Social Simulation for Non-Hackers

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Abstract. Computer simulation is a powerful tool for social scientists, but popular platforms require representing the semantics of the model being simulated in computer code, leading to models that are either expensive to construct, inefficient, or inaccurate. We introduce SCAMP (Social Causality using Agents with Multiple Perspectives), a social simulator that uses stigmergy to execute models that are written as concept maps and spreadsheets, without requiring any programming expertise on the part of the modeler. This Repast-based framework has been extensively exercised in the DARPA Ground Truth program to generate realistic social data for analysis by social scientists.

Keywords: Social simulation, Stigmergy, Polyagent, Repast.

1 Introduction

Social simulation is a two-edged sword. On the one hand, computer simulation of social scenarios opens new research perspectives. On the other, computer programming and the social sciences involve complementary skills that can be difficult to integrate. There are three approaches to constructing a social simulation, each with drawbacks:

1. An expert programmer and a social scientist can work closely together to build the model. This approach is expensive and poses challenges of knowledge acquisition analogous to those experienced in the early days of expert systems.
2. The social scientist can learn some programming, typically in a platform such as NetLogo, and program the model personally. While some social scientists have commendably and creditably pursued this path, the effort needed to learn advanced programming idioms and testing disciplines is onerous and distracts the researcher from the social science aspects of the problem.
3. An experienced programmer may construct the model based on an intuitive understanding of the problem, again risking inaccuracy, this time by missing the social and psychological nuances of the scenario.

SCAMP (Social Causality using Agents with Multiple Perspectives) is a framework constructed in Repast [1] whose models are external to the computer code, rather than embedded in it. Social scientists construct these models using concept maps, a drawing program, and a spreadsheet, model.xlsx. The key to moving the model outside of the code is stigmergy, inspired by social insects [8] but well documented in human systems as well [17], and a central technique of "swarm intelligence" [25]. Swarming agents move over these external models, coordinating their actions by leaving and sensing changes to them. While stigmergic techniques are common for modeling subcognitive behaviors, in SCAMP these techniques capture sophisticated psychological and social features [19], including preferential choice, goal-based reasoning, dynamic social affiliations that modulate agent preferences, non-deterministic decision-making, mental simulation, and bounded rationality. SCAMP's combination of event-driven causality, geospatial interactions, goal-based reasoning, and social networks draws on our earlier work on multi-perspective modeling [4,21] .

We[1] developed SCAMP for the DARPA Ground Truth program [26]. It was one of four simulators that generated socially realistic data that social scientists used to test methods for extracting causality from data. The known causal structure of each simulation then allowed evaluation of the analysis methods. A forthcoming issue of *Computational and Mathematical Organization Theory (CMOT)* will document each facet of the overall program. SCAMP's model represented a civil conflict inspired by recent events in Syria, and was constructed entirely by professional geopolitical analysts with no programming experience, demonstrating the point of this paper.

Section 2 describes the SCAMP stigmergic architecture, while subsequent sections document the various components of the model that social scientists construct, using a toy model for clarity: definitions of the social groups active in the scenario (Section 3), a causal event graph (CEG) (Section 4), the geospatial context of the scenario (Section 5), a set of hierarchical graph networks (HGNs) (Section 6), and discontinuous changes to agents (Section 7). SCAMP exposes a very large parameter space to users, but a default mechanism (not discussed here for lack of space) reduces the complexity of bringing up a new model. Section 8 describes the data produced by SCAMP and summarizes the full conflict model used in Ground Truth, and Section 9 concludes.

2 The SCAMP Architecture[2]

A SCAMP agent repeatedly chooses among accessible alternatives, based on their features and its own preferences. Alternatives are nodes in a graph and are accessible if they are adjacent to an agent's current location. The central graph is a directed graph of the *types of events* in which an agent may participate, and the outgoing edges from one event type indicate others that an agent could coherently choose next. Thus every path through this graph is a valid *narrative* about the domain. Some events are geospatial requiring an agent to move spatially, and lead the agent to a *geospatial lattice*, on which agents can move from one location to any adjacent one.

Each agent has a home group. The groups in our conflict scenario are an oppressive *Government*, neutral *People*, an *Armed Opposition* seeking to replace the government with democratic institutions, *Violent Extremists* with strong ideological motives, *Relief Agencies*, and the *Military*, initially affiliated with the Government.

