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# Computational Models of Group Dynamics for National and International Security Applications

**Defense Threat Reduction Agency Nuclear Technologies Directorate**


**ABSTRACT**

**SUBJECT TERMS**

<table>
<thead>
<tr>
<th>SECURITY CLASSIFICATION OF:</th>
<th>17. LIMITATION OF ABSTRACT</th>
<th>18. NUMBER OF PAGES</th>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
</tr>
</thead>
<tbody>
<tr>
<td>report</td>
<td>UU</td>
<td>19</td>
<td></td>
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<tr>
<td>abstract</td>
<td>unclassified</td>
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Computational Models of Group Dynamics for National and International Security Applications

Mihaela D. Quirk, Ph.D.

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Nuclear Technologies Directorate

The views expressed herein are those of the author and do not necessarily reflect the official policy or position of the Defense Threat Reduction Agency, the Department of Defense, or the United States Government.
Overview

Classes of problems
Algorithmic representation of social dynamics
Identify and evaluate “soft metrics”

Directions:
- Mathematical models of strategic interactions
- Models for soft metrics
- Formalism for scenario specification
- Validation and technological challenges
- Knowledge bases and model refinement

Concluding remarks
Introduction: classes of problems

Aim: a methodology to build a computational framework to capture individual and group behavior.

Dimensions and attributes:
- CBRNE threats: veracity
- Context: geopolitical, economic
- Adversary: organization
- Organization: social, cultural, religious, economic
Strategic interactions/group dynamics

- Classical models:
  - Agent-based models
  - Game theory
- Social sciences, anthropology: models and computational approaches
- Policy
- Political analyses
- Goal: develop a suite of formally specified and implementable computational models of strategic interactions
- Emphasis on the formal certifiability and scalability
Mathematicians must justify their existence

“So far as the law of mathematics refer to reality they are not certain; and so far as they are certain, they don’t refer to reality.” Albert Einstein, 1951

“Everything should be made as simple as possible, but not simpler.”

Albert Einstein
Mathematical models of strategic interactions

- Priorities: the emergence of social hierarchies, the dynamics of opinions, and the emergence of leadership in social structures.
- The models will be developed in a quantitative theory of social dynamics.
- Theoretical analysis relies on techniques such as scaling, asymptotic analysis, boundary layer analysis, and extreme value statistics.
- Improved frequent patterns algorithm used to detect abnormal behaviors
- Large complex networks (CN) which have computationally intractable properties of interest
Mathematical models of strategic interactions

- Graph representation of the topology of agents’ states and an update schedule capturing causal dependencies among agents.
- Measures and techniques for dynamic graph algorithms

- AGENT-BASED MODELS
- GAME THEORY
- STATISTICS
- POSSIBLITY/EVIDENCE/BELIEF/PLAUSIBILITY
Mathematical models of soft metrics

• Motivation and intent
• In a game-theoretical context: reflection of disparities among utilities
• Economic studies of long term effects
• Setting: multi-valued logic, possibility and probability measures
Implementation and validation

- Social sciences, anthropology,
- Situation theory, the theory of moves,
- In-group/out-group theory, decision theory, game theory, etc.
- Example: honor-based societies.
- Implement a prototype of formal specifications for scenarios and courses of actions
- “Universal scenario generator” that captures the most salient features of a multi-agent simulation.
Implementation and validation

• Focus on efficient representation and management of contexts
• Build a knowledge base and enhance existing models of group behavior, terrorism, infrastructures,
• Design predictive methodologies – yes, it is possible!
Validation and technological challenges

• Validation permeates the work
• Soft metrics devised for both defenders and adversaries.
• Select a relevant set of soft metrics
• Classes of decision agents: SME, decision makers, people.
• Technological challenges: heterogeneous database management systems, so as to resolve both syntactic and semantic conflicts.
• Research performance and functionality improvements to ensure scalability of large agent-based simulations of CN
Formalism for scenario specification

- A test for the success of the method: the extent to which it can represent theoretical frameworks such as: game theory, theory of moves to model international relations, models of bounded rationality (for computational efficiency), and models of collective action.

- A formalism for specification and representation of scenarios of use for multi-agent simulations with natural language semantics (situation theory) and

- Formal verification
High level overview

This chart was used to rank power substations in a big city – thus it represents the L.M. H levels for population affected by power loss.

- Models of organizational cultures
- Models of honor-based societies
- Indicators of likelihood of attacks
  - Soft metrics module

Software Integration

- Data mining module
- Data mining module

Knowledge extraction and fusion
Agent-based models

Simon’s Bounded Rationality:

Agent-based models, following Simon (1982), also assume Bounded Rationality. “Indeed, in the absence of Turing machine (universal calculator), it is difficult not to.”

Epstein (2006) reflects:

“One wonders how the core concerns and history of economics would have developed if, instead of being inspired by continuum physics ... blissfully unconsidered as it is with effective computability — it had been founded on Turing. Finitistic issues of computability, learnability, attainment of equilibrium (rather than mere existence), problem complexity, and undecidability, would then have been central from the start. Their foundational importance is only now being recognized.”
Agent-based models

Epstein notes on the virtues of boundedly rational agents...

“As Duncan Foley summarizes:
`The theory of computability and computational complexity suggest that there are two inherent limitations to the rational choice paradigm.
• One limitation stems from the possibility that the agent’s problem is in fact undecidable, so that no computational procedure exists which for all inputs will give her the needed answer in finite time.
• A second limitation is posed by computational complexity in that even if her problem is decidable, the computational cost of solving it may in many situations be so large as to overwhelm any possible gains from the optimal choice of action’ (Albin 1998)”
Game theory, Bayesian statistics

- Game theory: an analysis tool, not always a prediction tool
- Probabilities: too restrictive, hence misused
- Learning-based models: promising yet there is no training data
An integrated framework

Computational Models of Group Dynamics
Application: Networks of Proliferants
Michelle Quirk, D-4

Los Alamos National Laboratory
Unclassified Report LA-UR-05-4898

Milestones
Select and validate relevant indicators (soft metrics)
Study: past events and impact of future events

Quantify Intent

Validate
Hierarchical societies

Validate/Predict

Cultures propitious to proliferation (Agent-based models)

Validate

Milestones

Dry run

Dry run

Milestones

Multiple players/coalitions
Multiple objectives
Fuzzy goal/objectives
Utility-based agents

Multiple players/coalitions
Multiple objectives
Fuzzy goal/objectives
Utility-based agents

Expert System
for Efficient operational plans

Simple models of proliferation

Intelligent agents for strategic interactions

Game theory

Drama theory

Milestones

Complex adaptive systems for specific nuclear threat cases

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18
Concluding remarks

• The problem dictates the method!
• Failures are unthinkable.