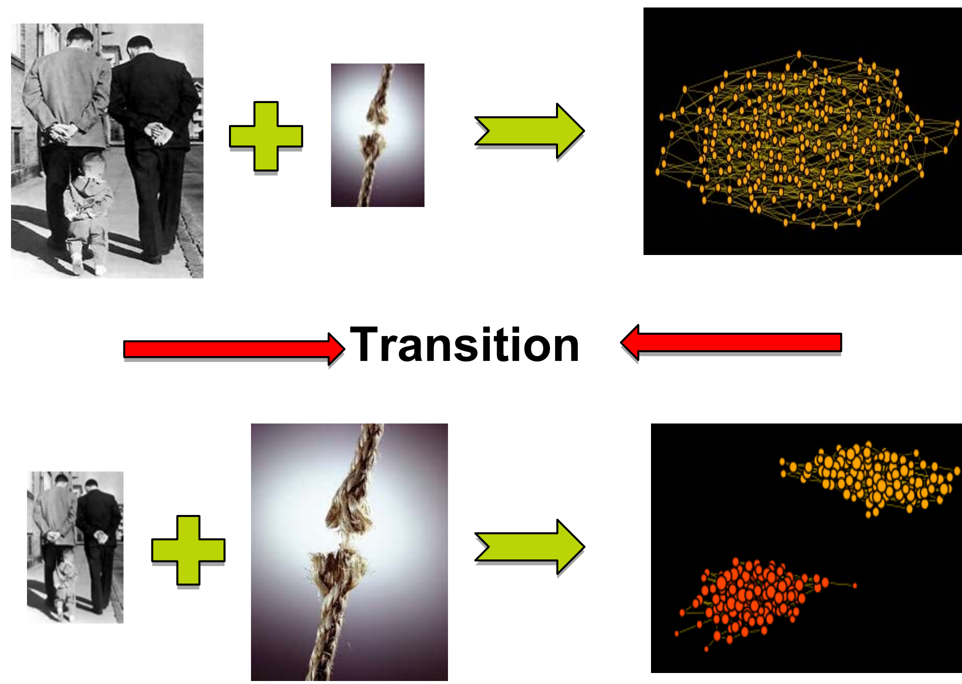


Choosing neighbors

Network Fragmentation Transition

Fragmentation due to **competition** of time scales:

- evolution **of** the network (link dynamics)
- evolution on the network (node state dynamics)



Critical value of plasticity p_c

Coevolving Voter Model + Noise

Diakonova et al. Phys. Rev E ***92****, 032803(2015)*

Social Imitation

Choosing neighbors

Free Will, External influences

Voter Model

Rewiring

$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad}_{\text{Coevolving Voter Model}}$

Coevolving Voter Model

Noise:

random change of state,
with probability $\epsilon/2$,
at end of update

3 PARAMETERS
- Plasticity *p*
- Noise intensity $\epsilon/2$
- Fraction of noisy nodes *q*

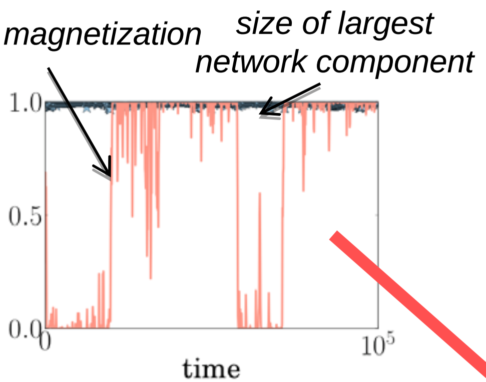
NOISE
- Homogeneous (*q=1*)
- Targeted Noise (*0<q<1*, $\epsilon = 1$)

Coevolving Voter + Homogenous Noise

*Diakonova et al. Phys. Rev. E **92**, 032803 (2015)*

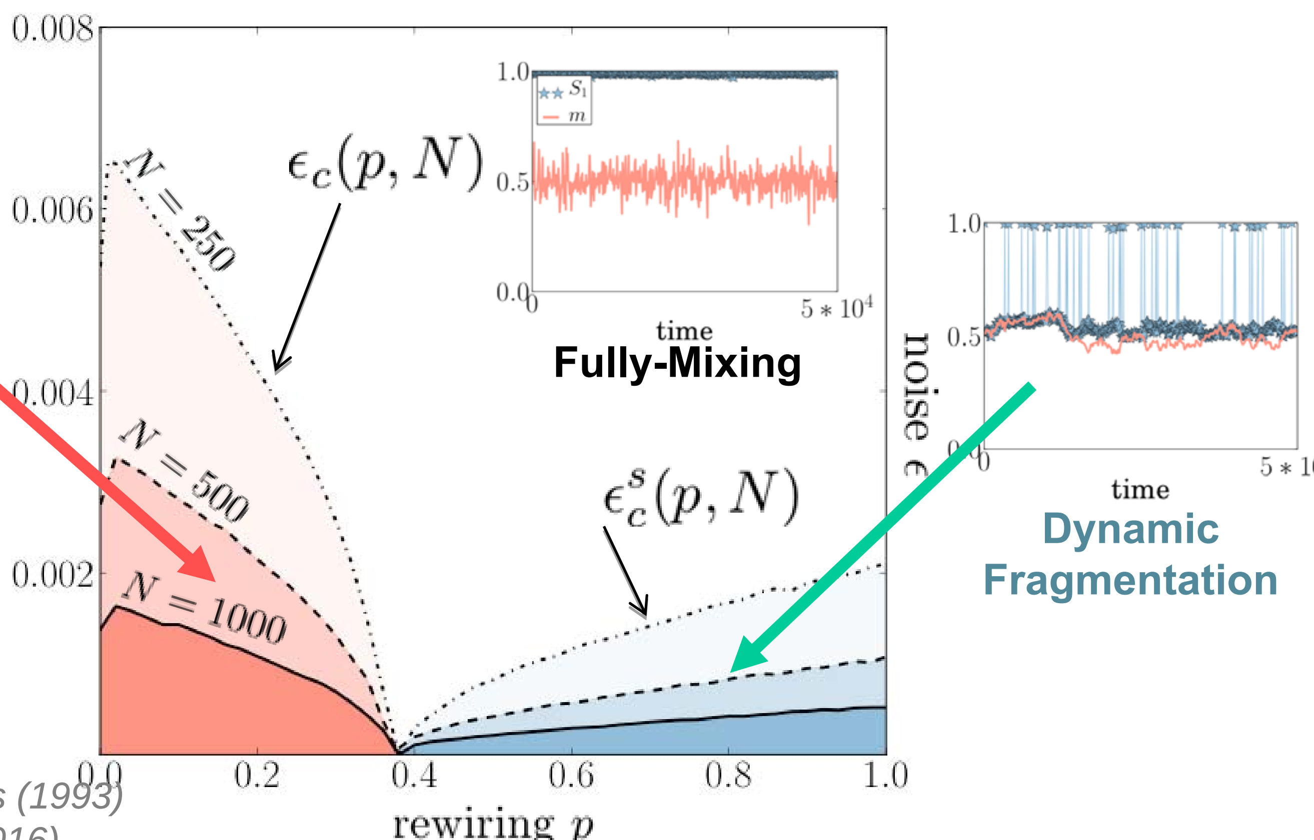
- Noise destroys fragmentation transition. No absorbing states
- Three regimes separated by finite-size noise induced transitions

