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Third and final annual research project report.

14. ABSTRACT
This project aimed at modeling future trajectories of irregular warfare (IW) through multiagent social simulation. The project objectives were to use social science to understand the social and political landscapes of IW; create a high-fidelity multiagent social simulation model (LRG-AFG) of the co-evolution of insurgency and counterinsurgency (COIN), embedded in a realistic and theoretically informed model of the local social, political, and economic landscapes; build an understanding of forces in the local population that support or oppose the existence of covert networks; describe the evolution of friend-or-foe attitudes among the population, and develop a model of the political economy of insurgency. To the best of our knowledge, LRG-AFG is at the time of submission of this report the most sophisticated, open source simulation of a political economy affected by armed conflict. LRG-AFG is a simulation of rural Afghanistan with 1.5M household agents that lends itself to rigorous analytical work and robust support for decision making.

15. SUBJECT TERMS
Afghanistan, Counterinsurgency, Empirical Modeling, Irregular Warfare, Multiagent Simulation, Multisource Data Fusion, Qualitative Agency Design

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2011 ONR Annual Report

PI: Dr. Armando Geller

Organization: George Mason University

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Award Title: Forecasting Irregular Warfare via Agent-based Network Models

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2011 ONR Annual Report

PI: Dr. Armando Geller
Organization: George Mason University
Award Number: N00014-08-1-0378
Award Title: Forecasting Irregular Warfare via Agent-based Network Models

a. Scientific and Technical Objectives

This project aimed at modeling future trajectories of irregular warfare (IW) through multiagent social simulation. The project objectives were to:

- Use social science to understand the social and political landscapes of IW.
- Create a high-fidelity multiagent model of the co-evolution of insurgency and counterinsurgency (COIN), embedded in a realistic and theoretically informed model of social, political, and economic landscapes.
- Build an understanding of forces in the local population that support or oppose the existence of covert networks.
- Describe the evolution of friend-or-foe attitudes among the population.
- Develop a model of the political economy of insurgency.

The specific scientific and technical objectives of year three were to:

- Implement and validate three modules called ─identity", ─belief system", and ─political economy".
- Integrate each standalone module into a country-scale model dubbed LRG-AFG.
- Validate the integrated model.
- Simulate scenarios in the security, economy and governance domains for policy analysis.

The project did not deviate from the scientific and technical objectives as stated in the original proposal. All proposed scientific and technical objectives have been achieved.

b. Approach

We built an integrated multiagent simulation model (LRG-AFG) that equips researchers and policy analysts and decision makers with new insights on IW and insurgency in Afghanistan in the domains of identity, belief system, and political economy. The domains were expressed as modules, and were computationally implemented into models that can be empirically validated. Developing each model required a complete modeling cycle of information collection, ontology development, coding, code verification, and model validation. Models were subsequently integrated. The integrated model represents a regional model of IW in Afghanistan exhibiting granularity down to the household level. Integration entailed defining interfaces that enable each module to attach and talk to other modules. These interfaces and the flows among them reflect doctrinal and scientific understandings of IW and COIN as experienced in Afghanistan.

Methodologies and concepts developed in this modeling effort to understand IW function as demonstrators and can also be used for cases other than Afghanistan.

Additionally, outputs of each module provide data imputation and fusion mechanisms that can produce functional and structural equivalents of real-world data that is hard to obtain. The integrated model is flexible and detailed enough to make developing scenarios to inform academic and policy debates possible, and support finding answers and making informed decisions in the IW and COIN domain.

The approach taken does not deviate from the approach originally proposed.

c. Concise Accomplishments

The key accomplishments of the final year of the project are the implementation of the three modules ‖identity", ‖belief system", and ‖political economy", and the integrated model into computer code, validation, and the subsequent use of the integrated and validated model in scenario generation exercises. To simulate scenarios that are of use to the decision maker, the integrated model, LRG-AFG, had to be informed with empirical data. To initialize the simulation with demographic and geospatial data a Common Unified Data Image (CUDI) that is true to the model ontology was developed. To inform agent behavior using openly available qualitative data technique called qualitatively induced agency design (QIAD) was developed. Both processes, CUDI and QIAD are designed to be transferrable across cultural and geographic domains. To the best of our knowledge, LRG-AFG is at the time of submission of this report the most sophisticated model of a political economy affected by armed conflict. LRG-AFG is a simulation of rural Afghanistan with 1.5 million household agents that lends itself to rigorous analytical work and robust decision making support. It enables among other things