[1] In addition to the author, the SCAMP team included J.A. Morell of 4.699 LLC; L. Sappelsa of ANSER LLC; J. Greanya and S. Nadella of Wright State Research Institute (now Parallax Advanced Research). Kathleen Carley of CMU consulted on social network issues.

[2] An ODD protocol for SCAMP is available [14].

Each node that an agent can choose carries a vector in an underlying *feature space* with three kinds of features.

Some features describe *intrinsic characteristics* of the choice, in [-1, 1]. A geospatial node might be characterized by its terrain and gradient, while an event is marked by its impact on the physical, psychological, and economic wellbeing of participating agents.

Some features summarize the *recent presence* of agents by group (one feature per group), in [0, 1]. Agents augment these features as they traverse the graph, like insects depositing pheromones. Like pheromones, presence features evaporate over time.

Some features describe the *urgency* of a node for achieving each group's goals, in [0, 1]. Urgency features vary over time, depending on the state of the system.

Each group has a baseline set of scalar *preferences* in [-1, 1] over the feature space. When agents are initialized, they draw their preferences from distributions whose means are defined by their group's baseline.

At any moment, an agent is participating in one event and has a set of accessible alternatives. To make its choice, it computes the cosine distance between its preference vector and the feature vector of each accessible alternative, exponentiates these distances (to make them positive), and normalizes them to form a roulette wheel. This fundamentally stochastic decision process recognizes recent research in decision making [16] showing that the basis for human choice is not deterministic preference, but a probability *Pr*(A, B) of choosing A over B. SCAMP is heavily influenced by the decision field model [2] of stochastic decision theory. Modelers can adjust the degree of determinism by exponentiating the roulette segments and renormalizing. An exponent of 0 makes all segments equal, yielding random choice, while an exponent larger than 1 biases the choice toward the strongest alternative.

People make decisions using mental simulations [12,13], a mental rehearsal of possible story trajectories to decide how to proceed. SCAMP implements this insight by representing each active entity as a set of agents, a *polyagent* [23]. One agent, the *avatar*, is persistent, and manages a population of transient *ghosts* that simulate its possible future courses of action to a limited horizon. Each ghost explores one possible future, using preferences and features. As it moves, it augments the presence features for the groups with which its avatar is affiliated. Collectively, the ghosts develop a field over alternative trajectories. To simulate a scenario, the avatar selects from its alternatives, weighting its choice by the presence features on each accessible alternative.

SCAMP's accessibility to non-programmers is evident by comparing it with the other three social simulations in the Ground Truth program, each using a different agent-based social modeling technology. In the huge space of social simulations (e.g., [3,5-7]), these three offer a particularly apt comparison because they were all constructed for the same purpose: generate realistic social data to test analysis methods in the social sciences. SCAMP's social expressivity is comparable to them.

George Mason University, Tulane University, and the University of Buffalo produced a model of Urban Life [36] in the MASON modeling toolkit [15] and its GeoMASON extension [35]. Numerous aspects of the model are generated algorithmically, including the agent population, the geospatial map, and the social network among the agents. The system provides a pre-defined set of triggers (sensitive to both internal and external factors), behaviors to which they lead, actions that make up behaviors, and goals that determine when actions stop. Defining new triggers, behaviors, actions, and goals requires programming, but a drag-and-drop interface allows modelers to assemble and parameterize these components to define a scenario..

Raytheon BBN produced ACCESS [28] in the Repast framework. The model highlights the interactions among individual agents, groups to which they belong, and the overall population or "world." ACCESS models space as a list of locations, but without orientation or distances, so there is no "map" for a user to enter, and the individual behaviors are determined by equations embedded in the code.

USC ISI produced a disaster world [27] in their PsychSim social simulation framework. Agents are driven by partially observable Markov decision processes (POMDPs) and can reason recursively about one another. PsychSim provides one interface that allows social scientists to create simulation models directly, and another allowing them to manipulate the parameters governing the simulation. However, both interfaces abstract over the full complexity of a PsychSim model (e.g., limiting the types of probability distributions and reward functions), so specifying arbitrary probability and utility models requires sufficient programming ability to use the PsychSim API.