Initial condition: RRN, μ=<k>=4



Bimodal Magnetization

$$\varepsilon_c(p,N) = \left(1 + \frac{N}{2(1-p)}\right)^{-1}$$

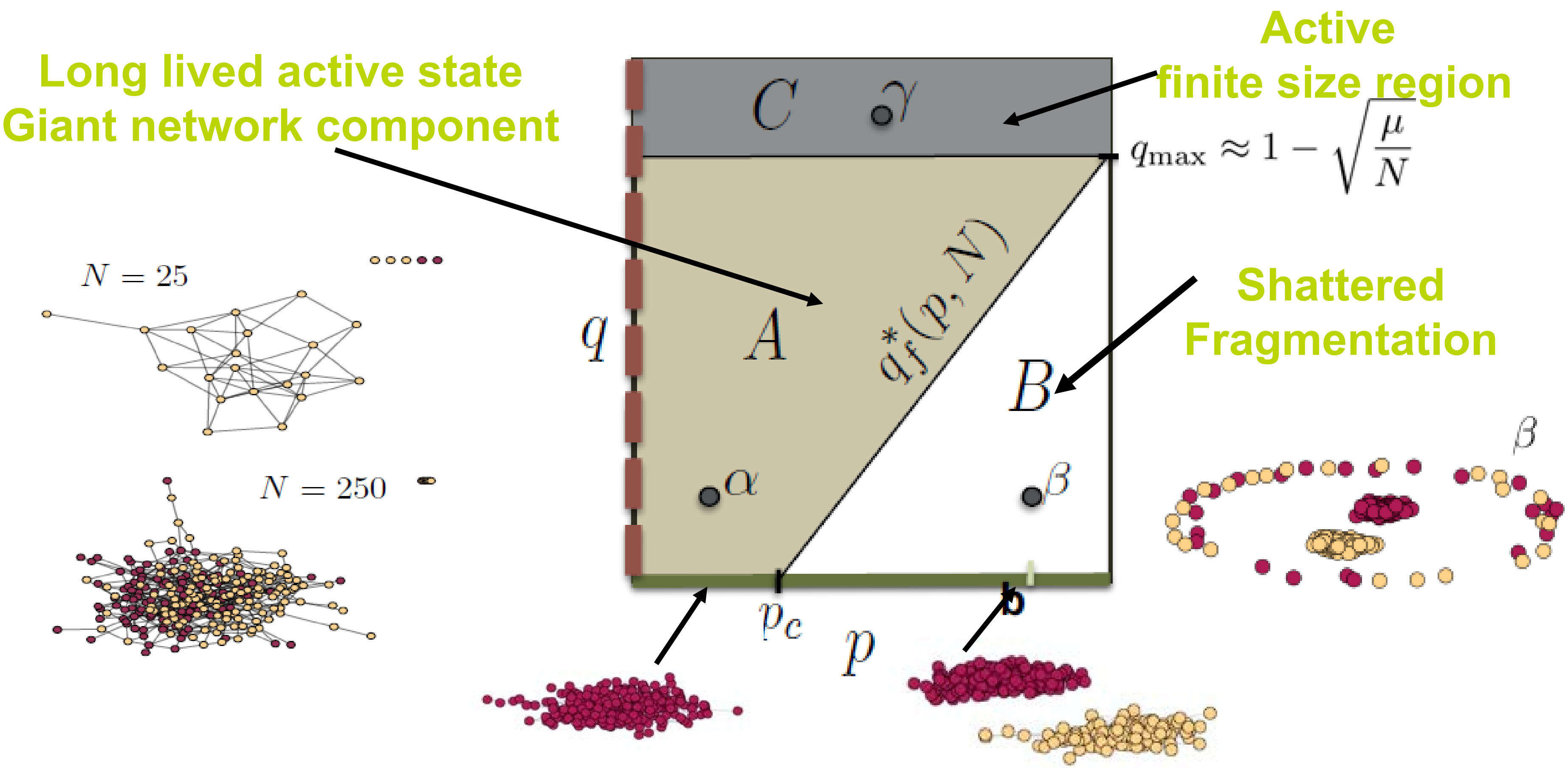


p=0 transition for voter + noise

Kirman, Quarterly J. of Economics (1993)

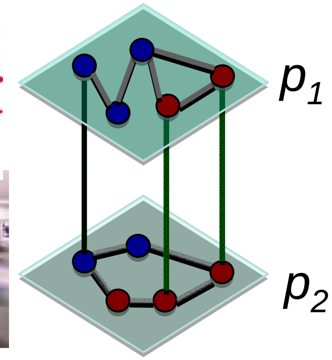
*Carro et al. Sci. Rep. **6**, 24775 (2016)*

- Topological absorbing states are possible
- Three regimes and a *shattering* fragmentation transition at *q*(p,N)*



Multilayer Coevolving Voter Model

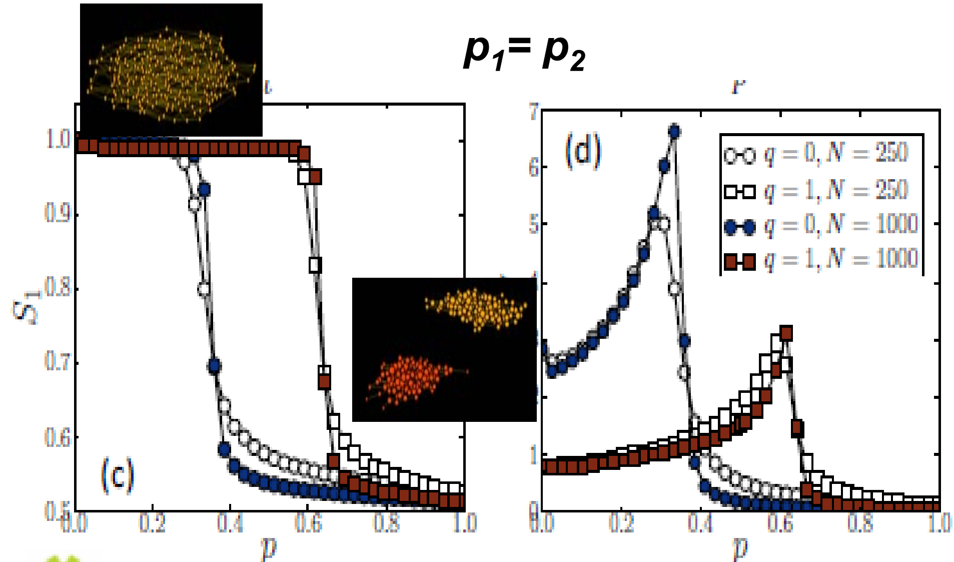
*Diakonova et al., Phys. Rev. E **89**, 06218 (2014)*



Different plasticities p_i

Imitation **Choosing neighbors** **Social Context: *MULTIPLEXING***

$p_1 = p_2$



Rewiring Probabilities

p_1 p_2

ratio of link/node state updating

Degree of Multiplexing
(interlevel connectivity)

q

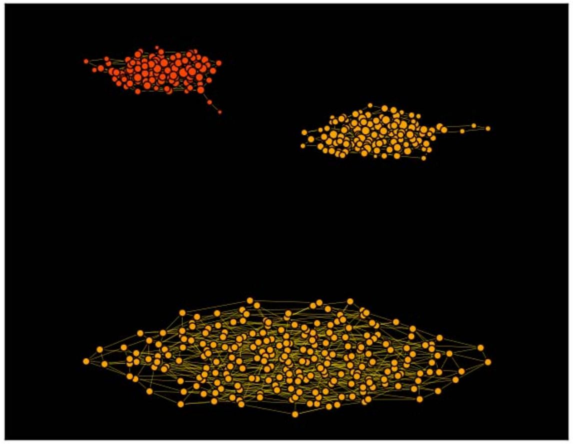
identifies nodes that are the same in both layers

Transition shift: $p_c(q) > p_c(q=0)$
Multiplex structure
can prevent fragmentation

Multilayer Coevolving Voter Model

Diakonova et al., Phys. Rev. E **89**, 06218 (2014)

$q = 0$



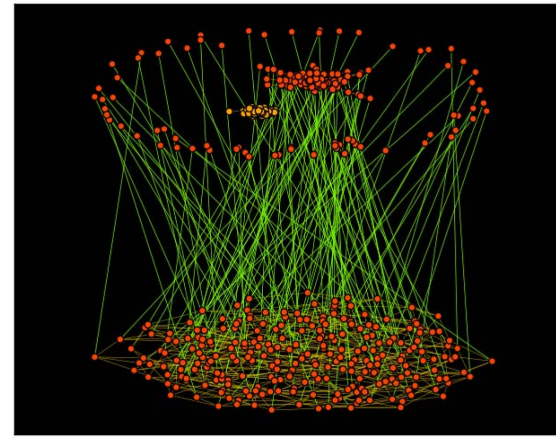
$p_1 = 1$

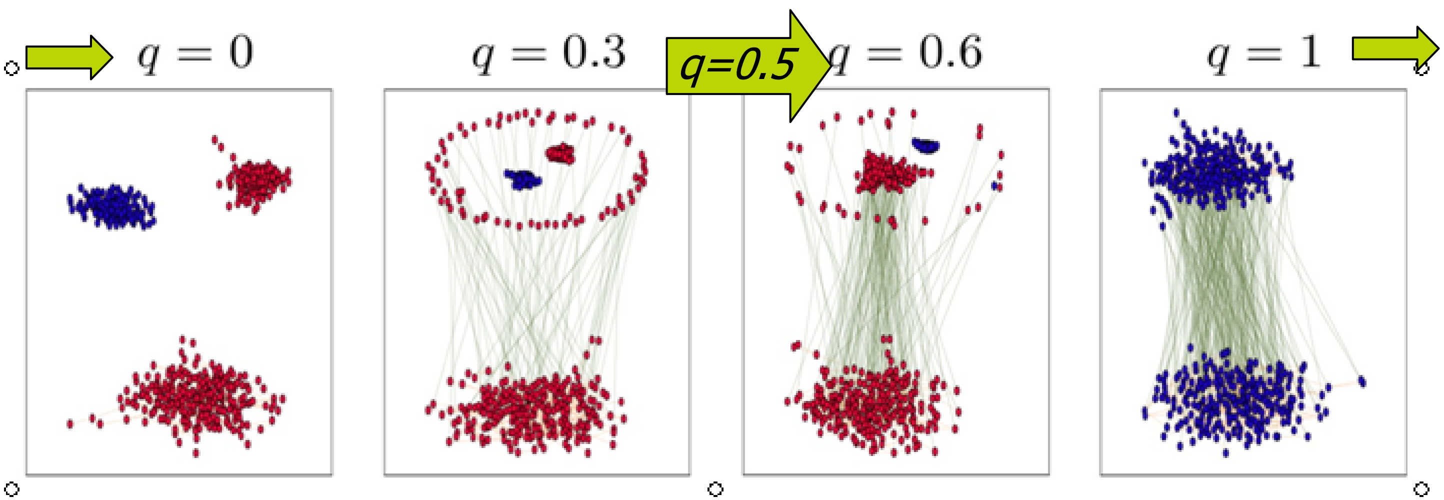
fully-dynamic

$p_2 = 0$

voter

$q = 0.5$





p_1=0.9

p_2=0.1

- ***Critical degree of multiplexing q*(p_1,p_2):prevents fragmentation of dynamic layer***
- ***Shattered fragmentation transition for q<q****

Lessons from Voter Model on imitation processes:

-Choice of variables

-Irrelevance of topology of fixed network

-Importance of activity patterns

-Coevolution as a mechanism of group formation

-Role of imperfect imitation: Noise/free will

-Role of social context: multiplexing

Voter Model: Beyond understanding mechanisms

Data?

