W911NF-12-1-0509

ARO MURI: Evolution of Cultural Norms and Dynamics of Socio-Political Change

Ali Jadbabaie*

Alfred Fitler Moore Professor of Network Science

Electrical & Systems Engineering, Computer & Information Sciences, Operations & Information Management

University of Pennsylvania

jadbabai@seas.upenn.edu

http://www.seas.upenn.edu/~aromuri

* Visiting Research Scientist at Laboratory for Information and Decision Systems, MIT

The Team

Ali Jadbabaie (PI) Michael Kearns Daron Acemoglu Asu Ozdaglar Munzer Dahleh Fotini Christia

ESE, CIS,OPIM CIS, STATS, OPIM Econ/LIDS EECS/ORC/LIDS EECS/ESD/LIDS Poli.Sci

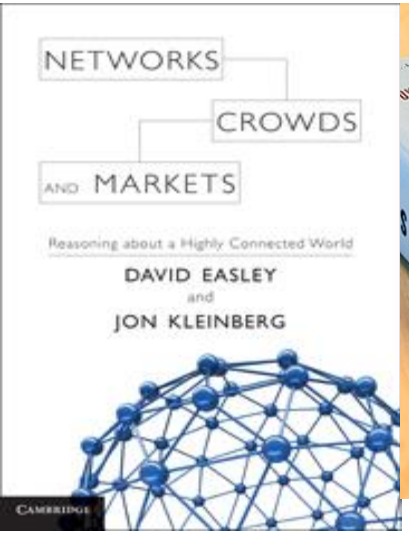
University of Pennsylvania Massachusetts Institute of Technology

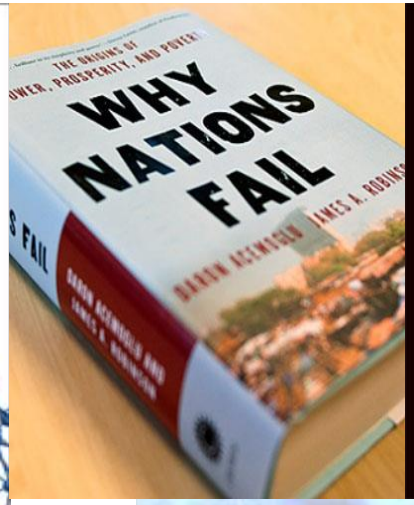
Matt Jackson Jure Leskovec Jon Kleinberg Larry Blume