- Analyzing Afghanistan's conflict-torn rural political economy, including flows of goods and emergent social networks.
- Concluding that corruption is key to creating security and enforcement causes competition for protection.
- Establishing optimal force mixes for counternarcotic efforts across multiple scenarios.
- Hypothesizing that much that is going on in Afghanistan has to do with how competing ‖states" and ‖governments" arrange themselves with private actors for the pursuit of maximizing personal profit.

Results and data have garnered interest from academia, federal agencies, and national and international private businesses and state agencies.

d. Expanded Accomplishments

In what follows brief descriptions of year three accomplishments are given, including the scenarios that were ran. All reported accomplishments are documented in detail in written and can be requested by the PI.

Codebase

The project has already contributed to the open source social simulation community. We have developed a scalable discrete event scheduler, suitable for social simulations with millions of asynchronously interacting agents. We have thoroughly tested this solution with the developers of the MASON simulation toolkit and shared it with MASON users as a new customized capability. We have also distributed our code for new advanced

visualization capabilities, including stacked and multi-axis time series, in MASON. We are preparing data fusion procedures for upload onto a community repository. More computational products will be attached to follow-up publications per requirements of journals they are being reviewed at.

The computer model is available upon request from the PI.

Economy and conflict

Links between licit and illicit economies fuel conflict in countries mired in irregular warfare. We argue that in Afghanistan, cultivating poppy and trading drugs bring stability to farmers who face the unintended consequences of haphazard development efforts while lacking alternative livelihoods and security necessary to access markets. Drug trafficking funds the crime-insurgency nexus and government corruption, in turn foiling attempts to establish a unified governance body. We show how individual rationality, market forces, corruption and opium stocks accumulated at different stages in the supply chain counteract the effects of poppy eradication. To that end, we use initial results from a multiagent model of the Afghan drug industry. We define physical, administrative, social and infrastructural environments in the simulation, and outline objectives and inputs for decision making and the structure of actor interactions.

(a) Wheat   (b) Opium
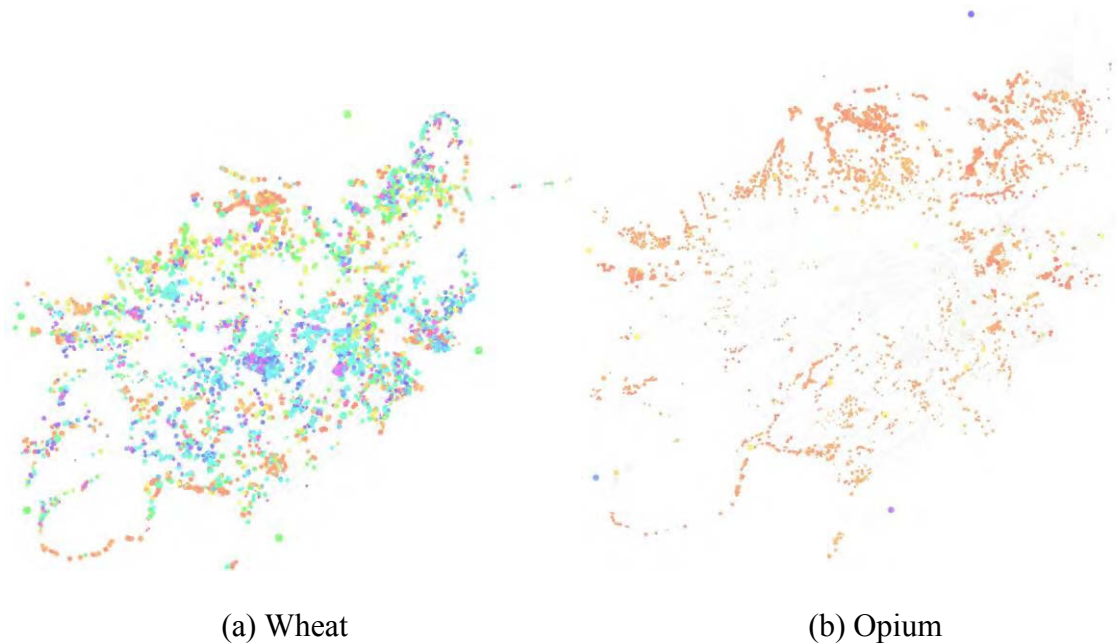
Figure 1: Spatial distribution of trades taking place in a sample summer week in year 4. The area of a dot is proportional to the logarithm of the volume of crop exchanged. Orange markets have the lowest prices while purple markets have the highest prices.

