Combating Terrorist Networks:
Current Research in Social Network Analysis for the New Warfighting Environment

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The GeoGraph 3D Computational Laboratory

Abstract
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Human interactions of all kinds, both friendly and unfriendly, are increasingly structured by networks of transportation and communication spatial technologies. Yet our tools to model, understand, and predict dynamic human interactions and behavior on spatial networks and geographic landscapes have lagged far behind. Even recent progress in social network modeling has not yet offered us any capability to model dynamic processes among mobile agents who interact at all scales on small-world and scale-free *geographic* networks. Computational laboratory modeling of dynamic human interactions on richly structured landscapes is important for understanding the sometimes counter-intuitive dynamics of such loosely coupled systems of non-linear interactions. Deeper understanding is more important than ever not only because the stakes are so much higher, but because we now have greater strategic control over the structural design and therefore the effects of our networks of organizational and spatial technologies.

The authors' *GeoGraph* extensions to the RePast agent-based simulation platform support models in which mobile agents interact on network landscapes. GeoGraphs contribute to spatially integrated strategic social science research by allowing us to develop models that include not only heterogeneous site-specific characteristics, but also the complementary organizational and spatial-technology networks that mediate each agent's mobility, communications, and encounters. GeoGraph computational laboratory tools are designed to support controlled experiments for agent-based geographic science through their ability to generate richly structured parameterized families of synthetic geographic landscapes or of complementary GIS-derived geographic landscapes. GeoGraphs support building and testing simulation models grounded in interesting spatial structures such as spatial small-worlds, geographic scale-free networks, hybrids between the two, or GIS representations of real-world landscapes; homogeneous or heterogeneous distributed mobile agents, including their social networks; and context-specific behaviors.

This paper introduces the new GeoGraph extensions to RePast. As part of illustrating GeoGraph capabilities, we provide demonstrations of implemented simulation models for civil violence outbreaks such as riots or looting and for complementary effective deployment of mobile networked teams of peacekeepers. To the best of our knowledge, this team model represents the first general purpose operational model of social networks among geographically mobile teams of agents. Although we discuss peacekeeping teams and Warlord gangs in our example, GeoGraph team models could also be used to model the movements of and interactions among spatially clustered or dispersed members of terrorist cells. Other implemented GeoGraph models include epidemiological models of infectious diseases among heterogeneous mobile agents on synthetic networks and on real-world geographic landscapes imported from Geographic Information Systems (GIS).

Introduction

The current state-of-the art in agent-based simulation tends to be a mass of agents that have a series of states that they can express as a result of the environment in which they are embedded. This level of interaction allows for flocking or diffusion dynamics, and for related models such as ethnic mobilization (Srbljinovic et al. 2003). Agent-based simulations that examine the effects of inter-agent communication are quite recent and rare (Durlauf 2003).

At the same time, visualization for research simulations tends to be limited to simple grid landscapes or to one or more aspatial 2D plots of agent characteristics such as happiness or wealth. Although these views can be informative, they are limited in their ability to model and to visualize more interesting spatial contexts that structure agent interactions. At the other extreme, highly detailed, photorealistic renderings of simulated agent behavior are appearing in the entertainment sector; in movies sequences such as the "Helms Deep" battle in *The Lord of the Rings* (Animation Artist 2002), and in computer games such as *Battlefield 1942* (Electronic Arts 2003).

Our GeoGraph libraries for RePast (University of Chicago Social Science Research Computing 2000) are a significant step forward for agent-based simulation. By combining a more sophisticated 3D visualization system with agents that understand hierarchical control and spatial landscapes, it is possible to explore far more complex simulations that address the sorts of issues that arise when considering the ramifications of Command, Control, Communications, and Intelligence (C3I). For example, with GeoGraphs it is possible to model the full transition from a strategic decision (invade Europe at Normandy) to the lowest tactical level (Private Jones advancing with the remnants of his squad up the cliff base to a machine-gun nest). GeoGraph visualization allows the modeler to view the simulation through a variety of information spaces; ranging from synthesized sensor views to 3D "fly through" displays, to portrayals of their respective information spaces and communication networks.