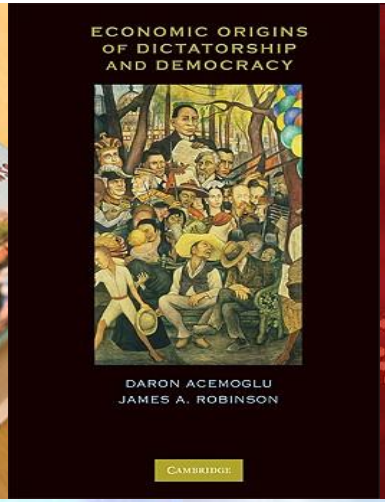
Econ CS InfoSci, CS Econ, InfoSci

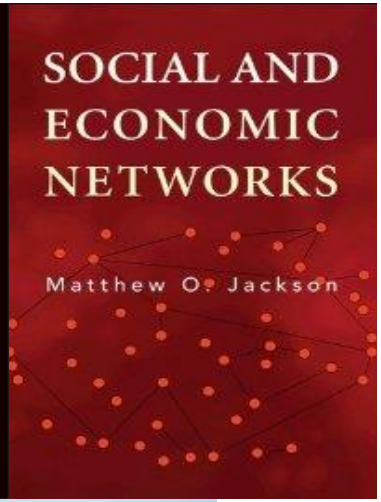
Stanford University Cornell University

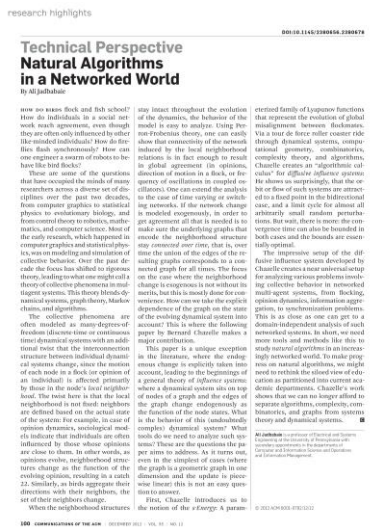
Background of team members

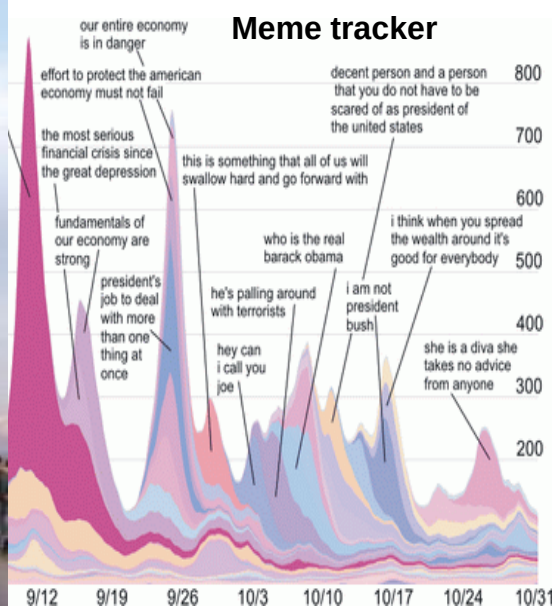










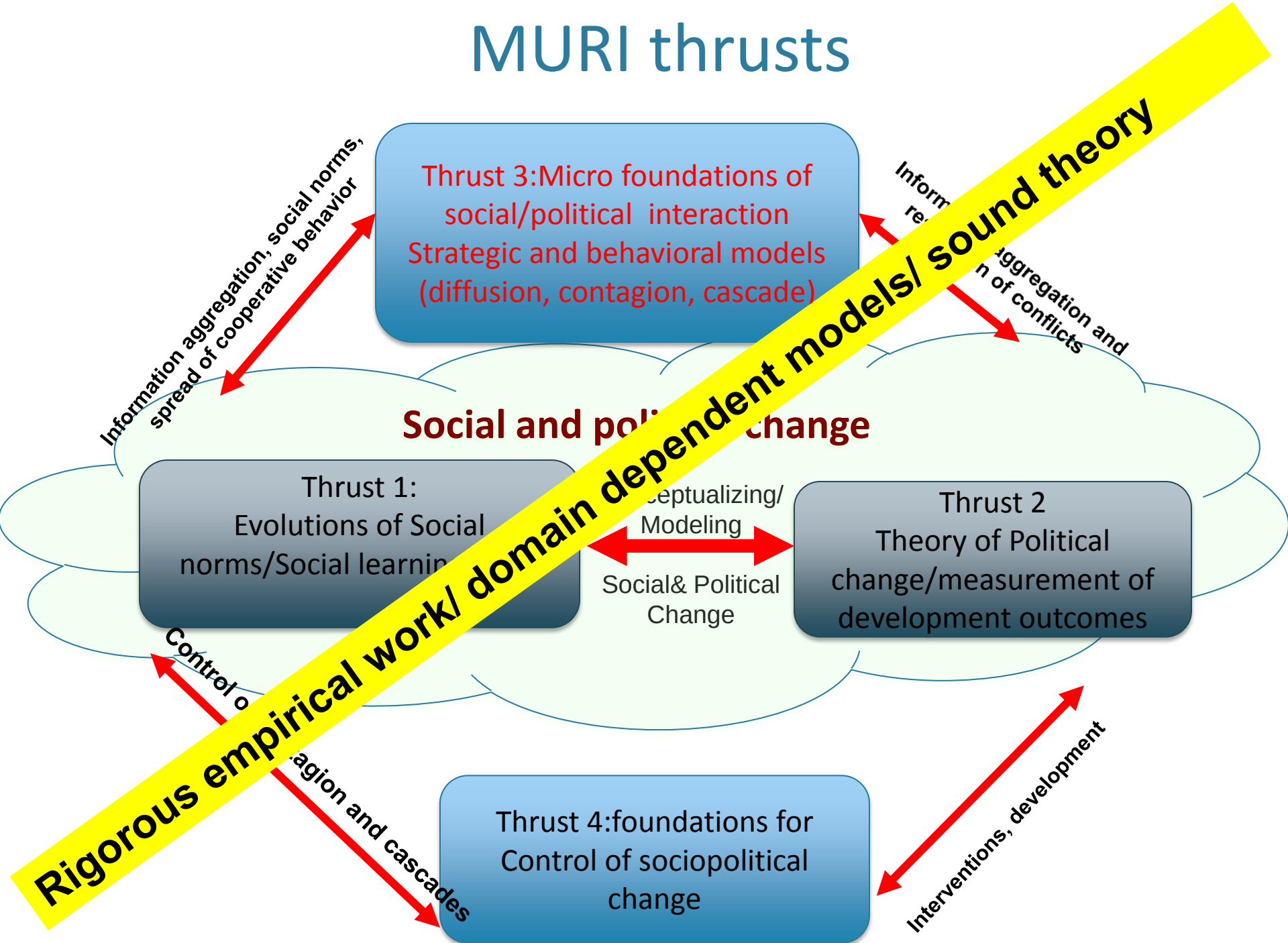


Motivation and Overview

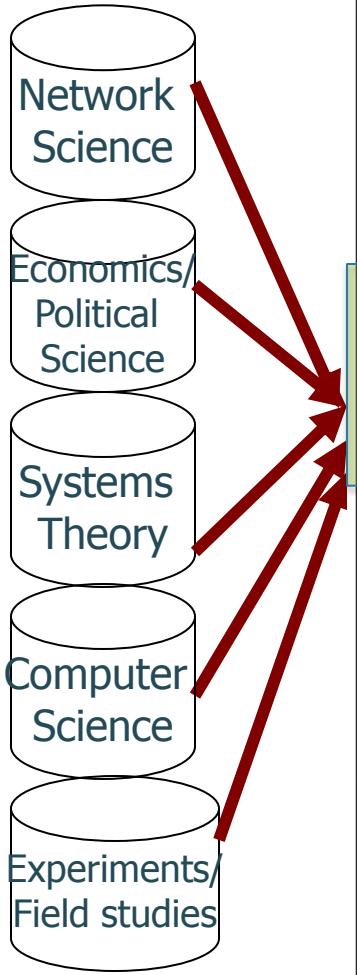
Goal: Rigorous theoretical framework, and modeling and empirical analysis of how patterns of communication, interaction, and learning in networked societies affect the evolution of behavior, how this understanding (the endogeneity of behavior) affects the optimal design of policies and interventions designed to influence beliefs and social norms.