A full description of the work can be found in a paper authored by Maciej M. Łatek, Seyed M. Mussavi Rizi and Armando Geller titled ―Persistence in the Political Economy of Conflict: The Case of the Afghan Drug Industry‖ and published in Complex Adaptive Systems—Resilience, Robustness, and Evolvability: Papers from the AAAI Fall Symposium Series. pp. 86-92.

Security and economy

We report the results of multiagent modeling experiments on interactions between the drug industry and corruption in Afghanistan. The model formalizes assumptions on the motivations of players in the Afghan drug industry, quantifies the tradeoffs among various choices players face and enables inspection of the time, space and level of supply chain in which one can expect positive and negative impacts of counternarcotic policies. If reducing opium exports is one measure of effectiveness for NATO operations in Afghanistan, grasping the links between corruption and the drug industry should provide a better picture of the second-order interactions between corruption and investment in improving the governance quality, in deploying security forces tasked with eradication and interdiction and in programs to enhance rural livelihoods.
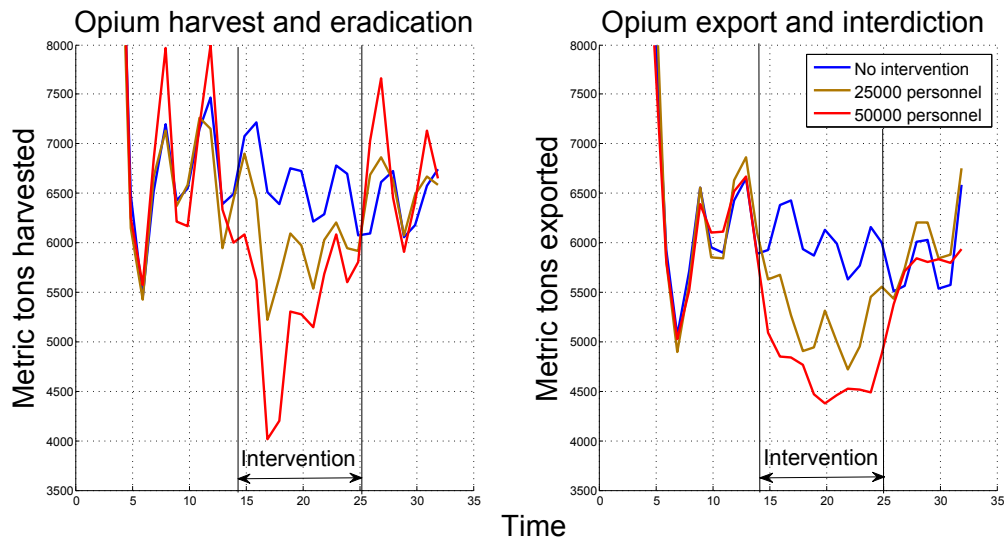

Figure 2: Results of interventions with corruption. On the left panel, we use eradication to suppress opium harvests. On the right panel, we target traders with interdiction to suppress opium exports. Intervention is introduced in year 15 and lifted after year 25. Opium losses before reaching border and export are about 10%. Each condition is an average of 10 independent model runs.

A full description of the work can be found in a paper authored by Armando Geller, Seyed M. Mussavi Rizi, Maciej M. Łatek titled ―How Corruption Blunts Counternarcotic Policies in Afghanistan: A Multiagent Investigation‖ and published in J. Salerno, S.J. Yang, D. Nau and S.K. Chai (eds.), Social Computing, Behavioral-Cultural Modeling and Prediction 2011 conference. Lecture Notes in Computer Science 6589. pp. 121-128.