Preliminary GeoGraph Models

GeoGraph models have been developed for epidemiological studies of infectious disease transmission among mobile agents; for epidemiological studies of domestic US malaria risk in conjunction with climate models of global warming; for settlement patterns, sector migration, and long-run regional development; for the effects of globalization processes on both epidemiology and regional development; for visualization and modeling of dynamic social networks and spatial games on geographic landscapes; and for civil violence and effective strategies for preventing or controlling riots and related civil unrest. This paper discusses complementary models related to civil unrest among mobile civilians and to C3I connections among mobile members of peacekeeping teams.

Rumors and Looting

Agent behavior for this prototype model of rumors and looting is derived from the grid-based Brookings Civil Violence model (Epstein et al. 2001).   Each square citizen agent decides whether or not to loot depending upon the net balance of his or her perceived hardship, individual risk aversion, and the subjective legitimacy of the current regime. Finally, the decision to loot or to behave at any given moment is also a function of the balance between the agent's attitudes and his or her perceived probability of arrest if looting. An agent's individual perception of the probability of arrest depends upon the distance to the nearest peacekeeper(s) and upon the ratio of currently active looters to peacekeepers in the agent's immediate neighborhood.

In the Brookings model, civilian agents and peacekeepers occupy one cell of a square grid and move at most to neighboring cells.   Our simple prototype extends the Brookings model by allowing both civilian agents and peacekeepers to move around on any network landscape.   Figure 1 illustrates the example here, which includes a mesh network enhanced by several spatial small-world shortcuts. In our model, both civilian agents and peacekeepers may occupy the same places in the landscape, agents may interact either directly or indirectly, and the ring around each agent shows how far it can see.

Future versions of this model will incorporate the endogenous diffusion of rumors among civilian agents. We have already implemented sophisticated models of diffusion among heterogeneous mobile agents as part our epidemiological models of infectious diseases. This additional capability to model rumors among civilian agents could support strategic research regarding the effective use of counter-information for the prevention or control of looting, rioting, and other forms of civil violence among civilian agents.

Similarly, future models could combine this Rumors and Looting model of civilian unrest with the GeoGraph model of C3I among teams of peacekeeper agents, which we present in the next section.