- Many of the central questions involve interactions among individuals and groups with different identities
- Understanding endogeneity of behavior relates to understanding patterns of communication, dissemination of information, and expectations of others' behaviors
  - Need more quantitative approaches, beyond descriptive analysis
  - Need theory, principled modeling, data analysis, lab experiments, and field surveys
  - Need to educate a new breed of computational social scientists and engineers

MURI thrusts



Thrusts and connections



Thrusts, Tasks and Milestones	
Thrust 1. Social change, evolution of social norms	Jackson, Blume, Acemoglu, Jadbabaie
[S1] Social change and evolution of social norms	
[S2] Information aggregation and social learning	
[S3] Emergence of generalized trust and economic outcomes	
Thrust 2. Political change and societal stability	Acemoglu, Christia, Leskovec, Jadbabaie, Dahleh,Kearns, Ozdaglar
[P1] Emergence of democracies and challenges to law and o	
[P2] Field experiments: role of post-conflict development	
[P3] Empirical study of social interaction on political change	
[P4] Behavioral experiments in political and societal influence	
Thrust 3. Modeling and analysis of social interaction, cascades, and contagion	Kleinberg, Ozdaglar, Acemoglu, Leskovec, Dahleh,Jadbabie, Kearns,Blume,Dahleh
[M1] Modeling social interaction	
[M2] Modeling and analysis of cascades in networks	
[M3] Idiosyncratic shocks and cascades	
[M4] Robustness in multiagent simulation	
Thrust 4. Control of Sociopolitical change	Ozdaglar, Leskovec, Kleinberg, Jadbabaie Dehleh
[C1] Robust dynamic mechanisms and network global games	
[C2] Influencing social evolutionary dynamics	

Jadbabaie
Network science, dynamics, Collective behavior, decision th.

Acemoglu
Political Economy, Economics, Game Theory, growth

Ozdaglar
Game Theory , OR, Dynamics, Network Economics

Christia
Political Science, field studies, large, randomized surveys from conflict zones

Kleinberg
Networks, games algorithms, comput. social science

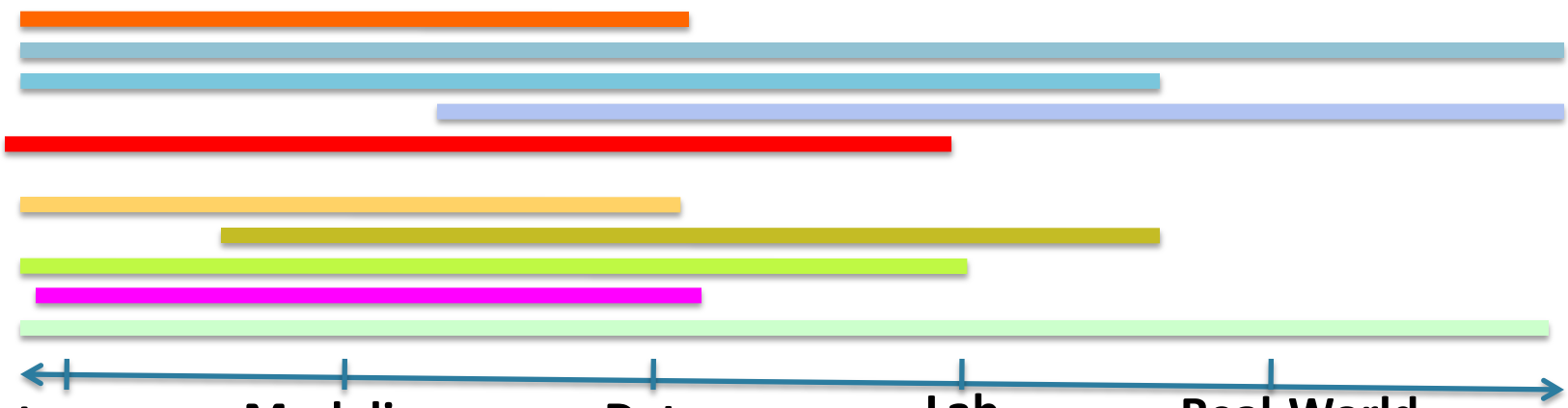
Dahleh
Control, Decision making, networks, games

Jackson
Social and economic networks, games, social norms

Blume
Microeconomics, Game theory, social networks, norms

Leskovec
Social network analysis, algorithms, data , experiments

Kearns
Algorithms, Game Theory, ,Computational Social Science



Theory
- First principles
- Rigorous math
- Algorithms
- Proofs

Modeling
- Economics
- Sociology
- Political Science
- Empirical data
- How to deal with "no physics"

Data Analysis
- Analysis of social network data
- Statistics/Econometrics

Lab Experiments
- Stylized, Controlled
- Clean, real-world data

Real-World Surveys
- Extremely challenging!
- Randomized, large scale studies

Thrust 1: Evolution and emergence of social norms

Main scientific question and foundational contributions:

- How do social norms emerge and evolve? When is an 'optimal' cooperative outcome achieved, resulting in a social norm?
- How does law abiding behavior emerge?
- What are the effect of changing laws?