Governance

Government corruption represents pathological interactions between the central state and local power structures that can cause internal armed conflict and shape its course. To investigate the interplay of corruption and conflict, a multiagent model based on LRG-AFG of corruption mechanisms and processes in the Afghan drug industry that sheds light on whether corruption causes conflict or results from conflict is devised. If the latter

is true, combating corruption may prove futile if it simply results from conflict. We investigate how corruption shapes the course of the conflict and show that the initial capacity of the Afghan state produces different trajectories of conflict.
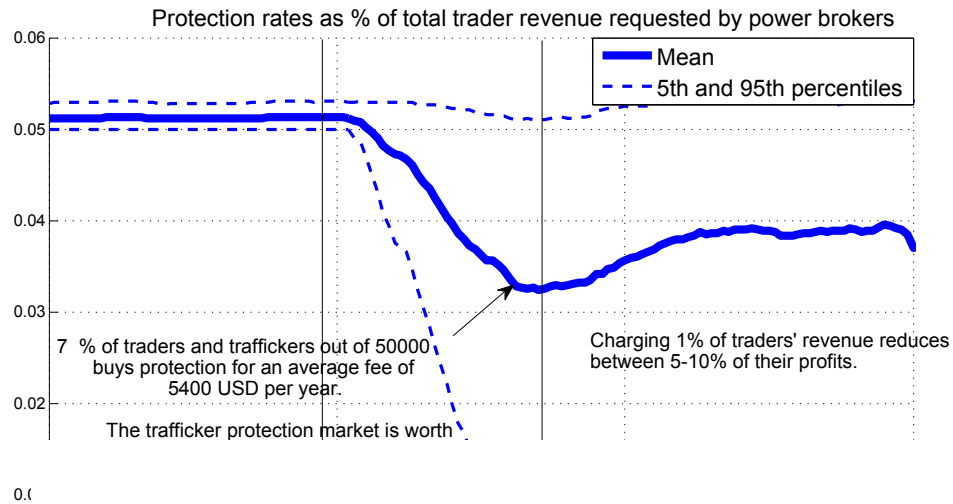

Figure 3: brokers.
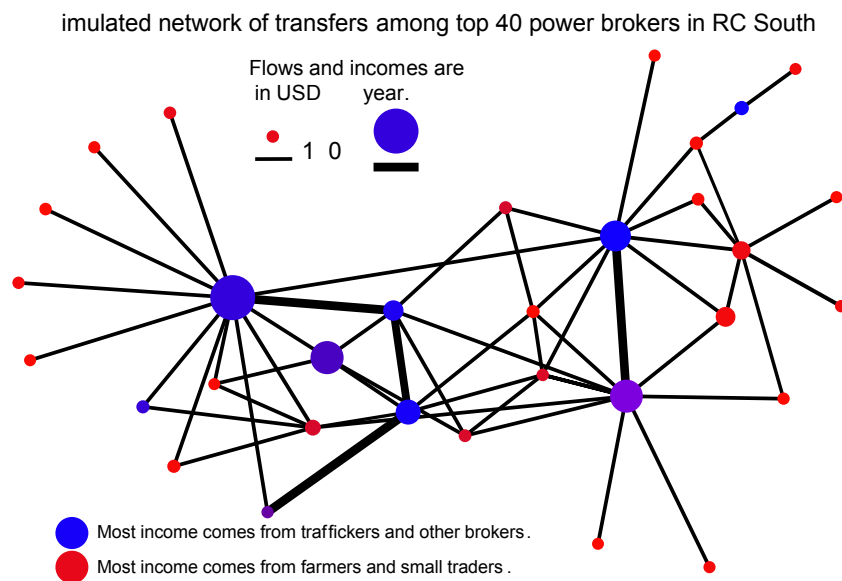
Figure 4: Emergent broker-to-broker network.