Warlords – C3I Among Teams of Mobile Heterogeneous Agents

GeoGraphs have a series of classes that allow for the creation and observation of teams of agents that behave as social hierarchies.   For each layer of responsibility in the organization, there can be a specific type of "Hierarchy Agent" that fits that role.   In addition to the normal capability of a GeoGraph Agent, these agents have additional capabilities that allow for command and message passing to follow a "chain of command."   To support this, the simulation can show visualizations of these communication links in a variety of contexts, ranging from lines drawn between the members of the group, to group coloration, to tree views that show the hierarchy by group member name, command, and status. These displays are linked, so that selecting an agent in one display highlights the same agent in different displays.
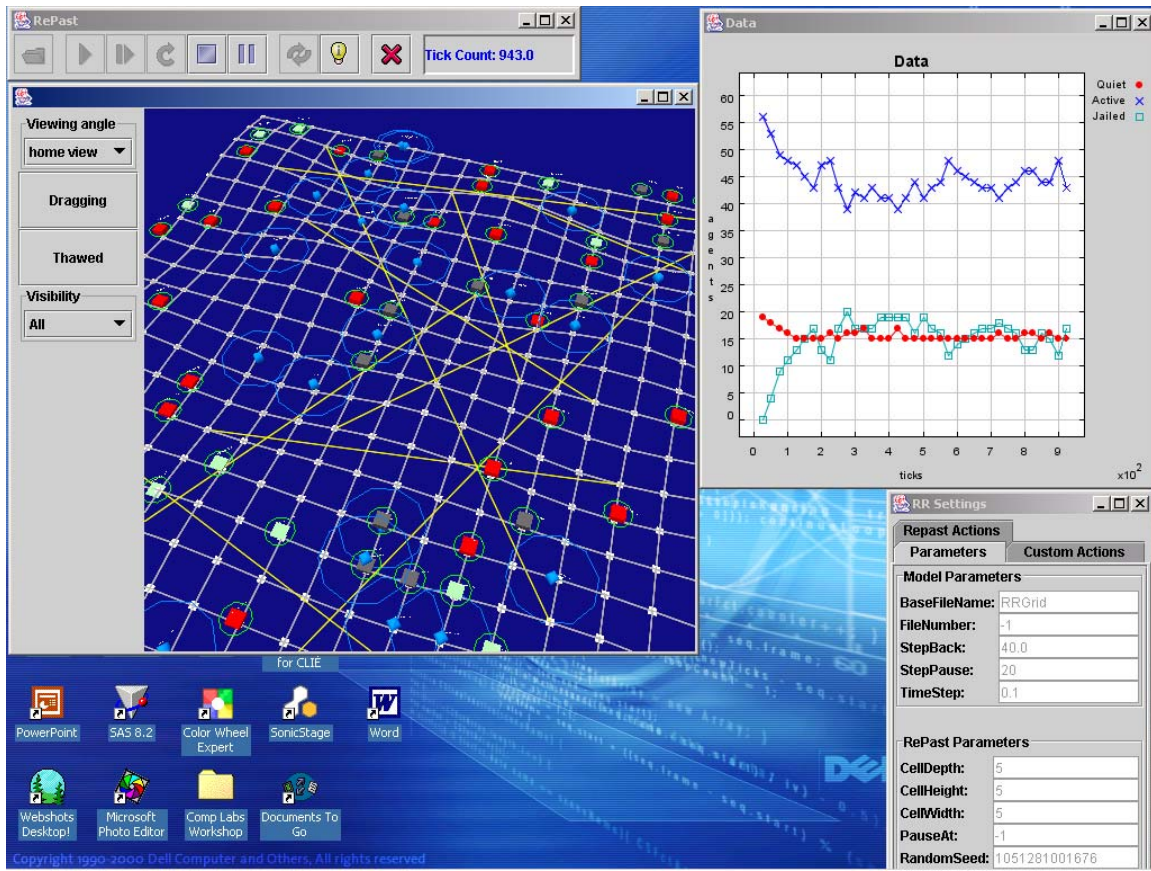
Figure 1: Rumors and Looting extensions to the grid-based Brookings Civil Violence model (Epstein et al. 2001). Red squares are looters, green squares are peaceful, gray squares are temporarily arrested; blue dots are peacekeepers; rings around agents show how far each can see. Yellow lines are shortcuts in the landscape.

The first practical implementation of this teams system has been to develop a model of competing "warlords" in an urban setting. Each warlord selects a "home base" to work from, and then sends his lieutenants forth to gather food from unoccupied nodes, to raid food from occupied nodes, to attack other agents, or to defend a node. The lieutenants in turn command their soldiers to gather food, deliver food, or attack a node. The warlords make their decisions based on the amount of food other warlords have and on the history of attacks by other warlords.

Although simple, this system illustrates the basic capabilities of a simulation that supports a command and control structure: Warlords can be designed to focus on the "strategic" picture; how to maximize their food stores and prestige among other warlords. Lieutenants are designed to take strategic level commands and convert them to a more limited set of tactical commands for the foot soldiers. The soldiers in turn are only concerned with handling the immediate task at hand.

As in any command and control hierarchy, the communication between agents is not perfect. Agents may not heed their superior. Communication between and agents and its superior may be spotty. The situation on the ground may not allow for an order to be