1. Community structure of online games

Imitation + coevolution + multilayering

Klimek et al., New Journal of Physics 18, 083045 (2016)

2. Is the Voter Model a Model for Voters?

Imitation + imperfect imitation + mobility

Fernandez-Gracia et al. Phys. Rev. Lett.112,158701 (2014)

Community structure of multilayer societies

*Klimek et al., New J. of Physics **18**, 083045 (2016)*

“..an award-winning graphical browser-based MMORPG … set in a futuristic universe where players interact and compete in space. It is a persistent-universe, open-ended game with a player-driven economy. Players travel through hundreds of "sectors" or solar systems while trading, building or battling with Non-Player Characters … and other players.” ***https://www.pardus.at/***

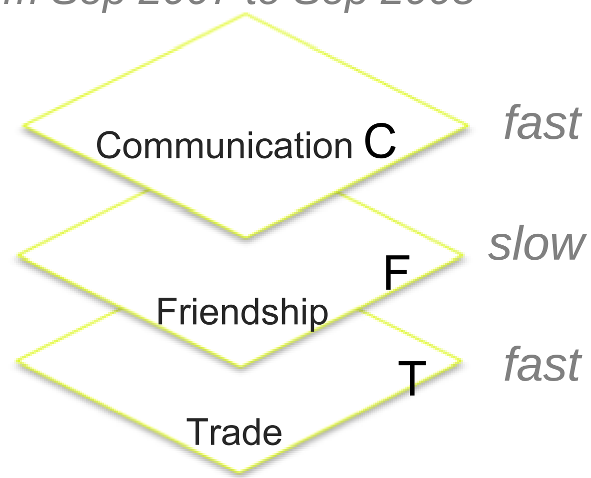
Online characters:	300
Active characters:	8,712
Registered characters:	426,165

Pardus Multiplex Network

- **Friendship F** Links established by clicking.
- **Communication C** Private messages.
- **Trade T** Exchange of game money/commodities

Multiplex network constructed for each month from Sep 2007 to Sep 2008

α	Friendship	Trade	Communication
p_α	0.004(1)	0.27(1)	0.35(2)
L^α	$1.45(2) \times 10^4$	$5.57(2) \times 10^4$	$1.90(3) \times 10^4$



Different community structure from different plasticities?

Community structure of multilayer societies

*Klimek et al., New J. of Physics **18**, 083045 (2016)*

Lesson from data: Topology of networks with high triangular clustering

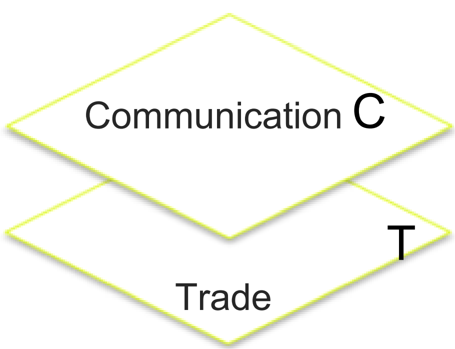
Modified coevolving model: Rewiring with triadic closure

Consequence of triadic closure:

Partial multiplexing not required for shatered fragmentation
Analysis of fully multiplexed Pardus data (q=1)

Data analysis: Mesoscopic structure of the layers exhibits significant heterogeneity in size of largest community (S_1) and relative number of communities (Nc),

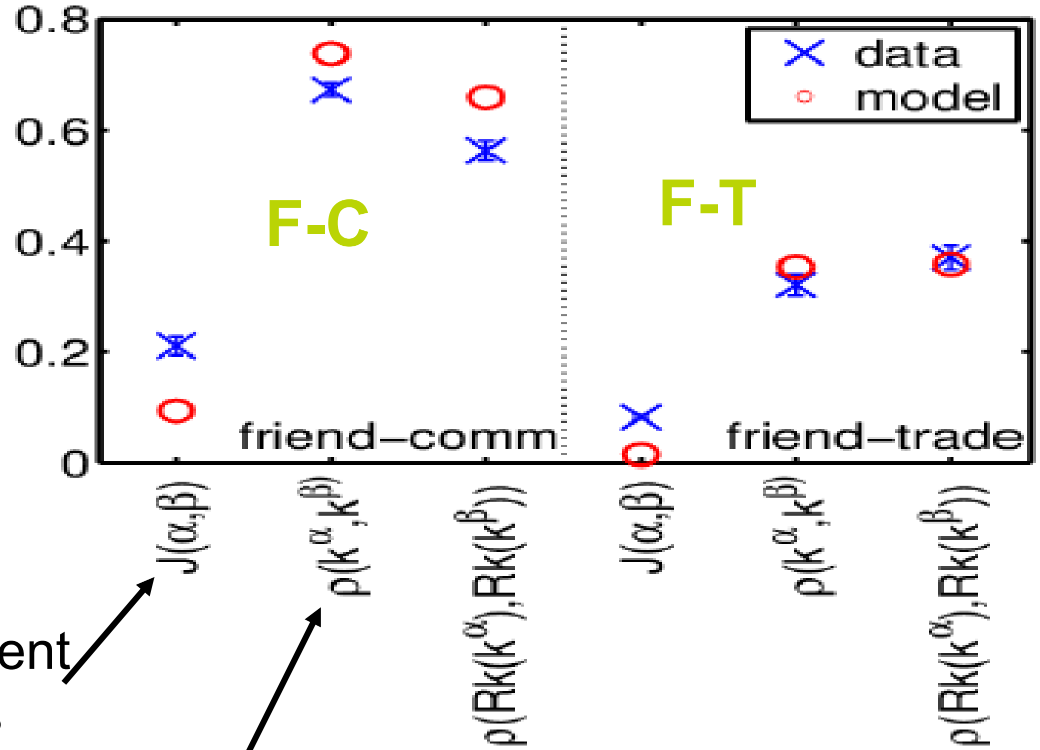
CONFIRMING MODEL PREDICTIONS FOR TWO FAST LAYERS



$$p_T < p_C \Rightarrow \begin{cases} S_1^T > S_1^C \\ N_c^T < N_c^C \end{cases}$$

*Klimek et al., New J. of Physics **18**, 083045 (2016)*

Comparison topology of fast and slow layers



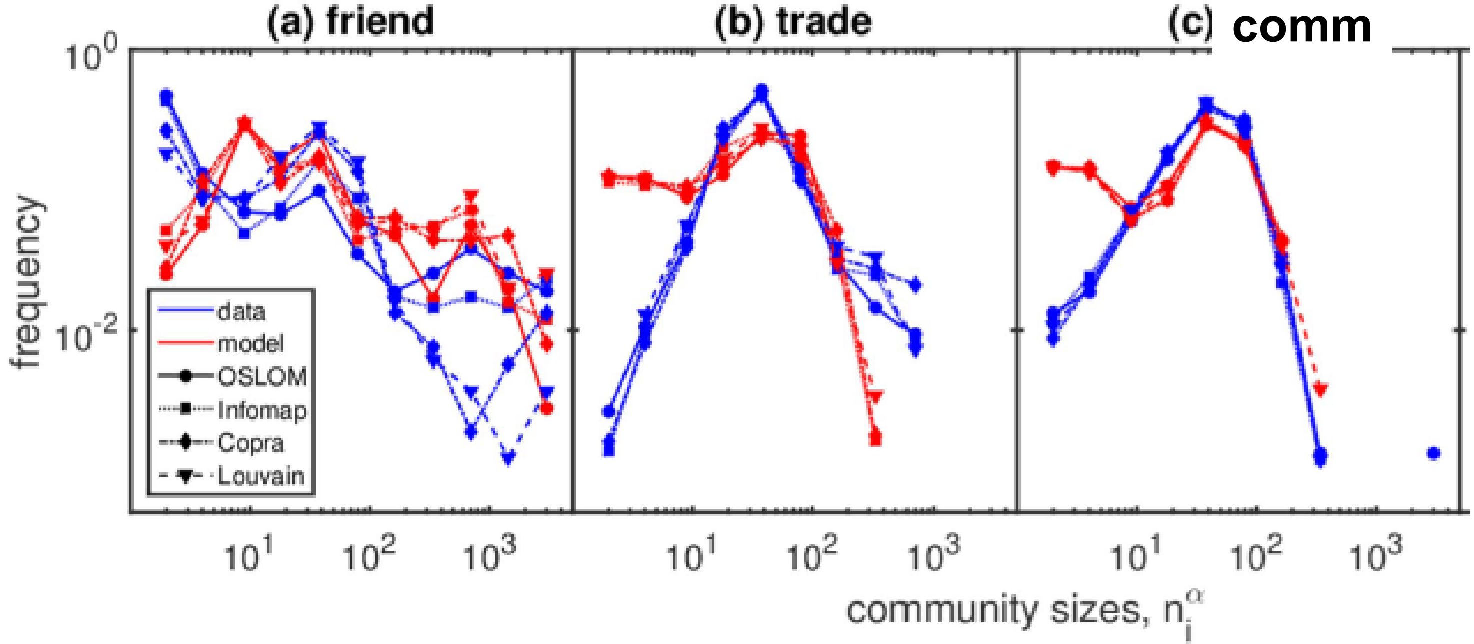
Jaccard coefficient of edge sets

Degree correlation

Degree rank correlation

*Klimek et al., New J. of Physics **18**, 083045 (2016)*

Community size distribution: Data vs model



Different form of shattering for different plasticities

F layer: Small plasticity implies
small number of very large communities (flat tail distribution)

T and C layers: Large plasticity implies
large number of small communities centered around n=50

Voter Model: Beyond understanding mechanisms

Data?

1. Community structure of online games

Imitation + coevolution + multilayering

Klimek et al., New Journal of Physics 18, 083045 (2016)

2. Is the Voter Model

a

Model for Voters?