A full description of the work can be found in a paper authored by Armando Geller, Seyed M. Mussavi Rizi, Maciej M. Łatek and Cameron Thies titled ―State Capacity and Conflict: Evidence from Afghanistan".

Decision making support
We introduce the notion of strategic uncertainty for boundedly rational, non-myopic agents as an analog to the equilibrium selection problem in classical game theory. We then motivate the need for and feasibility of addressing strategic uncertainty and present an algorithm that produces decisions that are robust to it. Finally, we show how agents' rationality levels and planning horizons alter the robustness of their decisions.
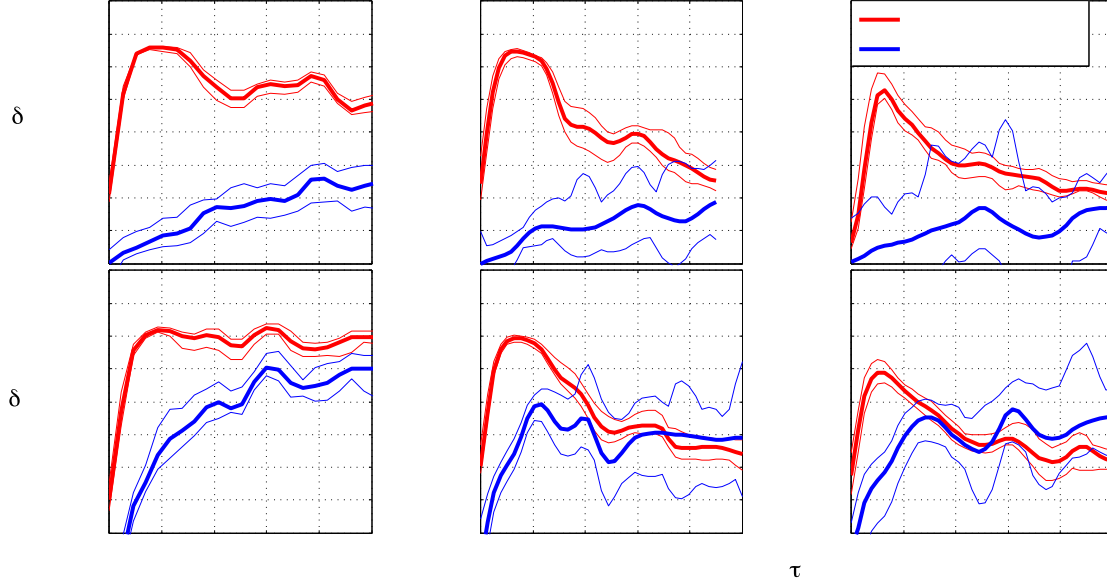
Figure 5: *A*'s predicted and observed payoffs as a function its planning horizon h_A and the number of forward-looking sample τ_A. Levels of rationality are fixed at $d_A = 2$ and $d_B = 1$. *B* has planning horizon $h_B = 1$ and $\tau_B = 1$. In the upper panel, the cost of strategy adjustment δ is zero. In the lower panel $\delta = 0.25$. Thin lines correspond to a 95% confidence interval.

A full description of the work can be found in a paper authored by Maciej M. Łatek and Seyed M. Mussavi Rizi titled ―Robust Decision Making under Strategic Uncertainty in Multiagent Environments" and that is to appear in the Workshop on Applied Adversarial Reasoning and Risk Modeling (AARM) AAAI 2011 in San Francisco, California (August 7-11, 2011) workshop proceedings.

Radicalization
How do individuals become radicalized, turning into terrorists, insurgents, violent actors. Computational agent-based models of irregular warfare, internal war, domestic political violence, and related conflicts require violent agents capable of carrying out attacks. Rather than introducing such agents as an exogenous process, as a *deus ex machina*, this paper presents an agent-based model where radicalization is generated as an emergent phenomenon from within a population of individuals. The model (tentatively called ―MASON RadicalAgent'') is based on a new process-based theory of individual