- **Theorem (Dynamic coordination game/emergence of cooperation as a norm):** *Myopic* rational agents in a (changing) networked society, repeatedly observing noisy private signals and the action of their neighbors, will eventually coordinate on an unknown**, optimal outcome**, except for a set of measure zero of common priors. Consensus in action generically results in agreement on norm.
- When agents non-myopic: equilibrium non-unique

- **Theorem (Social norms and laws):** A sudden tightening of law can create substantial law breaking in the steady state equilibrium while a gradual tightening does not.

- **Theorem:** Cooperative acts may not be reciprocated in resource-poor societies and the failure of cooperation is a contagion phenomenon

Thrust 1: Social learning and information aggregation

Information aggregation, social learning, and patterns of communication

Main Scientific Questions: *Scalable mechanisms for aggregation of dispersed streaming observations. Understanding Role of network structure and quality of private information. Understanding polarization. Learning & diffusion*

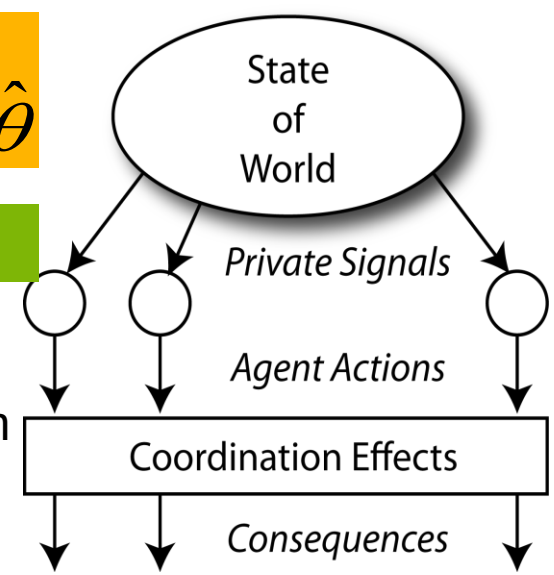
Theorem: Learning speed depends on Interplay of centrality of informed individuals and discriminative power of their private observations. If there is a partial order then a positive match of informativeness and centrality will result in fastest learning. When information endowments are incomparable, fastest learning could come from the least informed being most central

$$r \approx \min_{\theta} \min_{\hat{\theta} \neq \theta} \sum_{i=1}^{n} v_i h_i(\theta, \hat{\theta})$$

Informativeness of agent i for distinguishing θ from $\hat{\theta}$

Eigenvector centrality of i

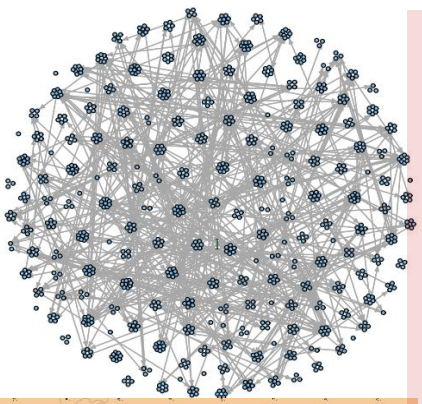
Theorem: Bayesian learning with limited memory:
Over-interpretation of ambiguous signals, due to lack of recall or memory (quantization effect) causes polarization, even when agents are fully Bayesian



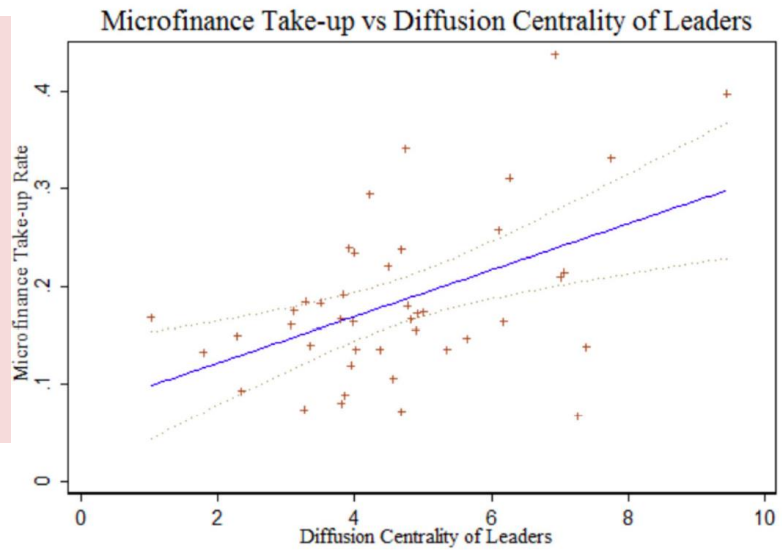
Thrust 3: Role of network structure on diffusion:

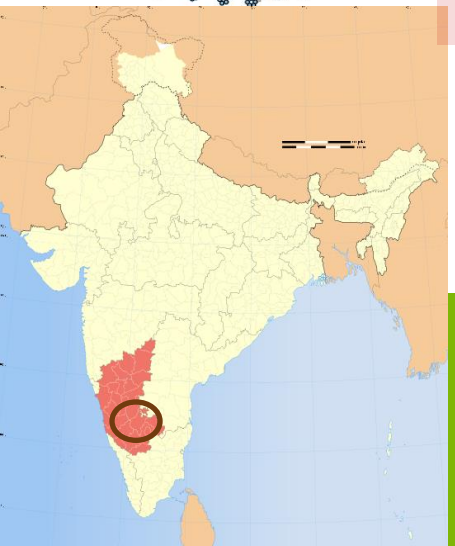
- Diffusion of microfinance : 75 rural villages in Karnataka, India, relatively isolated from microfinance initially. Microfinance offered to 43
- Surveyed 33 villages before entry, observed network structure and various demographics. Tracked microfinance participation over time.
- Villagers can identify highly central individuals, but how? by observing gossip traffic

diffusion centrality of injection points highly correlated with uptake of microfinance



Diffusion centrality: Agent *i* is initially informed,
each informed node tells each of its neighbors
with prob p in each period, run for T periods.
How many nodes informed?





$$DC(p,T) = \sum_{k=1}^{T} (pG)^k$$

Diffusion Centrality

Theorem: Diffusion centrality is the limit of Bonacich and eigenvector centralities

Inverse problem: How people learn other's diffusion centralities by observing local gossip?

Theorem: Gossip centrality and diffusion centrality highly correlated.

Thrust 3: Micro-foundations: Models of endogenous social Interactions

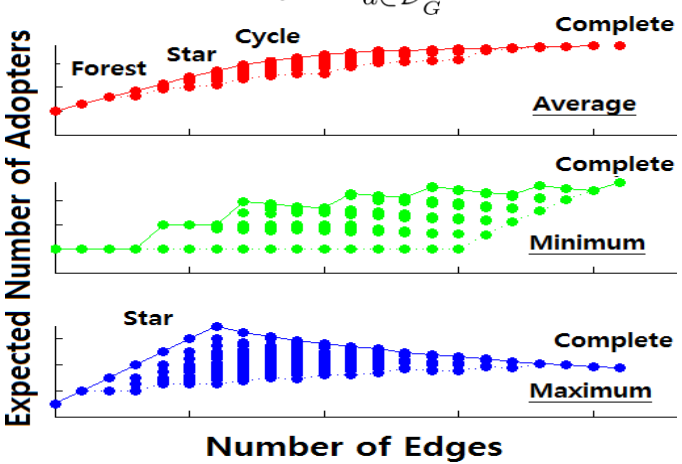
- Objective Modeling and analysis of endogenous local interactions. Investigate implications of endogenous local interactions on aggregate social and political outcomes. Behavioral investigation of competitive contagion
- Key Scientific Questions answered:
  - Which patterns of local interactions lead to rapid diffusion of innovations and ideas? What is the role of network structure on in the real time control of diffusion of negative disturbances, fads, and epidemics?
  - Innovation: A *tractable* Stochastic Linear Threshold Model (SLTM)

Theorem: In an SLTM with random uniform threshold the Expected # of adopters given by $\sum^{n} C_i$, total sum of cascade centrality of agents. C_i is given by $\sum_{l=1}^{n-1} \sum_{j \in \mathcal{S}_G} \sum_{d \in \mathcal{D}_G^{(l)}} \left(\frac{p^l}{d}\right) \cdot \left(M_d^{(l)}\right)_{j,i}$

$\mathcal{S}_G$ is the seed set of agents

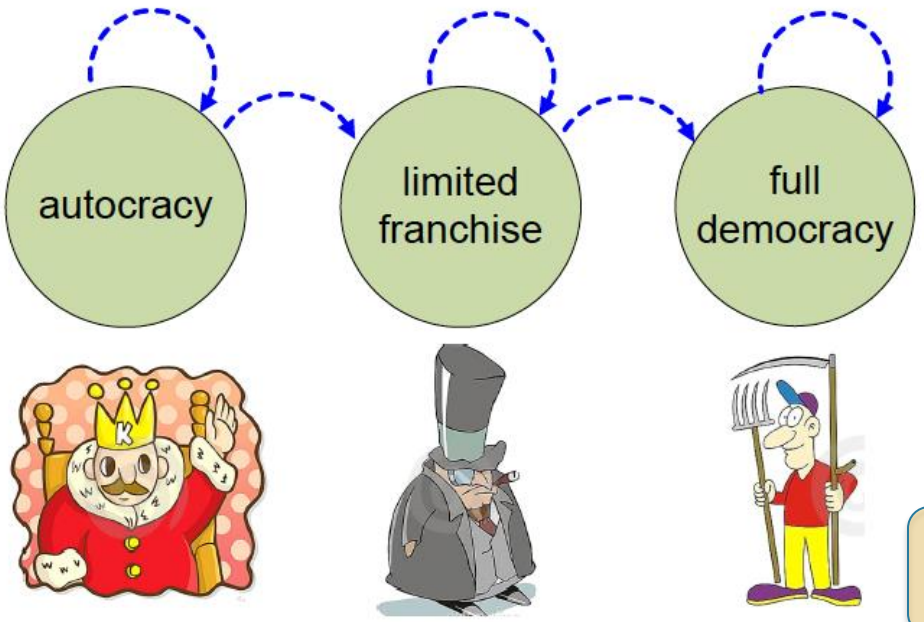
$\mathcal{D}_G^{(l)}$ is the set of all possible product of degree sequences (excluding a seed set of agents) of length l.