fulfilled. GeoGraph team models support this reality by having specified communication links between each individual, and control software in each agent that allows the agent to make decisions based on local information as well as on a remote order. This in turn allows for the study of command and control itself; observing how well the hierarchical system can perform a task under degraded conditions.
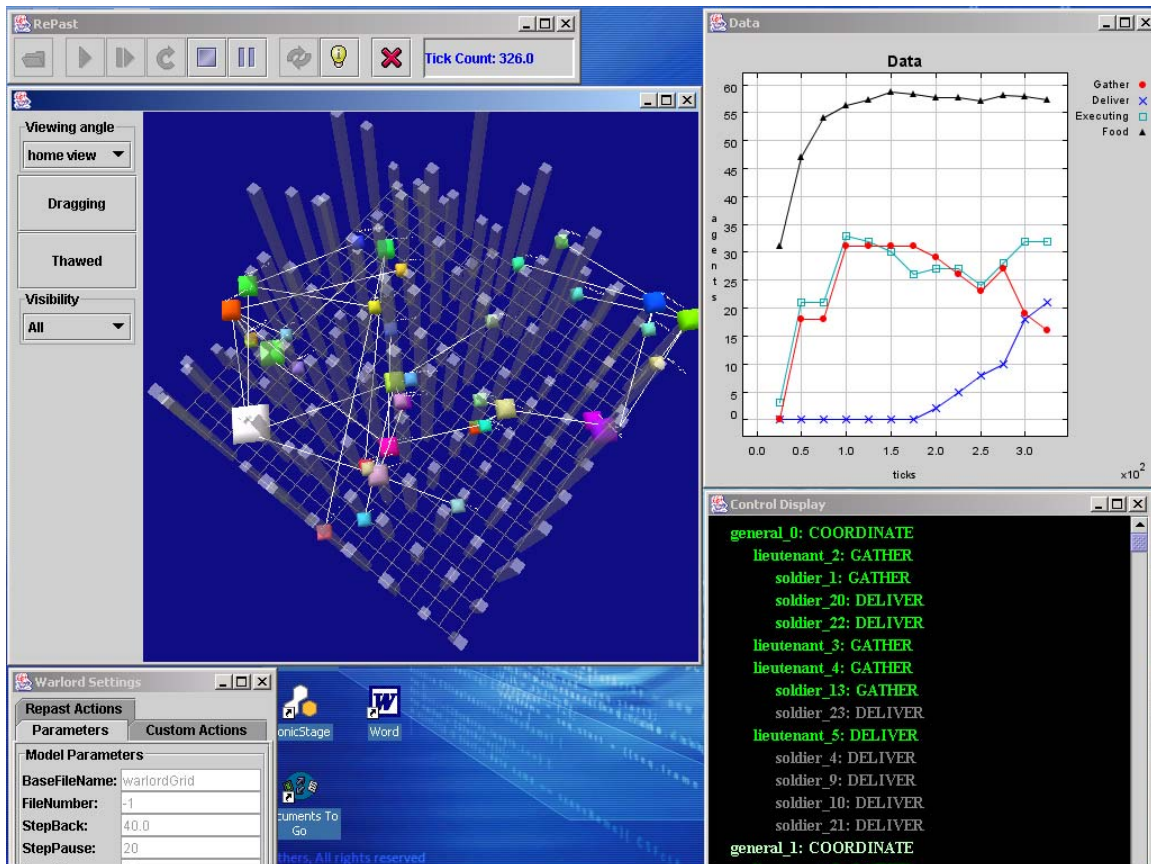