radicalization and is implemented in the MASON simulation system. Our paper describes the underlying theory, model structure, and some preliminary results intended for demonstration. This modeling effort is part of a broader project for modeling conflict in complex polities by combining computational simulations and network models.
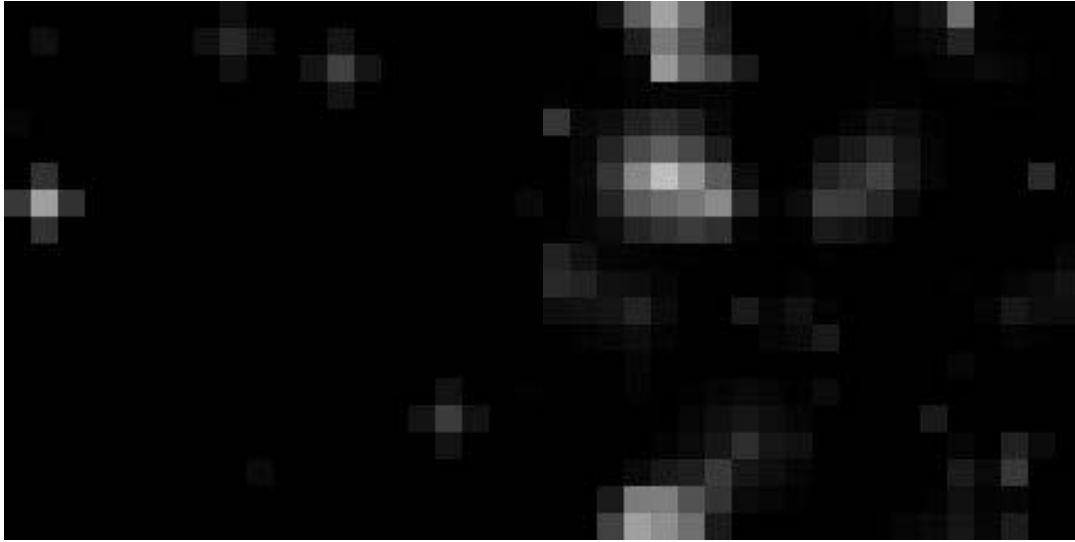
(a)   (b)

Figure 6: Echo effect in a 20 by 20 grid of agents experiencing randomly generated traumatic events. The color gradient indicates the level of grievance, with black being zero and white indicating the threshold. The events in (a) are echoed once using a von Neumann neighborhood. In (b) the events are echoed twice using the Moore neighborhood.

A full description of the work can be found in a paper authored by Claudio Cioffi-Revilla and Joseph F. Harrison titled ―Pandemonium in Silico: Individual Radicalization for Agent-Based Modeling" and prepared for the Annual Convention of the International Studies Association, Montreal, Quebec, Canada, March 16–19, 2011.

Qualitative modeling
There is a clear trend toward data-driven computational social science. While ―data" in this case typically refers to the uses of quantitative data, the use of qualitative data in computational social science modeling has only been marginally discussed from a social science point of view. We contribute by reflecting on two important questions: How can data be translated into computer code? What characteristics of qualitative data make it a particularly useful approach in agent-based modeling? We argue for a matching translation procedure. As a corollary we theorize on the surplus we get from qualitative data in modeling, which lies in its sequential nature and its nature to be evidence for causal and social mechanisms at work.

A full description of the work can be found in a paper authored by Armando Geller, Rebecca Goolsby and Lee Hoffer titled ―On Qualitative Data in Agent-Based Models".