GMU and ISI both support non-programmers who wish to modify a scenario, but still require programmers to modify details, and introduce proprietary interfaces. SCAMP allows non-programmers to define new groups, actions, and goals and their relations, using tools with which they may already be familiar.

3 Group Definitions

The modeler defines the model's groups in the *groups* tab of model.xlsx. SCAMP also supports an impersonal *Environment* group whose agents generate background events not modeled in detail, such as drought and economic collapse.

Agents have a home group, but can affiliate with other groups, if their preference vector is close enough to the baseline vector of those groups.

The user provides each group with an ID number, a descriptive name, and a short abbreviation used in defining other parameters that refer to the group (in our scenario, Gov, Peo, AO, VE, RA, Mil, and Env). For each group, the user defines

- A baseline *preference vector* in $[-1, 1]^n$, specifying the group's preference for each feature in the n-dimensional feature space. -1 indicates that the group's agents are strongly repelled from the feature; +1 indicates that they are strongly attracted to it.
- *Starting locations* in geospace where agents in the group should begin.
- Overall *speed* of geospatial movement of agents in the group.
- Parameters governing how agents in a group *affiliate* with other agents:
  - Do group members affiliate with other groups?
  - Does the group accept affiliations from agents in other groups, and if so, how close must they be to its baseline preference vector? A high threshold (close to 1) characterizes an exclusive group, while a low one (close to 0) marks an open one.
- How much *variation* is applied when sampling individual agents from the group baseline? Groups can range from highly homogeneous group to more diverse.
- Does the group reason strategically by using a *hierarchical goal network* (HGN)?

- *How many agents* in the group should SCAMP initially generate?

Some execution parameters governing the polyagent simulation can also vary by group, including how many ghosts the avatar sends out, how far they explore into the future, and how many iterations they perform before reporting. In our work so far, these have been set by system developers rather than by modelers, but an area of future work is deriving them from variables that are meaningful to modelers.

4 Causal Event Graph

SCAMP's central modeling construct is the Causal Event Graph (CEG), a directed graph whose nodes represent different types of events, based on our previous work on narrative spaces [24,30]. The CEG is inspired by narrative graphs in common use in intelligence analysis [9], cyber security planning [33], discrete event simulation [31], analysis of social disagreement [32], computer games [14] and the study of natural-language texts [29], among other applications. In all these formalisms,

- Nodes are event types, not the variables used in other causal formalisms.
- A directed edge between two nodes indicates a causal relation between event types.
- Every trajectory through the graph represents a possible narrative.
- The graph summarizes many possible narratives.

Most event types make sense only for members of some groups. Those groups "have agency" for those events, and agents can choose to participate in events for which their groups (home or affiliated) have agency. As a result, the CEG is a collection of group-specific subgraphs, though some event types support participation by multiple groups. In particular, the CEG has a single START node and a single STOP node for which all groups have agency. Fig. 1 illustrates a simple CEG for a well-known children's rhyme:

> Little Miss Muffet sat on a tuffet / eating her curds and whey.
> Along came a spider and sat down beside her / and frightened Miss Muffet away.

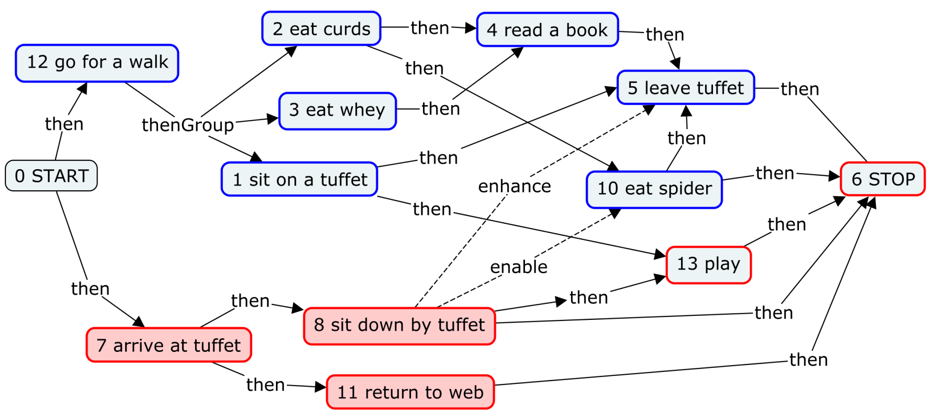

Fig. 1. CEG for Little Miss Muffet

Alternative paths through the CEG generate not only the canonical version of the poem, but a version that ends, “and she ate that too,” another that ends, “and they began to play,” and others as well.