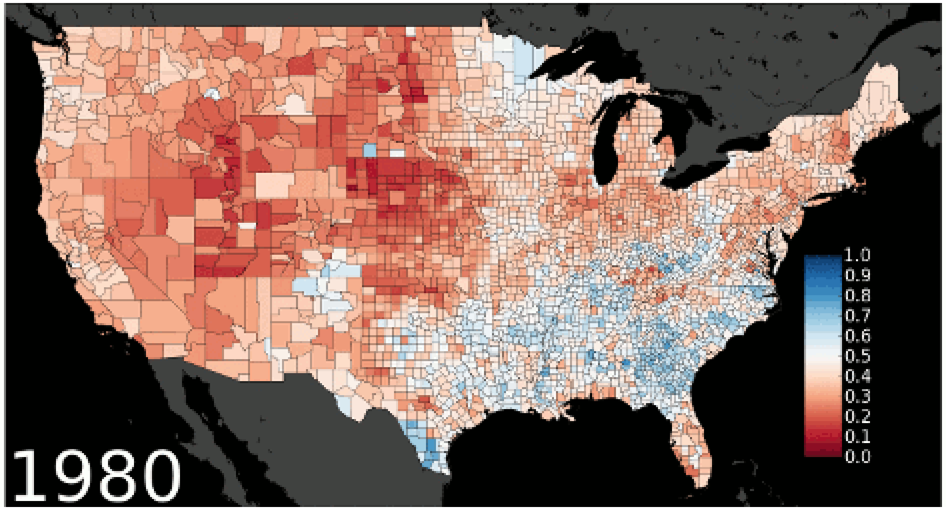
Imitation + imperfect imitation + mobility

Fernandez-Gracia et al. Phys. Rev. Lett.112,158701 (2014)

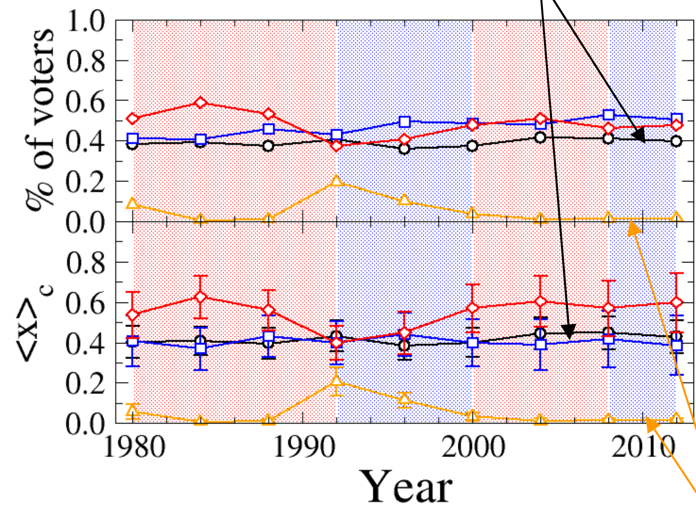
Is the Voter Model a Model for Voters?

US presidential elections 1980-2012

Evolution of democrat shares

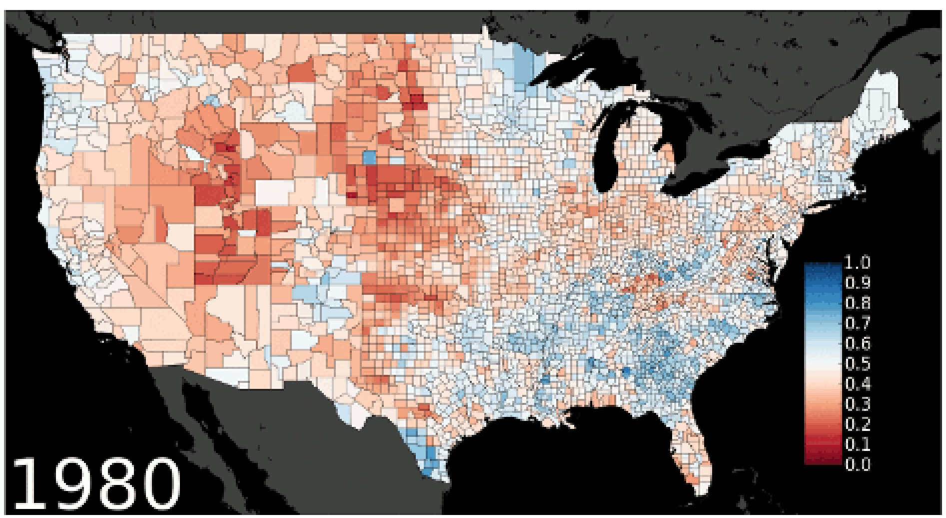


Global percentage of votes for each party and turnout



Other parties

Evolution of republican shares



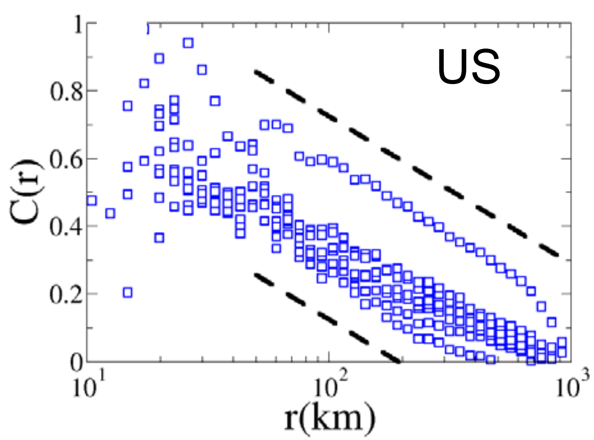
Basically two option system

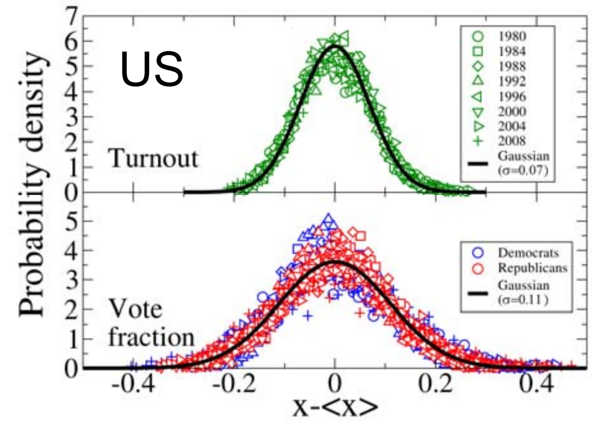
Blue: Democrat

Red: Republican

Statistical regularities of electoral data

Irrespective of the winner!

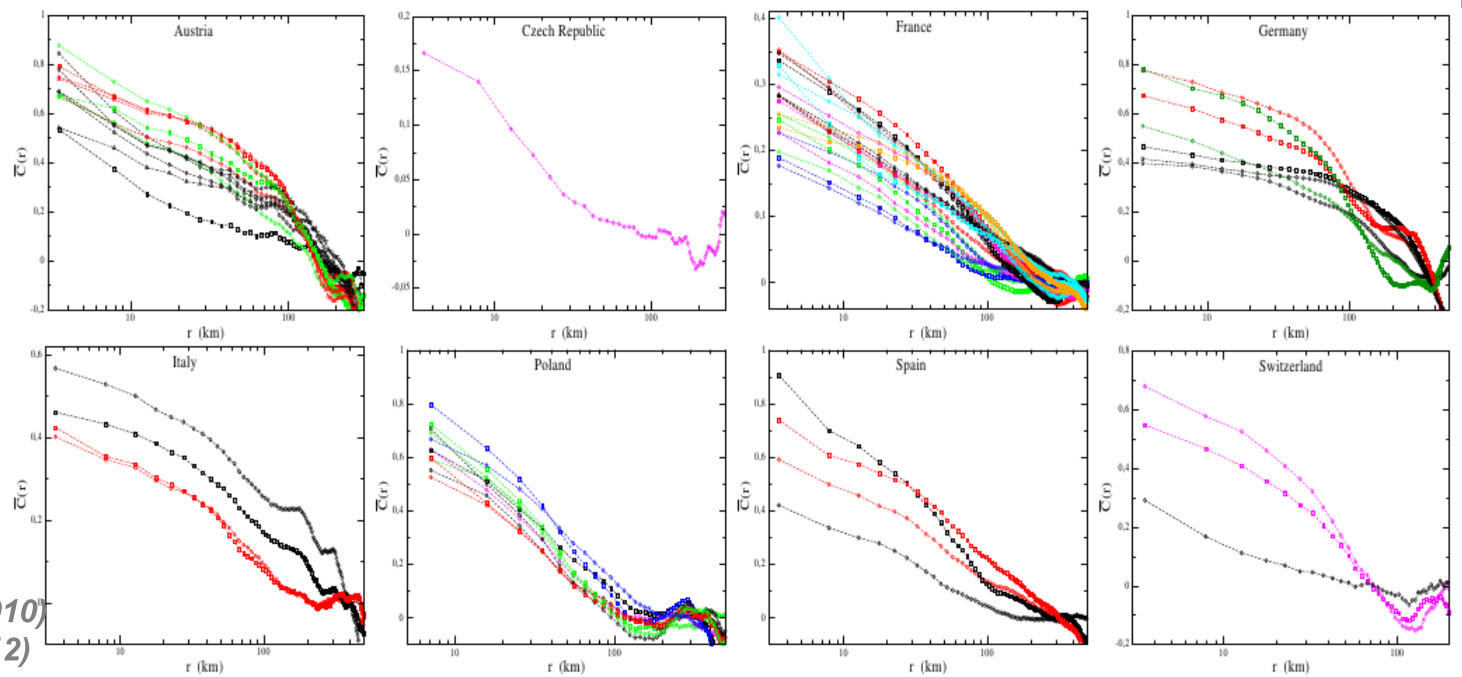




IBM
Diffusive model?

SPATIAL CORRELATIONS

~log decay



C. Borghesi et al.
Eur. Phys. J. B 75, 395-404 (2010)
PLoS ONE 7(5):e36289,05 (2012)

Ingredients of a social influence model:

a) **Interaction mechanism:** Imitation as basic manifestation of social influence.