$(M_d^{(l)})_{j,i}$ is the number of length l paths from agent j to agent i that has d as a product of degree sequences.



Thrust 2: Political change

- **Main Scientific Question:**
  - How can we think about non-cooperative collective decisions, especially dynamic choices, systematically? Dynamics is a major source of inefficiency!
  - Many group decision-making procedures (voting, bargaining, lobbying) do not lead to Pareto inefficient outcomes in static settings, but they may in dynamic settings.
  - A new theory to characterize political change, regime dynamics, and the inefficiencies and outcomes



•Pareto inefficiency due *to political loser's* effect

•Non-cooperative collective decisions often depend on political power, but political power is itself endogenously determined

• A complete theory generalizing this to many states, many coalitions

Output: A recursive characterization of equilibrium structure and limit outcomes.

Thrust 2: Political Development

Power of state/Provision of public goods

- A novel network-based approach to modeling and estimating the direct and spillover effects of state capacity on public goods and prosperity using data across Colombian municipalities.

Question: what is the effect of "infrastructural" power of the state (e.g., presence of the state and its employees) on economic/political development? What is the direct effect of spill-over effects of infrastructural power of the state?

- Presence of local state may create spillovers on neighboring areas according to network structure.
- The estimation of spillovers is fraught with econometric difficulties because of reasons related to both endogeneity and correlated effects.
- The estimation of strategic interactions is even more difficult.

Our approach: model the impact of state capacity in one municipality on public goods provision and economic outcomes in neighboring areas

- A network game to determine direct & spill-over effects between:
  - Players: National government and Local municipalities
  - Estimate whether a network game of strategic substitutes or complements
- **State Presence has large impact on prosperity, due to network effects**

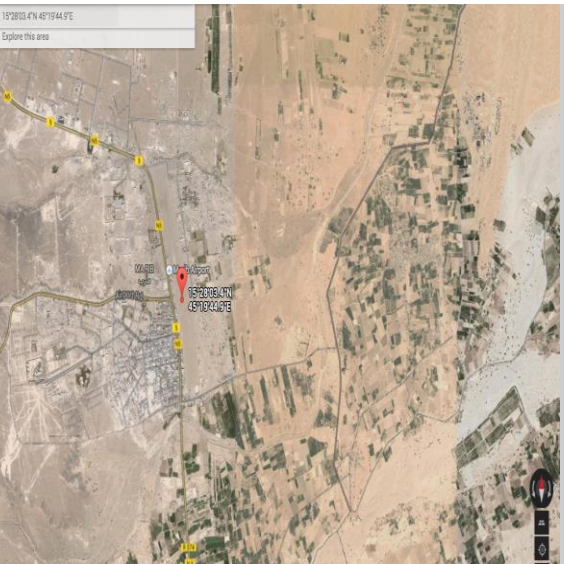
Thrust 2: Provision of development aid

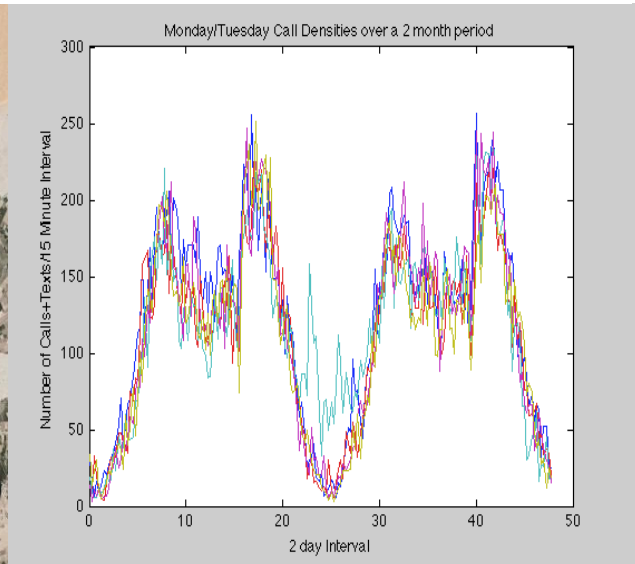
- Field Experiment on development aid across 500 Afghan villages to look at the effect of aid provision on security outcomes (**Largest of its kind)**:
- **Major Finding:** public goods provision has **a positive effect** on solidifying security **in areas that are not highly insecure to begin with, but no effect in highly insecure areas.**
- Ongoing work: effect of information campaigns on security outcomes.
  - Exploit local random variation in radio signal to see correlations between security and radio signal+government services
- clean identification strategies for both public goods provision and for government radio reception and can make causal arguments for our effects.