An *event* in SCAMP occurs when agents participate in an event type over a continuous period. Multiple events of the same type can occur during a simulation run.

Time in SCAMP is an integer, representing units of domain time (hour, day, week, …) appropriate to the domain. Each event type has a transit time (how long an agent participates in the event before selecting another) and an effect time (how long the event’s presence features remember the agent’s participation). The modeler specifies nominal values for these variables in the *events* tab of models.xlsx based on each event’s semantics. SCAMP samples the actual times for each participating agent from an exponential distribution, reflecting interarrival times of a Poisson process.

CEGs have two kinds of edges.

Agency edges (solid arrows in Fig. 1) capture an agent’s possible choices. These reflect the subjective choices made by the modeler. For example, in Fig. 1, the modeler has decided that eating a spider (node 10) only makes sense after eating curds (another solid food), not after eating (actually, drinking) the liquid whey, while either 2 or 3 can be followed by reading a book.

The agency edges labeled “then” connect an antecedent event to a single successor, while the “thenGroup” multiedge specifies a group of events that execute concurrently. Such a group of events behaves like a single event with the following constraints:

1. It can have at most one event type that requires geospatial movement (it makes sense for an agent to walk and chew gum, but not to walk from A to B while driving from A to C).
2. The transit time for the set of events is the maximum of the events in the group.
3. The set of event types accessible to the agent after completing the group is the union of the successor events of the event types in the group. (Thus in this case, the agent may well choose to eat the spider after eating whey, but the causal precondition is eating the curds, which will also be complete.)

Agency edges define the narrative trajectories available to agents. Every event type must fall on at least one trajectory from START to STOP, subject to two restrictions and one exception. The restrictions are:

1. Each agency edge must define a coherent snippet of narrative, so that it makes sense for an agent on the first event type to participate subsequently in the second one. As a result, any path of agency edges through the CEG is a meaningful narrative.
2. An agency edge can only join two events if the same group has agency for both.

The exception is that the agent change system described in Section 7 can move agents discontinuously across the CEG.

Influence edges (dashed edges in Fig. 1) capture causal influences among event types between which agents do not move directly (for example, an impersonal Environment event type such as a drought causing People agents to move from the countryside into the city). The effect of an influence edge depends on the level of participation in the influencing event type (that is, the total presence feature on the influencing node in the CEG). An influence edge adjusts the segments in the roulette wheel corresponding to the influenced event type, based on the total presence features on the influencing event type (that is, the degree of recent participation in the influencing event).

The hard influences *prevent* and *enable* probabilistically exclude or include an event type's segment in the roulette, depending on the total presence features on the influencing event. Soft influence edges, *enhance* and *inhibit*, adjust the size of the influenced event's segment, based on the influencer's presence features.

Modelers construct the CEG, with its events, agency edges, and influence edges, using CMapTools, a concept mapping tool [11]. The *events* tab in model.xlsx records

- The groups that have *agency* for the event type;
- The values in [-1, 1] of the *intrinsic features* in the event type's feature vector, for each group that has agency for the event type;
- The nominal values of the *transit time and effect time* for the event type;
- For event types that involve geospatial movement, a *destination* in geospace for each group that has agency in the event type;
- Whether or not the event type can be immediately *repeated*.

5 Geospatial Context

Some event types (e.g., "go to the post office") require physical movement. When an agent participates in such an event type, it drops into geospace (a hexagonal lattice) and moves through it until it reaches its destination, at which point its participation in the event ends, and it chooses another event type. The transit time for a geospatial event depends on the length of the agent's geospatial journey. Participation in an event moves an agent through time. Geospatial events also move agents through space.