THEORY

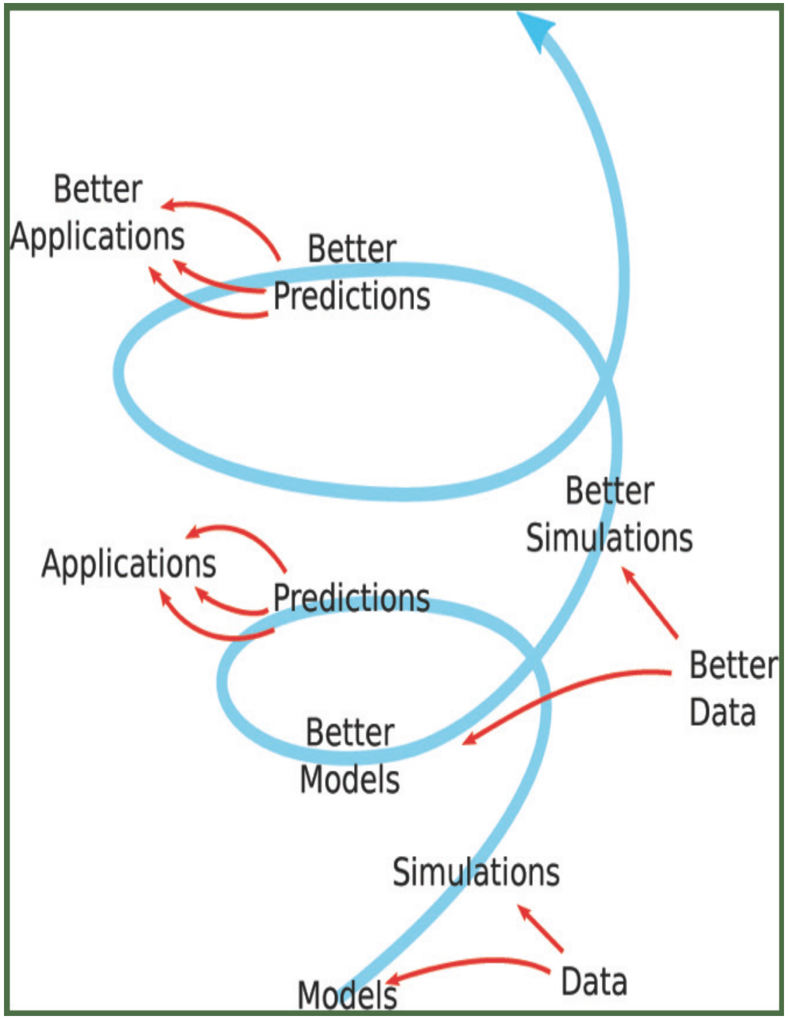
MODELLING

b) **Social context:** Set of all possible interactions of an individual with any other peer. We model it as a ***network of interactions*** from census data for population and mobility.

INPUT DATA

IFISC

MODELS and DATA



THEORY:
Mechanisms
Model

DATA
to be
understood

PARAMETERS
INPUT DATA

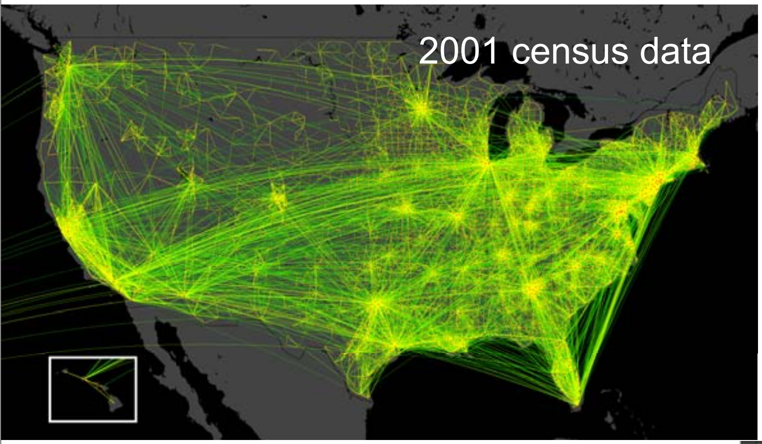
SOCIAL CONTEXT

MODEL

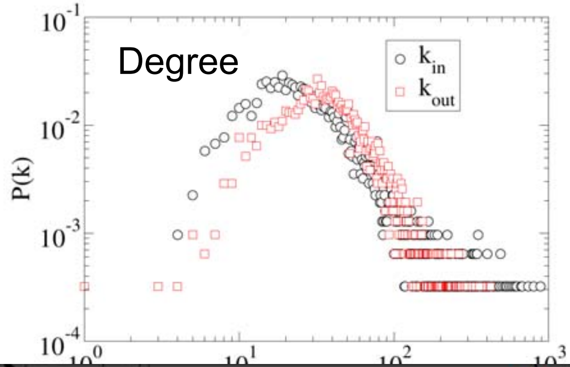
INFERENCE

DATA
to be
reproduced

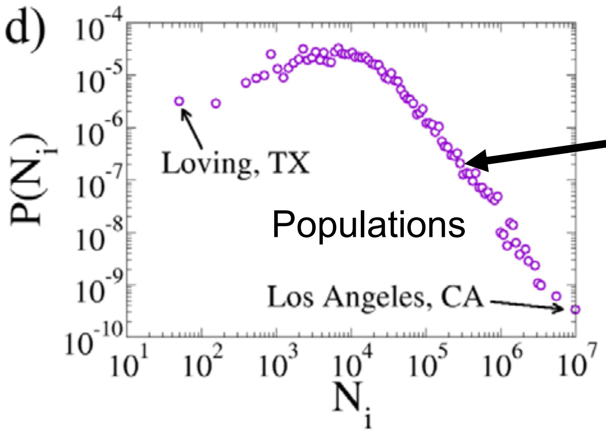
US: commuter network for human mobility

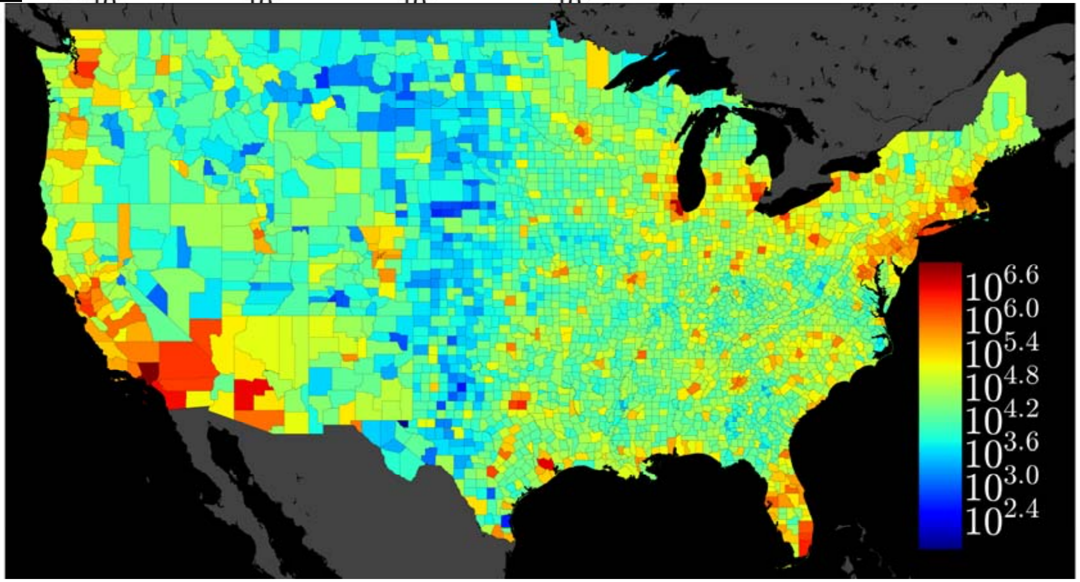


Directed, weighted network.



N=3114
<k>~50

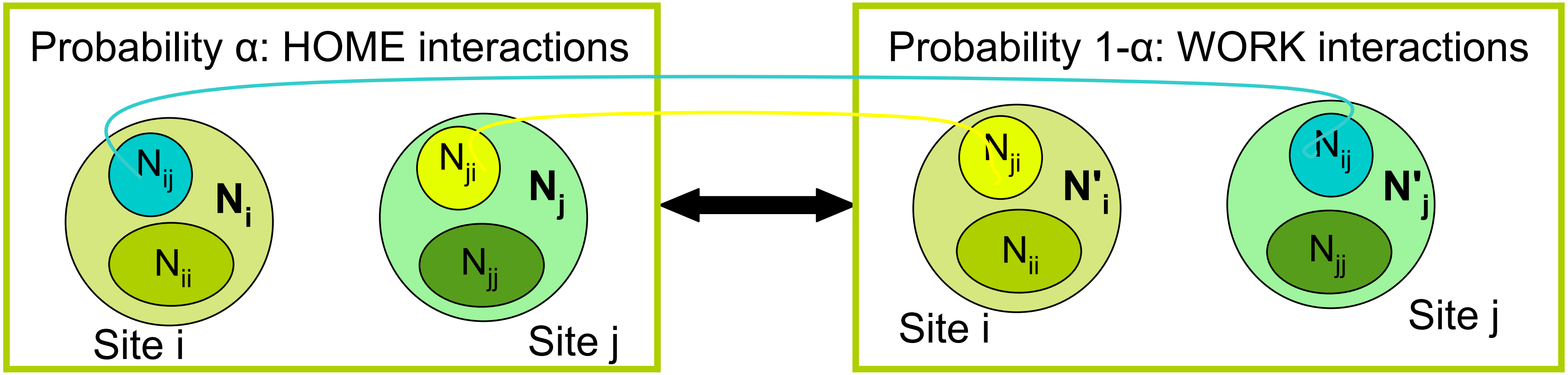




Heterogeneous network in many characteristics

Metapopulation Voter Model

- N agents with a binary variable (state, opinion,...) with **voter-like interaction**
- There are N_{sites} (counties).
- Each agent is considered in two sites: where she lives and where she works.



-N_{ij} = # of agents living in i and working in j.
-N_i = # number of agents living in i = $N_{ii} + \Sigma_j N_{ij}$
-N'_i = # number of agents working in i= $N_{ii} + \Sigma_j N_{ji}$

An agent interacts with probability α with anyone in N_i: lives where she lives.