Economy

This is an investigation of the informal value transfer networks—the *hawala* exchanges—through the methods of social network analysis. Based on a dataset constructed from the ―bottom-up‖ using proxies and informational conjectures derived from mass-media reports and the nested game theory, the analysis shows significant network externalities in the *hawaladar* networks from Pakistan and Afghanistan. One of these network externalities shows that terrorism in the NWFP is a lock-in emergence.
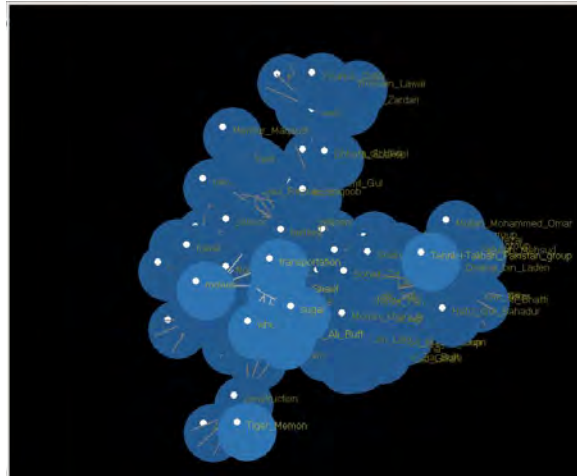
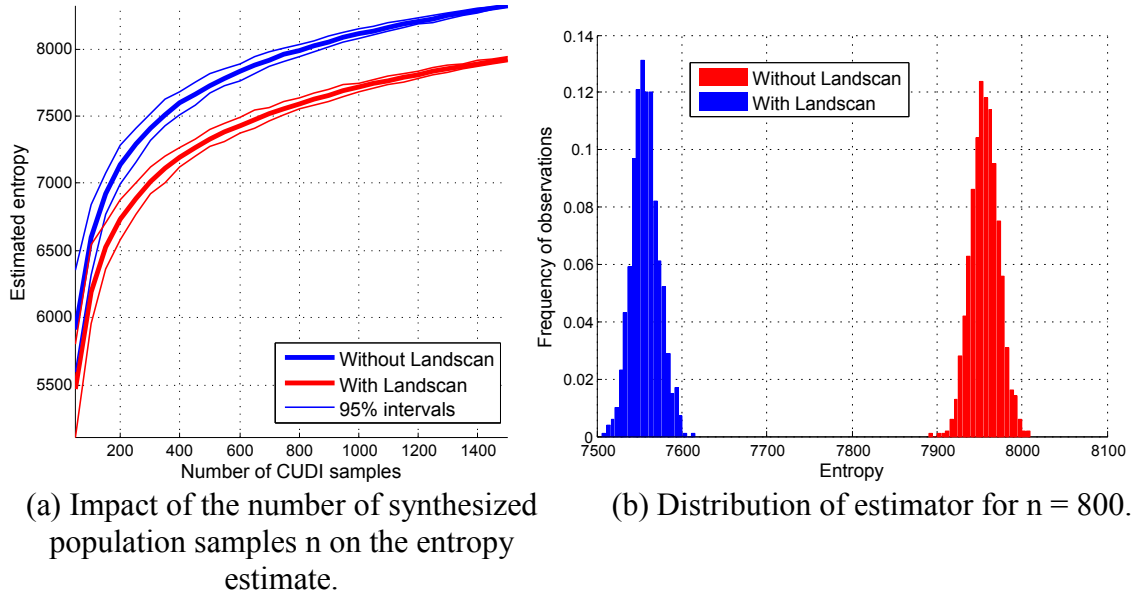**Figure 7:** Social network representation of *hawala* business network.

A full description of the work can be found in a paper authored by Anamaria Berea titled ―Network Externalities in *Hawala* Exchanges‖ and that was presented at the Social Complexity of Informal Value Exchange (SCIVE) 2010 workshop at the European Complex Systems Society Conference, Lisbon, September 16th, 2010.

Data fusion

In this paper we developed a protocol that uses local surveys and partial remote sensing data to recover country-level virtual rural populations that can be used to model licit and illicit economic activities in countries that are mired in irregular warfare. Our approach unifies scattered datasets into an ontology that is consistent with our target multiagent model, and by using a multisourced approach has potential to hedge against potential biases. Using Afghanistan as a case, we showed that the assumption that the distribution of rural population is driven by land availability is sufficient to recreate rural population below the district level and validated our procedure by an independent dataset.