Fig. 2 shows successive steps in Miss Muffet's movement, starting with her initial location (1). Superimposed on the terrain map are her home (magenta, lower left), the tuffet (green, center), and the spider web (yellow, upper right). For example, event 12 "go for a walk" has a destination of the tuffet, so to complete this event, Miss Muffet must drop into geospace (3), move from her current location at home to the tuffet (4), and then return to the event node (5).

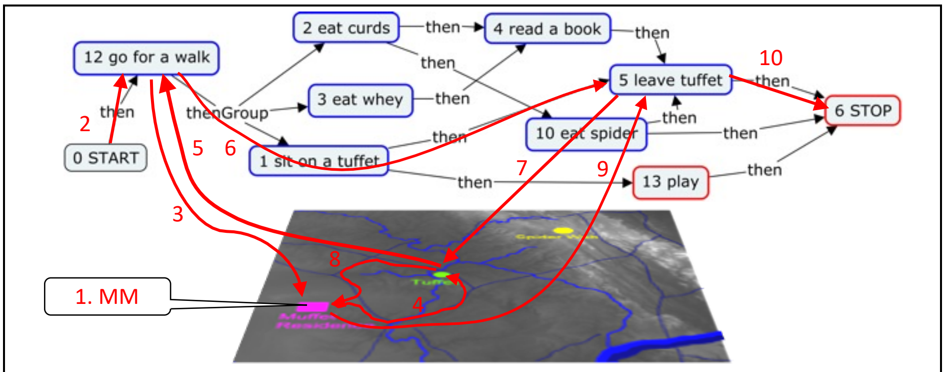

Fig. 2. Agent movement between CEG and Geospace

Hexagonal tiles in geospace, like events in event space, have feature vectors. Intrinsic features reflect the gradient of the underlying terrain. Presence features record the recent presence of agents of different groups. Urgency features record the proximity of the tile to the destination for each group, while the wellbeing features record the gradient of the local terrain. The transit time for an agent to move through one hex depends on the movement speed defined for its group, and the local terrain (it takes longer to cross water than to travel on land).

Modelers construct the geospatial model using the GIMP drawing program [35], which represents an image as a stack of layers. A required *heightmap* layer (the grayscale background in Fig. 2) shows the local elevation over the region of the map, while distinctive features (such as rivers, road networks, cities, and national boundaries) are distinguished by the layer in which they are represented and the colors used to depict them. The *regions* tab of model.xlsx identifies regions that can be specified as initial locations for groups and as destinations for events. For each region, it specifies

- An *identifier* (e.g., R003) used to refer to the region in the *events* and *groups* tabs
- A *descriptive name* for the region (e.g., "rivers," "capital city")
- The name of the GIMP *layer* containing the region
- The GIMP name of the *color* used to represent the regions
- The region's *falloff*, indicating how far away it is detectable by agents in geospace (falloff = 1 means that a gradient leading to the region is defined everywhere, while 0 means that an agent must stumble across the region before knowing where it is)
- A *speed modifier* for each group, indicating how that region impacts speed of agents of that group in moving across the region.

SCAMP reads the GIMP file saved in the OpenRaster file format. Mechanisms for movement of agents through geospace guided by polyagents in SCAMP are refined from methods we demonstrated in earlier projects [18,22].

The modeler determines for each event type whether it involves geospatial movement. In our conflict model, of 467 event types, 360 do not involve movement. In addition, while the transit time of a geospatial event is determined dynamically as the agent moves through geospace, the modeler can define a nominal transit time to be used if the geospatial processing is turned off (by a Repast parameter). Thus SCAMP readily accommodates non-geospatial scenarios.

6 Hierarchical Goal Networks

Human decisions reflect not only the immediate characteristics of available alternatives, but also the actors' long-range goals. SCAMP supports a hierarchical goal network (HGN) [34] for each group, capturing the group's high-level goal and its decomposition into subgoals. The lowest level subgoals are "zipped" to events in the CEG that either support or block them [20]. Fig. 3 shows an HGN for Miss Muffet, zipped to events in Fig. 1. Agents do not move over the HGN as they do over the CEG and geospatial lattice, but the HGN modulates their movement in event space.