With probability 1-α interacts with anyone in N'_i : works where she works.

Metapopulation Voter model

Parameters (census)

N_{ij}: number of agents living in i and working in j. $N_i = \sum_j N_{ij}$

X_i, Y_i: location of city i. $N'_i = \sum_j N_{ji}$

Variables

V_{ij}: number of agents living in i and working in j holding opinion +1. $v_{ij} = \frac{V_{ij}}{N_{ij}}$

Correlations $\langle v_i v_j \rangle$ of densities $v_i = \frac{\sum_j V_{ij}}{N_{i_j}}$

Transition rates

$$r^+_{ij}(V_{ij} \to V_{ij}+1) = (N_{ij} - V_{ij}) \left[\alpha \frac{V_i}{N_i} + (1-\alpha) \frac{V'_j}{N'_j} \right]$$

$$r^-_{ij}(V_{ij} \to V_{ij}-1) = V_{ij} \left[\alpha \frac{N_i - V_i}{N_i} + (1-\alpha) \frac{N'_j - V'_j}{N'_j} \right]$$

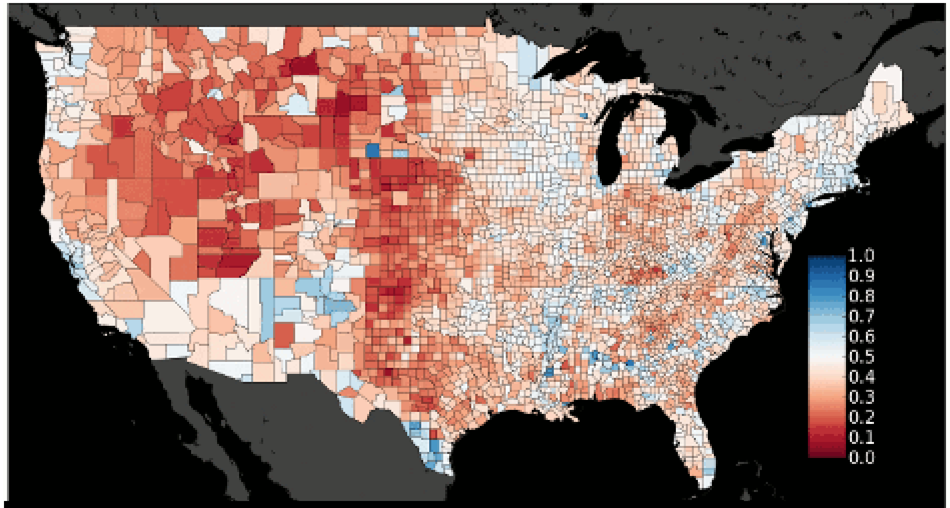
Langevin equation

$$\frac{dv_{ij}}{dt} = \alpha \sum_l \left(\frac{N_{il}}{N_i} - \delta_{jl} \right) v_{il} + (1-\alpha) \sum_l \left(\frac{N_{lj}}{N'_j} - \delta_{li} \right) v_{lj}$$
$$+ \frac{1}{\sqrt{N_{ij}}} \sqrt{(1 - 2v_{ij}) \left(\alpha \frac{\sum_l N_{il} v_{il}}{N_i} + (1-\alpha) \frac{\sum_l N_{lj} v_{lj}}{N'_j} \right) + v_{ij}} \; \eta^*_{ij}(t).$$

$$\boxed{v_{ij} = \frac{V_{ij}}{N_{ij}}}$$

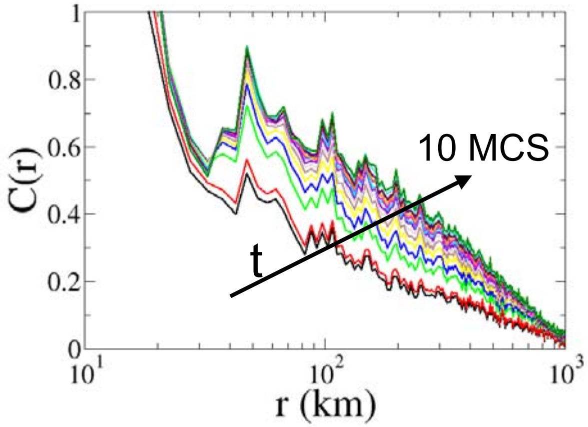
US presidential elections: Metapopulation Voter Model

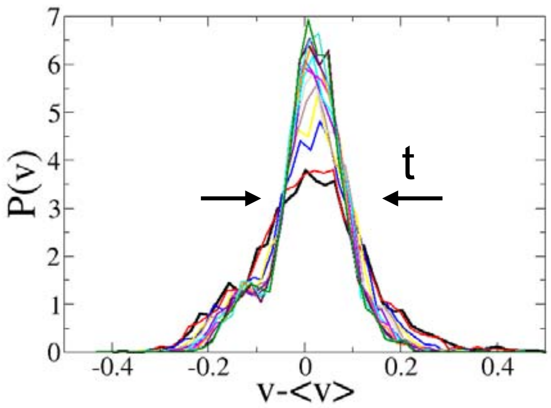
α=1/2



Democrat share. Initial condition 2000

Diffusion process:
→ correlations grow, share distribution narrows.





Extra ingredient needed for stationarity:
Imperfect imitation or External noise

Metapopulation Voter model: Analytical insights

Finite size (internal) + external noise

Parameters (census)

N_{ij}: number of agents living in i and working in j. $\quad N_i = \sum_j N_{ij}$

X_i,Y_i: location of city i. $\quad N'_i = \sum_j N_{ji}$

Variables

V_{ij}: number of agents living in i and working in j holding opinion +1. $\quad v_{ij} = \frac{V_{ij}}{N_{ij}}$

Correlations $\langle v_i v_j \rangle$ of densities $\quad v_i = \frac{\sum_j V_{ij}}{N_{ij}}$

Transition rates

$$r^+_{ij}(V_{ij} \to V_{ij}+1) = (N_{ij} - V_{ij})\left[\alpha \frac{V_i}{N_i} + (1-\alpha)\frac{V'_j}{N'_j}\right] + \boxed{N_{ij}\frac{D}{2}\eta^+_{ij}(t),}$$

$$r^-_{ij}(V_{ij} \to V_{ij}-1) = V_{ij}\left[\alpha \frac{N_i - V_i}{N_i} + (1-\alpha)\frac{N'_j - V'_j}{N'_j}\right] \boxed{+ N_{ij}\frac{D}{2}\eta^-_{ij}(t)}$$

Imperfect imitation

Langevin equation

$$\frac{dv_{ij}}{dt} = \alpha \sum_l \left(\frac{N_{il}}{N_i} - \delta_{jl}\right) v_{il} + (1-\alpha)\sum_l \left(\frac{N_{lj}}{N'_j} - \delta_{li}\right) v_{lj} \boxed{+ D\eta_{ij}(t)} \qquad (7)$$

$$+ \frac{1}{\sqrt{N_{ij}}}\sqrt{(1-2v_{ij})\left(\alpha\frac{\sum_l N_{il}v_{il}}{N_i} + (1-\alpha)\frac{\sum_l N_{lj}v_{lj}}{N'_j}\right) + v_{ij} \boxed{+ \frac{D}{2}\eta'_{ij}(t)}}\,\eta^*_{ij}(t).$$

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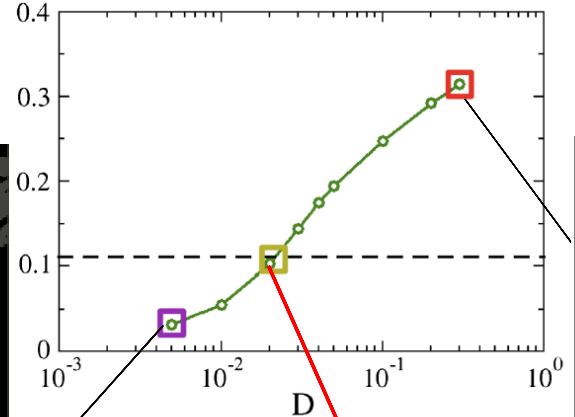
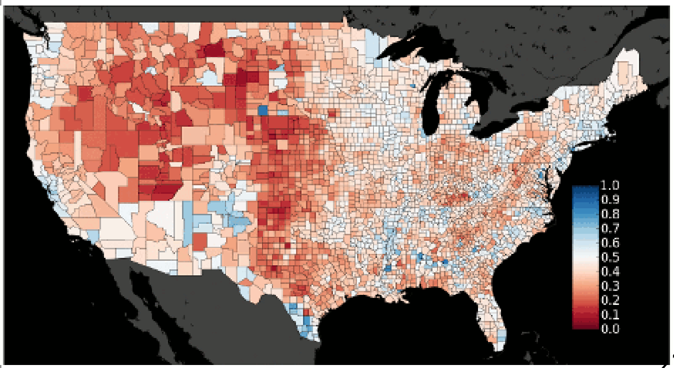
US presidential elections: Metapopulation Voter Model

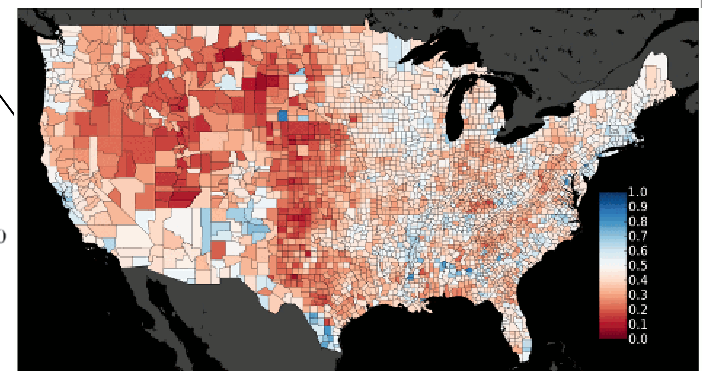
Noise calibration

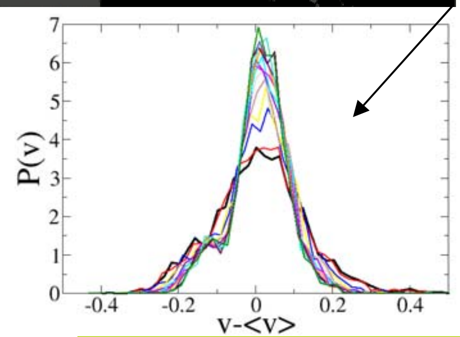
$\alpha=1/2$

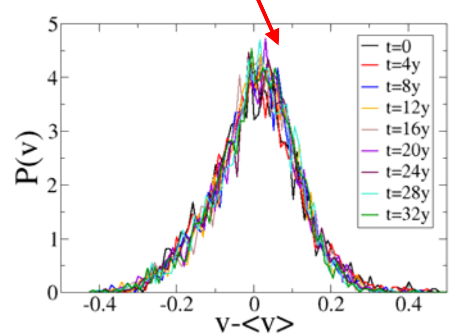
Vote share standard deviation after 1000 MC steps.