Figure 2: *Warlords, Terrorist Cells, or Military Units. Gray pillars are food or other resources to be looted or protected, targets of opportunity to be attacked, or other trouble to be addressed. In this example, agents are indigenous Warlord "Generals", Lieutenants, and Soldiers.*
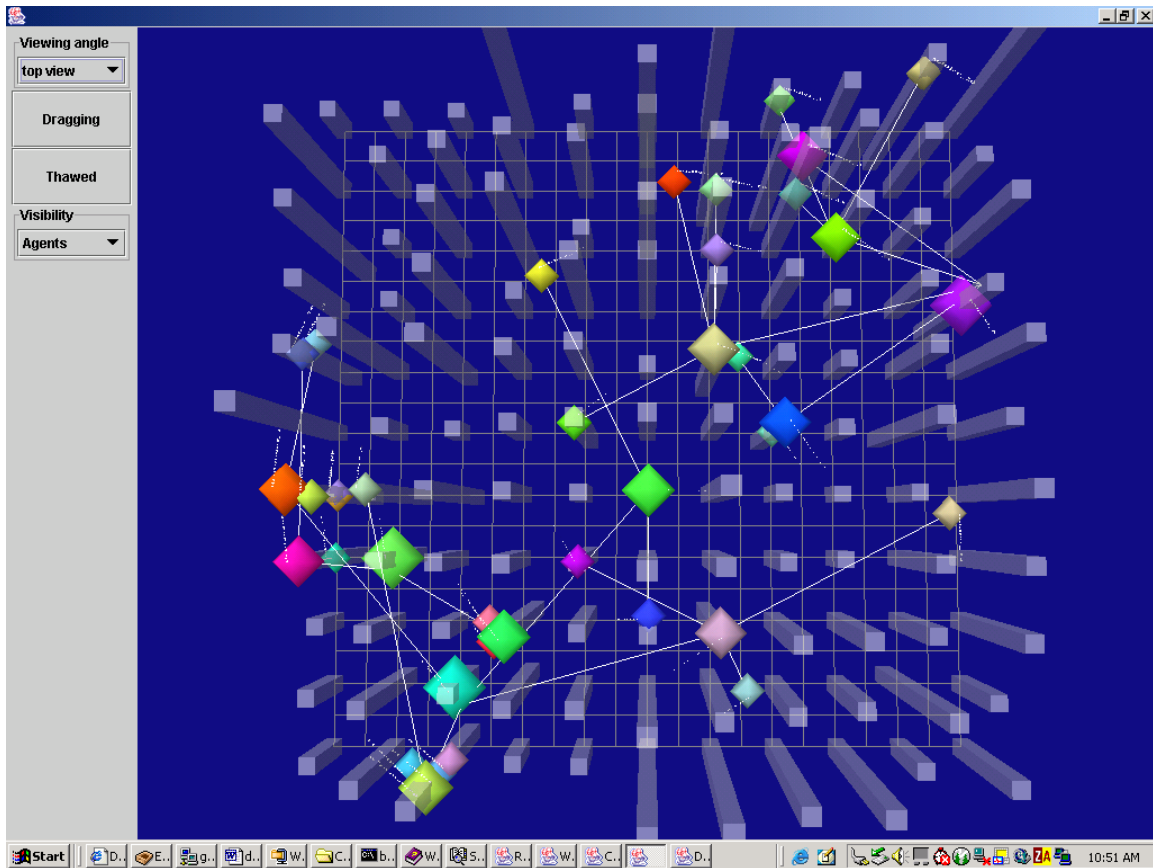
Figure 3:   *Full-screen top view of the main Warlords simulation window. This is a*
            dynamic simulation with agents moving around the landscape in order to address pillars of
            resources or targets.   Note the C3I lines of control connecting agents within each team.

GeoGraph Usage

GeoGraphs are designed from the ground up to handle the additional levels of complexity
involved in creating, viewing, and interacting with such hierarchical simulations.
GeoGraphs do this by breaking the creation and simulation process into three distinct
stages: Creation, Modification, and Simulation. XML files containing progressively
more sophisticated representations are initialized and then pipelined through the process,
until they are ready for the simulation to read them in and run. In this manner, the
complexity of the model's development is constrained to small, understandable steps.
For example, a simple population of generic agents is initially created through an
interactive tool. Later, that population of agents is modified and extended through the
use of subsequent interactive tools until the user has created a hierarchal network of
agents, each with its own tasks and responsibilities, where each has the capability to
move through either an abstract or a GIS-derived urban or regional landscape, and to
interact with other agents in the landscape.

Once the file is loaded into the simulation, the user can fly through the running
simulation, select individual agents to view their internal states, and view the interaction
of the agents with each other or with their environment by choosing which landscape they

wish to view through the use of dropdown menus. Finally, data from the simulation is displayed as charts or recorded to text files for further analysis.

Conclusions and Potential C3I Modeling Applications

Our GeoGraph tools for RePast provide a general purpose computational laboratory system that allows custom-tailored agents to sense and to respond to locational and social inputs within interesting organizational situations and geographic landscapes. This supports a broad field of study, ranging from urban and regional modeling, to ecological models, spatial evolutionary game theory, business practice simulations, robotic swarm testbeds, and mob behavior and control. Here we present a brief list of potential GeoGraph C3I modeling applications.

Optimal configuration of limited hierarchical organizations for mob control

One of the most challenging issues is how a small organized group such as police or soldiers can control a larger, disorganized group. This study proposes to examine multiple control hierarchies and agent responsibilities versus multiple potential mob conditions. Using genetic algorithms to determine the tasks for which task(s) each police agent is responsible and to determine the type and depth of the control hierarchy, test police organizations will be evaluated against a suite of mob conditions to determine the optimal control structures and strategies.