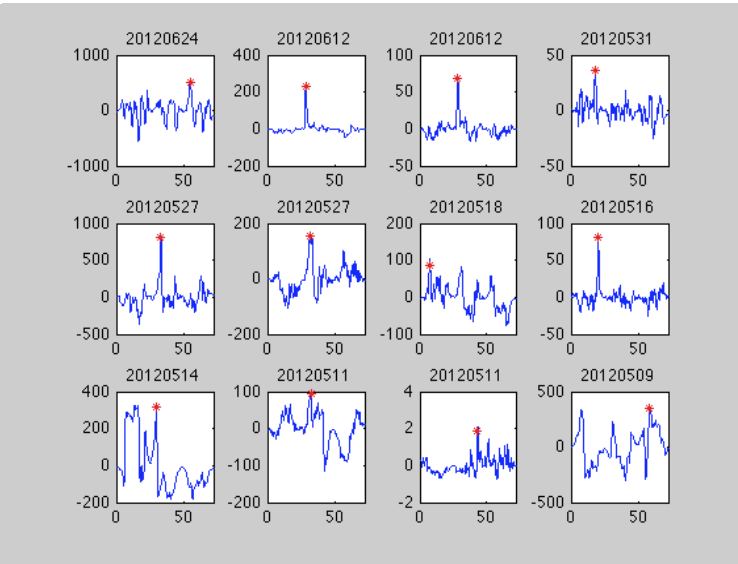
Empirical Study of Social Interaction
Violence, Sectarianism and Communication in Yemen

Three years worth of call records data from Yemen (January 2010-January 2013; for 2-4 million subscribers; 5-10 million calls per day)

- Assess the effects of shocks (+,-) on disruption of patterns of communication
  - drone strikes (exogenous violent shocks)
  - Arab Spring protests (violent shocks endogenous to the society)
  - Shiaa, Sunni, joint religious holidays, secular holidays
  - Evolution of social network of students protesters during the Arab Spring
- Developed a method that allows for identification and localization of drone strikes through the traces collected from cell-phone calls.
- Ongoing work: effect of endogenous shocks on the social network structure



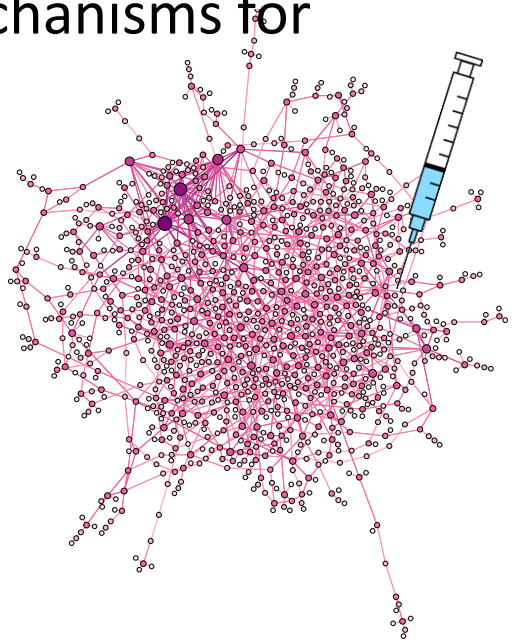


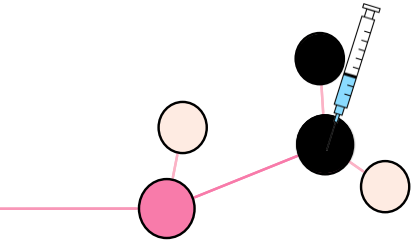


Thrust 4: Control of spreading processes

- Objective: Develop incentive and control mechanisms for maximizing/minimizing contagion
  - e.g., opinion dynamics, epidemics, social and political cascades.
- Achievements

  Developed dynamic control policies that use information about the current state of the contagion with fixed budget
- Developed Dynamic pricing policies for maximizng spread of idea/innovation when preferences are uncertain. Optimal price should be set to zero infinitely often!





- Tools: combinatorial optimization and Markov Processes
  - ✓ Complete characterization of network structures that are resilient against contagion processes.
  - ✓ New graph-theoretic measure at capturing how threatening a subset of nodes is in terms of spreading the contagion.

Theorem: For graphs with linear cutwidth (e.g., star graph), it is impossible to achieve sublinear extinction time with sublinear budget for any policy.

Theorem: For graphs with sublinear cutwidth, there exists a policy that achieves sublinear extinction time with sublinear budget.