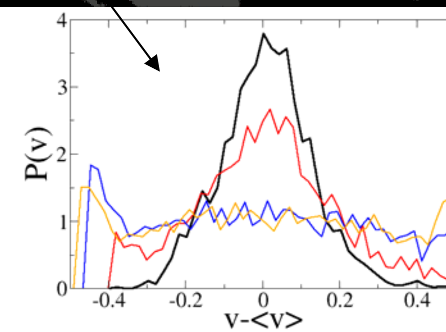










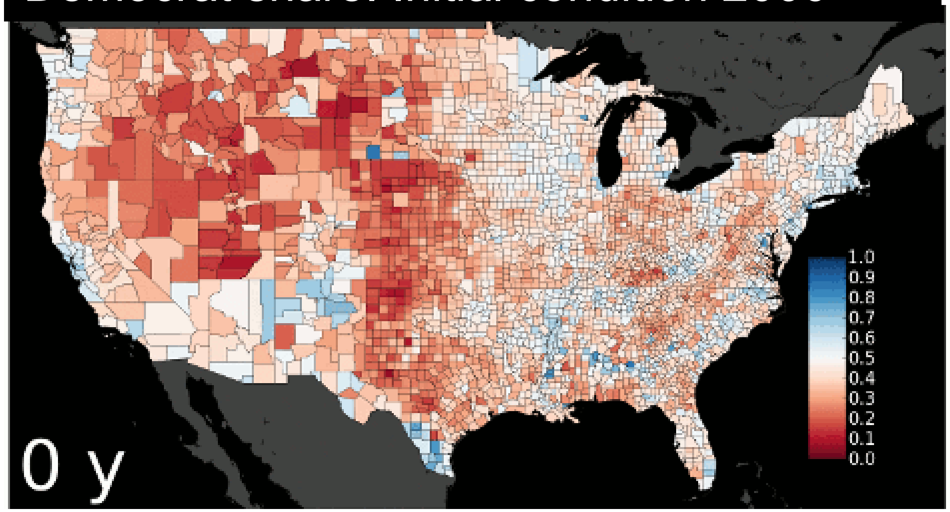


For D=0.02 the st. dev. of the vote share distribution remains stationary and fits the empirical value (data)

US presidential elections: Metapopulation Voter Model

Fernandez-Gracia et al. Phys. Rev. Lett.112,158701 (2014)

Democrat share. Initial condition 2000



Calibrated Model

α=1/2

Single fitted parameter: D=0.02

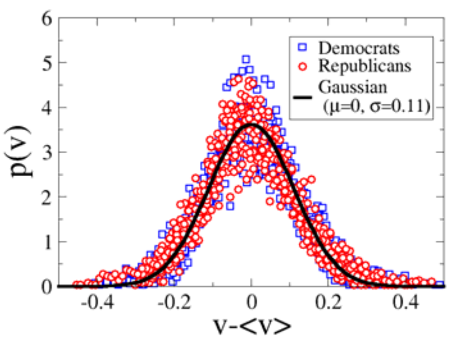
Time calibration:

10 MC steps =4 years=

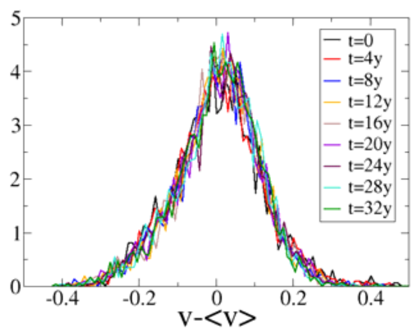
1 election period

Vote share distribution

Data



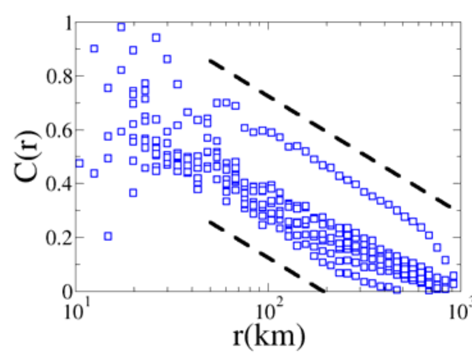
Model



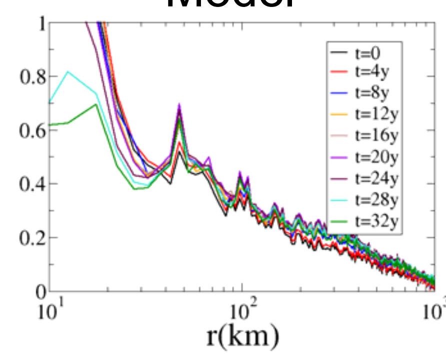
St. dev. remains constant.

Spatial correlations

Data



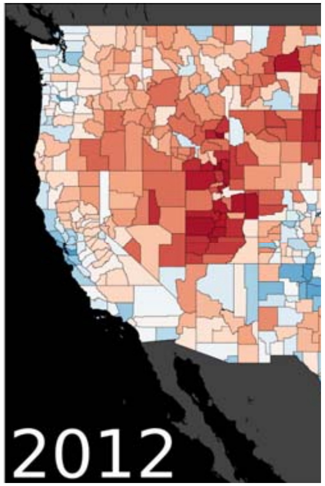
Model



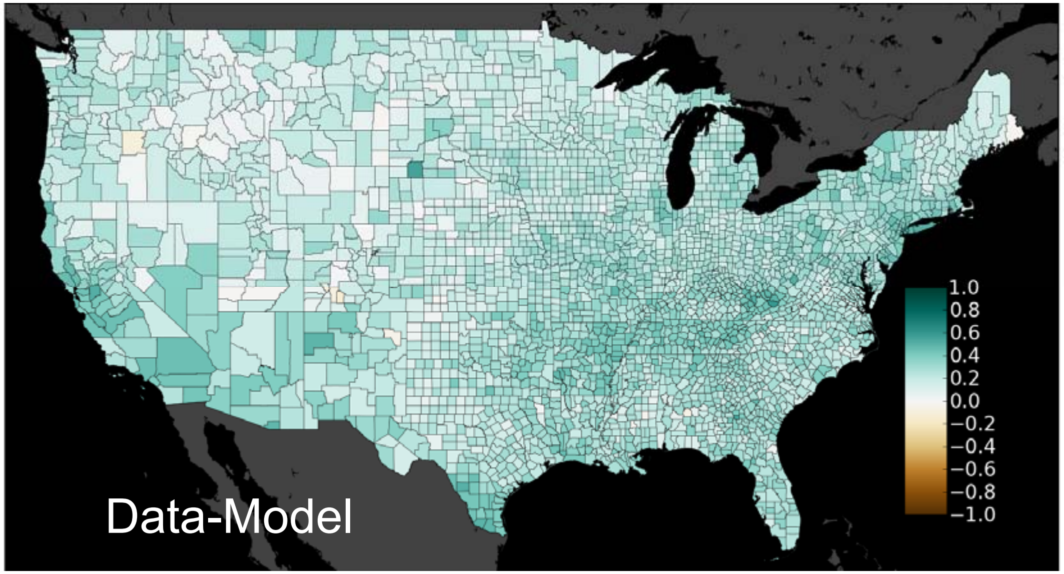
Logarithmic decay remains.

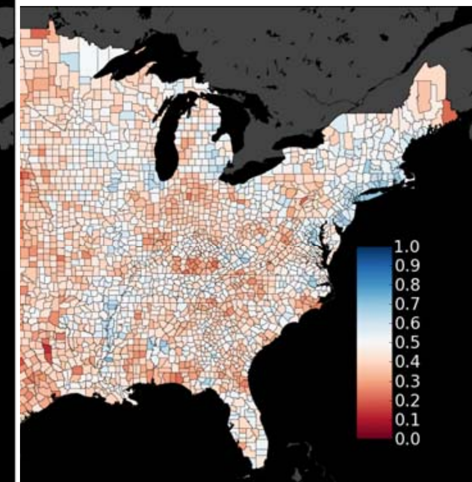
Electoral predictions?