Our effort contributes to both methodological and algorithmic debates in population synthesis. Methodologically, we plot a population synthesis procedure for multiagent modelers, particularly those envisioning large-scale spatial models in agriculture, land use and conflict domains, that enables them to glean from remote sensing and sparse demographic data a unified image of the population they need to instantiate. Algorithmically, we contribute to work on exploring the scalability properties of population synthesis procedures and measuring the underlying uncertainty of data generated by such procedures. The most interesting recent developments in population synthesis algorithms have focused on improving their scalability and on creating detailed synthetic populations of countries through multiresolution methods. Recent years have

also witnessed burgeoning attempts to formalize methods to grasp the underlying uncertainty of the multidimensional distributions of populations in synthesized datasets. We offer an alternative perspective on combinatorial optimization inspired by the problem of growing and imputing unknown network links. This approach enables integration of not only sparse surveys and microsamples, but also rarely used remote sensing and qualitative data into the algorithm. We then use our algorithm to create a household-level rural population of Afghanistan, a dataset similar to that have called for. Finally, we propose a general-purpose method to measure the entropy of plausible synthetic populations generated by our algorithm.

(a) Impact of the number of synthesized population samples n on the entropy estimate.

(b) Distribution of estimator for n = 800.

Figure 8: Entropy estimates before and after including Landscan as an additional data input. The estimator we use is biased, but even with the small number of algorithm runs, the right order of magnitude is quickly achieved. When $n \geq 200$, it becomes possible to statistically distinguish between entropies before and after including Landscan as the additional dataset.

A full description of the work can be found in a paper authored by Seyed M. Mussavi Rizi, Maciej M. Łatek and Armando Geller and titled ―Fusing Remote Sensing and Sparse Demographic Data: An Algorithm and Application to Rural Afghanistan".

e. Work Plan
Project completed.

f. Major Problems/Issues (if any)
Nothing to report.

g. Technology Transfer
The usefulness of using similar empirically informed models for creating common operating pictures and for designing data sharing processes have been explored with OSD NII at DOD CIO. The power of multiagent models for creating understanding and forecasting has been explored with the Army Environmental Policy Institute. And similarly fine grained models have been tested in collaboration with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for micro policy analysis and decision making in areas affected by armed conflict. We have also shared CUDI meta-data with the DataCards project at the National Defense University (NDU).

h. Foreign Collaborations and Supported Foreign Nationals
- Foreign collaboration: No formal foreign collaboration. Informally we regularly exchange internationally at workshops, seminars, and conferences.
- Supported foreign nationals:
    - Anamaria Berea (Graduate Research Assistant and registered PhD student with the Computational Social Science program at GMU).
    - Armando Geller (Research faculty GMU).
    - Maciej M. Łatek (Graduate Research Assistant and registered PhD student with the Computational Social Science program at GMU).
    - Seyed Mohammad Mussavi Rizi (Graduate Research Assistant and registered PhD student with the Computational Social Science program at GMU).

Forecasting Irregular Warfare via Agent-based Network Models – Annual Report 2011

Armando Geller (PI)

Center for Social Complexity, Krasnow Institute for Advanced Study, George Mason University

Objectives

- Create a high-fidelity multiagent simulation model of the co-evolution of insurgency and counterinsurgency.
- Implement and validate three modules called "identity", "belief system", and "political economy".
- Integrate each standalone module into a country-scale model dubbed LRG-AFG.
- Validate the integrated model.
- Simulate scenarios in the security, economy and governance domains for policy analysis.

Approach

- Applying geo-referenced social, economic, and political data into state of the art empirical multiagent modeling, including recursive and adaptive agents that exhibit evidence-based behavior.
- Modularizing model development so that policy scenarios can be developed in collaboration with stakeholders to inform academic and policy debates and enable finding answers to analytic questions that make informed decisions in the IW and COIN domain possible.

Accomplishments

- Implementation and validation of models and integration and validation of LRG-AFG.
- CUDI: An ontology-based process to create a common unified data image for modeling and applied purposes that can be transferred across cultures, domains and spaces.
- QIAD: A context-sensitive design process for agent ontologies.
- Running empirically informed scenarios in the domains of economic, security and governance

Transitions

- NDU: DataCards.
- NII, OSD: Platforms for data fusion (in progress).
- GIZ: Micro analysis of CIMIC in areas affected by armed conflict.

Population and geography

Markets and policy

Opium harvest and eradication

Opium export and interdiction

Patronage and corruption

Simulated network of transfers among top 40 power brokers in RC South

Most income comes from traffickers and other brokers.
Most income comes from farmers and small traders.