"Fog of War" or the effects of noise in control signals from remote locations versus local ground truth

The term "Fog of War" normally applies to situations where the combatants no longer have awareness beyond the immediate vicinity of their area of conflict. We have the capability to reproduce this effect in simulation by having a hierarchical group of agents attempt to perform a task that requires coordination between multiple remote agents. The study will selectively perturb the communication channels between the "implementer" agents performing the actual work, the midlevel "tactical" agents responsible for coordination and the high level "strategic" agents responsible for large-scale command and control issues. Net measures of the speed and level of completion of the task can then be used as the standard against which differing levels, locations, and types of signal noise can be judged.

Once proven, this technique can be applied to progressively more complex scenarios, leading up to "battles" between multiple hierarchies. In this case, different initial communication configurations could be applied to study the downstream effect between symmetric or asymmetric forces.

Determining the "breaking point" in social hierarchies, and the development of resilient hierarchies

Social hierarchies such as businesses or military chains of command can only perform correctly if they are functionally intact. This study would experimentally determine the areas within these hierarchies that are most sensitive to disruption. For example, if it is determined that disruption of the top of the hierarchy results in the largest effects, are there mechanisms that allow for a more effective distribution of tasks such that the hierarchy is more resilient, such as a "cell" structure? If so, are there tradeoffs with respect to responsiveness or other efficiencies? What in turn are the breaking points of these structures? See DeCanio et al. (2000) for genetic algorithm explorations of similar performance tradeoffs in the design of organizational networks.

Robotic Swarm testbed

Remotely Operated Vehicles (ROVs) are the beginning of a fundamental shift away from direct human involvement on the battlefield and in other dangerous situations. As in human interaction, robotic system performance will benefit greatly from organized group behavior. However, it should be understood that the same sorts of social and physical structures that are useful for human-centric organizations are not necessarily what is optimal for a robotic "swarm." For example, people fly in formations so that pilots need not be overly concerned with the position of their wingmen. However, a group of autonomous flying vehicles has the capability of flying in hyper-complex "flocks" that would be impossible for any organic creature to reproduce. Additionally, groups of autonomous air, land and sea vehicles can perform together more tightly than traditional arrangements, leading to a swarm "vehicle" that is a synthesis of its component parts.

There are two fundamental questions that must be answered about this new technology: First, what configurations or groupings are in fact the optimal, and second, how do humans interact with these systems? The advantage of the GeoGraphs system is that it can bridge both questions, allowing for the development of unique groupings and control systems while also allowing test subjects to interact with the proposed system in a real-time simulation.

References

Animation Artist (2002)
"Helms Deep" battle in *The Lord of the Rings* movie, documented online at
http://www.animationartist.com/2002/07_jul/features/lessons.htm

DeCanio, Stephen J., Catherine Dibble, and Keyvan Amir-Atefi (2000)
The Importance of Organizational Structure for the Adoption of Innovations
Management Science, October 2000, 46(10): 1285-1299

Durlauf, Steven N. (2003)
"Groups, Social Influences and Inequality: A Memberships Theory Perspective on Poverty Traps,"
Santa Fe Institute Working Paper 03-03-020, available online at
http://www.santafe.edu/sfi/publications/Working-Papers/03-03-020.pdf

Electronic Arts (2003)
Battlefield 1942 game, http://www.eagames.com/official/battlefield1942/home.jsp

Epstein, Joshua M.; John D. Steinbruner; Miles T. Parker (2001)
"Modeling Civil Violence: An Agent-Based Computational Approach"
Brookings Institution, Center on Social and Economic Dynamics, Working Paper No. 20,
http://www.brookings.org/dybdocroot/es/dynamics/papers/cviolence/cviolence.pdf

Srbljinovic, Armano; Drazen Penzar; Petra Rodik; Kruno Kardov (2003)
"An Agent-Based Model of Ethnic Mobilisation"
Journal of Artificial Societies and Social Simulation 6(1), available online at
http://jasss.soc.surrey.ac.uk/6/1/1.html

University of Chicago Social Science Research Computing (2000)
http://repast.sourceforge.net