Results for democrat party

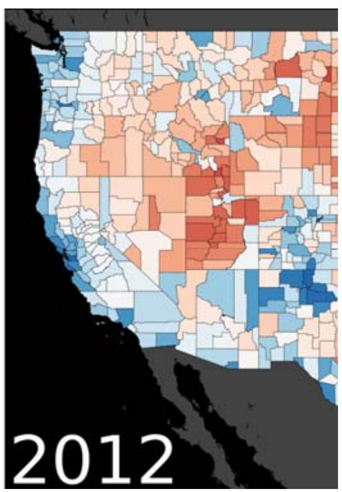


Data

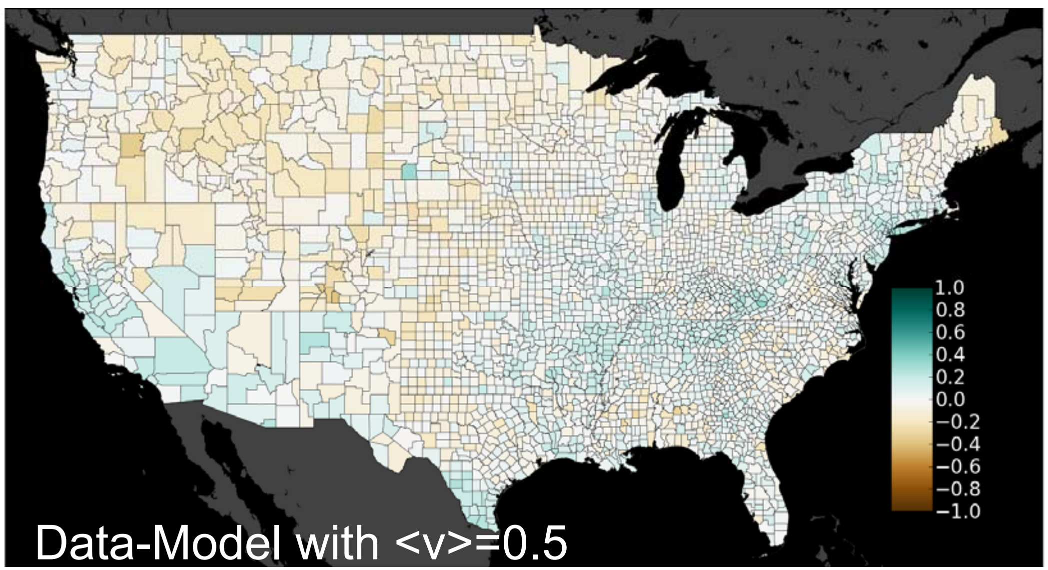


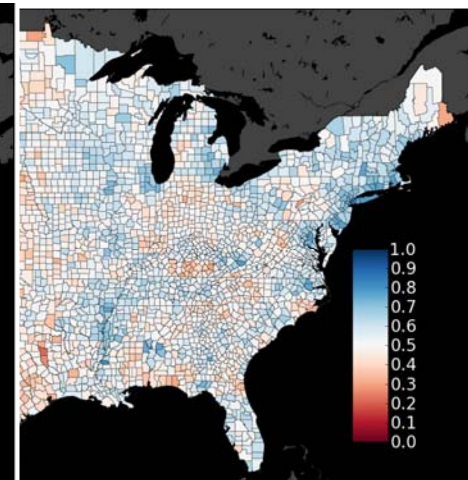


Model (i.c. 2000)



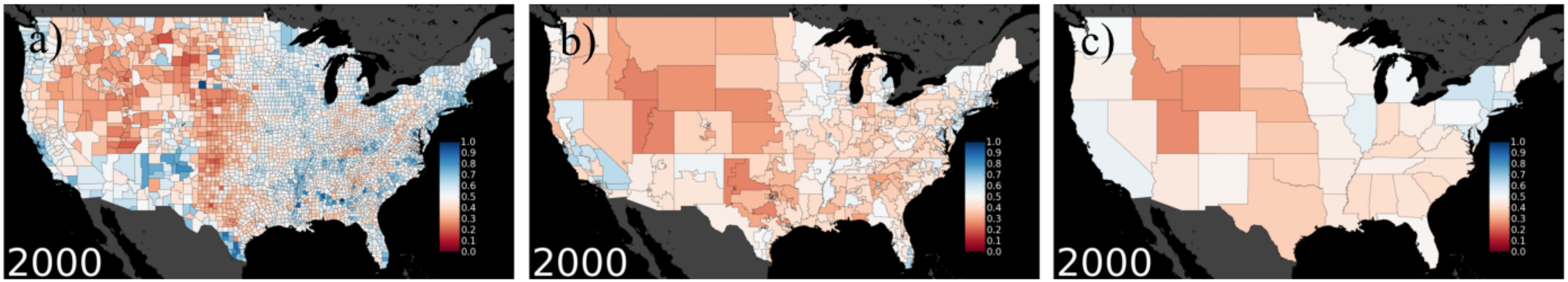
Data with <v



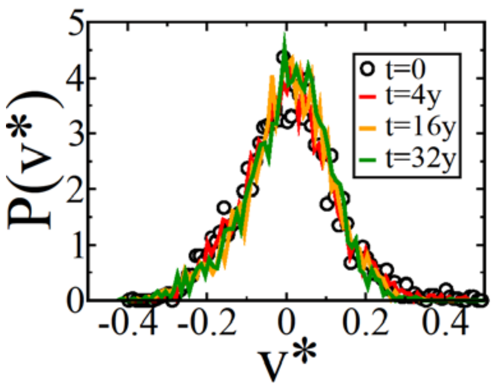


Model with <v>=0.5

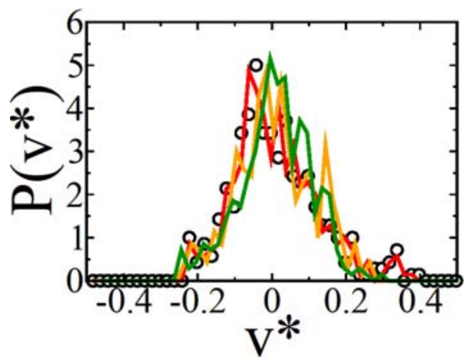
Multiscale Predictions



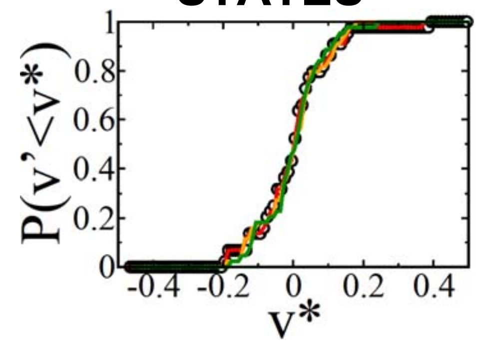
COUNTIES



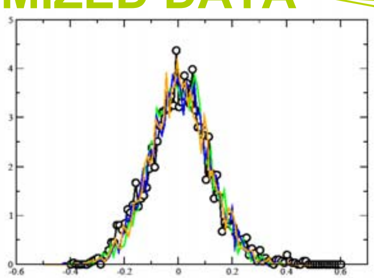
CONGRESSIONAL DISTRICTS

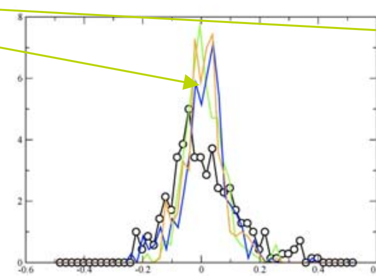


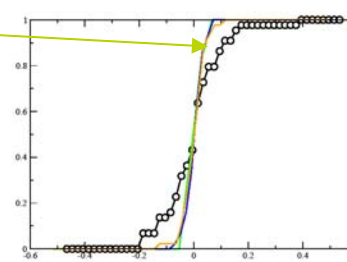
STATES



RANDOMIZED DATA







What have we learnt?

- **IBM implementation of a microscopic mechanism leading to *diffusive mesoscopic stochastic* dynamics reproducing statistical regularities of election data.**
- Data Based Modeling: Input parameters from census data for populations and commuting fluxes.
- Single calibrated model parameter: D, the noise intensity. Also calibration of time scale.
- **What do we explain?**
  -Two generic features in the background of election results:
  i)Stationarity of the dispersion of vote shares and ii) the time persistent logarithmic decay of spatial correlations.
  -Spatiotemporal fluctuations in electoral results at **different length scales**
  -***No attempt to predict electoral results***

THANKS!

ORIOL ARTIME

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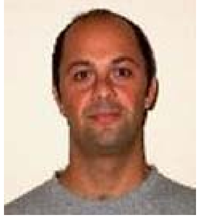
JUAN FERNANDEZ-GRACIA

KRZYSZTOF SUCHECKI



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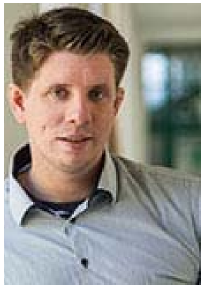

STEFAN THURNER

Master's Degree in Physics of Complex Systems

Master in Physics of Complex Systems

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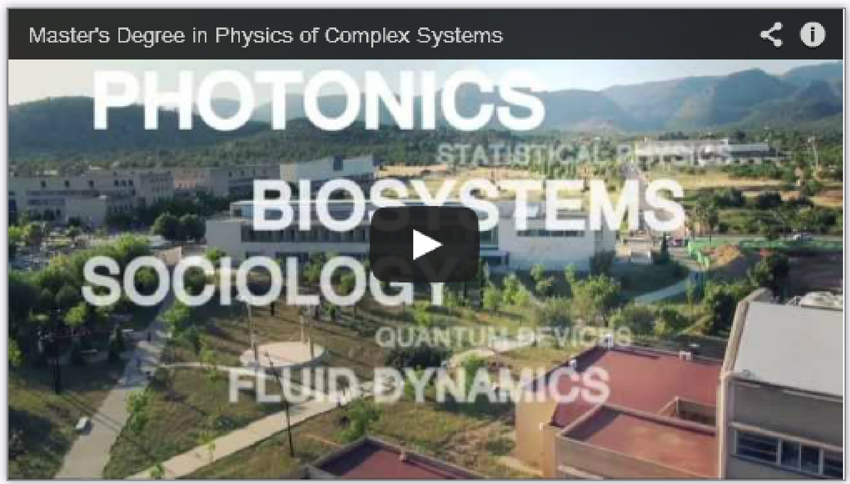

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