Summary of key contributions

- Social norms of behavior are endogenous and depend on beliefs, but:
  - beliefs are shaped by patterns of communication, and heterogeneity of networks
  - role of influential and informed individuals is the key in the outcome
  - various notions of centrality of agents determine the role they play in the eventual outcome
- Timing of intervention, structure of the network are key in determining the success of intervention for facilitating (or mitigating) spreads
  - Key contribution: development of domain-dependent models that are tractable, yet highlight the role of endogeneity of behavior, interaction structure, and patterns of communication in the eventual outcome
  - A formal, game theoretic analysis of political change
- Understanding the endogeneity of behavior relates to understanding patterns of communication, dissemination of information, and expectations of others' behaviors
- A general, game-theoretic framework for the analysis of political change, stability and regime dynamics

Questions to answer next

What are the intended and unintended consequences of interventions and institutional designs targeted at changing political equilibria and social norms?

1. What are the unintended consequences of interventions working through their impact on social norms, communication and learning in society?
2. What are the potential intended and unintended consequences of various institutional arrangements and interventions because of their impact on political reactions (e.g., changes in coalitions, additional investments in de facto power or illicit behavior)?
3. Which types of interventions can effectively change beliefs and social norms?
4. What is the role of the pattern of communication and observation across agents in determining the impact of interventions institutional arrangements?
5. In light of 1-4, how can optimal interventions be designed?

Summary of recent honors/accomplishments

- **Daron Acemoglu** was inducted to **NAS**, received the **Nemmers Prize** in Economics, the **Kadir Has lifetime achievement award**, and **Honorary PhDs** from **Univ. of Athens,** and **Bosporus University**
- **Ali Jadbabaie** received the **Alfred Fitler Moore Endowed Professorship in Network Science** from Penn's School of Engineering and Applied Sciences, was elected as Inaugural **Editor-in-Chief** of the new **IEEE Transactions on Network Science and Engineering,** and was elected as **an IEEE Fellow**
- **Jon Kleinberg** was elected as **Simon's Investigator** (NAE and NAS member)
- Asuman Ozdaglar received the inaugural Steven and Renee Finn innovation fellowship from the MIT EECS Department
- **Matt Jackson** gave the **The Hahn Lecture**, Royal Economic Society, April 2013;
- **Jure Leskovec** received the **2013 WWW Best paper award**
- **Munther Dahleh** leading a new interdisciplinary research and educational entity at MIT focused on the interplay of information and decision systems, socio-technical systems, and data science

Budget and # of students and postdoctoral scholars*

Penn: 8 students and 2 postdocs
MIT: 4 students and 2 postdocs
Cornell: 2 students
Stanford:6 students
GaTech: 1 postdoc, 2 students

* Numbers include partial support

Evolution of Cultural Norms and Dynamics of Socio-Political Change
W911NF-12-1-0509

UNITED STATES DEPARTMENT OF DEFENSE FY 2012 MURI / TOPIC #8

UNIVERSITY OF PENNSYLVANIA (Prime)

PROPOSED			PENN	MIT	CORNELL	STANFORD	GATECH
BASE PERIOD II (4 months)	9/1/12-12/31/12	$520,833	197,733	120,700	92,800	79,200	30,400
BASE PERIOD II (12 months)	1/1/13-12/31/13	$1,250,000	335,800	422,800	183,100	203,400	104,900
BASE PERIOD III (12 months)	1/1/14-12/31/14	$1,250,000	389,700	391,800	176,000	192,700	99,800
BASE PERIOD IV (8 months)	1/1/15-8/31/15	$729,167	163,467	257,600	110,500	132,300	65,300
	BASE TOTAL	$3,750,000	1,086,700	1,192,900	562,400	607,600	300,400
OPTION PERIOD I (4 months)	9/1/15-12/31/15	$520,833	187,633	125,500	111,100	64,500	32,100
OPTION PERIOD II (12 months)	1/1/16-12/31/16	$1,250,000	413,200	372,600	178,800	191,500	93,900
OPTION PERIOD III (8 months)	1/1/17-8/31/17	$729,167	188,267	253,100	116,500	108,800	62,500
	OPTION TOTAL	$2,500,000	789,100	751,200	406,400	364,800	188,500
	PROJECT TOTAL	$6,250,000	1,875,800	1,944,100	968,800	972,400	488,900

AWARDS								
W911NF-12-1-0509 Initial Increment	30 Aug 2012	$520,833	198,233	120,200	92,800	79,200	30,400	$520,833
W911NF-12-1-0509 Modification	19 Dec 2012	$1,250,000	335,800	422,800	183,100	203,400	104,900	$1,250,000
W911NF-12-1-0509 Modification	20 Dec 2013	$1,250,000	389,700	391,800	176,000	192,700	99,800	$1,250,000
	AWARDS-to-DATE	$3,020,833	923,733	934,800	451,900	475,300	235,100	$3,020,833
EXPENSE	TOTAL EXPENSE @ MAY 31 2014		$457,410	376,683	101,951	198,110	202,624	$1,336,778
	FUND BALANCE @ JUNE 1 2014		$466,323	$558,117	$349,949	$277,190	$32,476	$1,684,055
		BURN RATE	*50%*	*40%*	*23%*	*42%*	*86%*	*48%*
	DATE of LAST RECEIVED INVOICE (costs thru)		*n/a*	*May 31 2014*	*Nov 30 2013*	*May 31 2014*	*April 30 2014*	