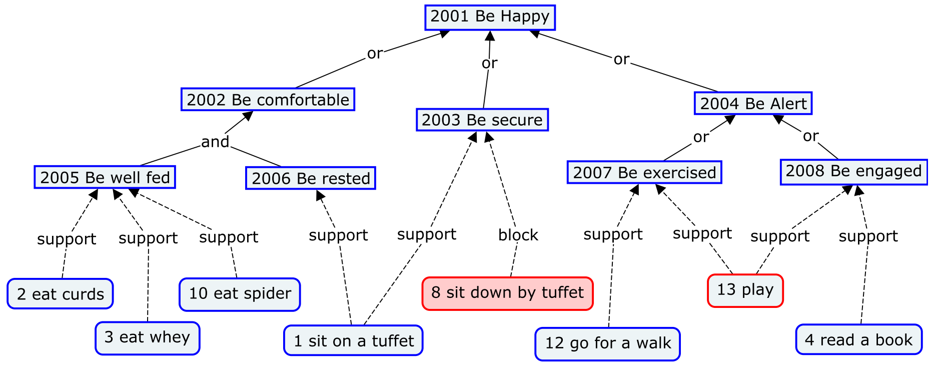

Fig. 3. HGN for Miss Muffet

Each goal maintains two scalar variables: its *satisfaction*, and its *urgency*. Satisfaction accumulates through a sigmoid, so it saturates at 1. At the root, `urgency` = 1 – `satisfaction`. The root determines its satisfaction by querying its subgoals recursively. Satisfaction propagates upward through *or* relations as the maximum of the satisfaction levels of the subgoals, and through *and* relations as the minimum. The lowest-level subgoals determine their satisfaction from the presence features of events in the CEG. Once the root goal knows its satisfaction, it propagates its urgency to its subgoals. The urgency of a higher-level goal is passed directly to subgoals that support it via *and*. Subgoals joined by an *or* subtract their own urgency from that of their parent goal. This process is inspired by quality in TÆMS [10], as implemented in our earlier work [20].

Satisfaction and urgency are thus driven by agent participation (reflected in presence features) in CEG events zipped to the HGN. The presence features on CEG events determine satisfaction of leaf subgoals, while urgency on those subgoals modifies the urgency features of events zipped to them. The HGN converts agent presence on events in the CEG into the urgency of those events for the strategic objectives of each group.

An event for which one group has agency can change the satisfaction of goals of other groups, and also respond to the urgency levels in other HGNs, if it is zipped to subgoals in those HGNs. As a result, agents can modulate their decisions by the desire to advance or hinder the goals of other groups.

Domain experts capture HGNs in CMapTools. The HGNs and the zip relations can be included in the same CMap file containing the CEG. It is also possible to generate separate HGNs and capture the zips between events and leaf-level subgoals in the *zips* tab of model.xlsx.

7 Agent Changes

Realistic modeling requires that agents change over time. In SCAMP, some changes are continuous. For instance: 1) Each event has an impact on an agent's emotional, physical, and economic well-being, and an agent's preference for these features changes depending on its current state in each of these dimensions. 2) As agents meet other agents, either by participating with them in the same events or by meeting them in geospace, they influence one another's preferences.

But some realistic agent changes are discontinuous. Agents should be able to 1) enter and leave the simulation as it runs (for example, through influx of new foreign fighters, or death in combat); 2) change group membership (not just side affiliations), either voluntarily as a result of interactions with other agents, or involuntarily as a result of abduction and forced indoctrination; 3) change location discontinuously (for example, when protestors injured in a street protest are moved to a hospital); or 4) suspend and resume involvement in the scenario (for example, by being taken prisoner and then later released). The *groupChanges* tab of model.xlsx provides a powerful facility for discontinuous changes. It allows the modeler to specify

- The event type or geospatial location that *triggers* the change, when an agent enters it;
- The *maximum number* of affected agents;
- The before-and-after *home group* of affected agents;
- The before-and-after *location* (either in event space or geospace) of affected agents;
- If the transition *depends on the presence of agents* of some group at some location, the groups and locations involved;
- The *probability* that the change will actually happen if triggered;
- *Groups that increase (promoters) or hinder (blockers)* the probability of the transition, and where they must be located to have this effect.

To enable birth and death of agents, SCAMP recognizes the pseudo-group Guf (named for the repository of souls in Jewish mysticism). An agent that changes from Guf to one of the regular groups is born at that point, while one that changes from a regular group to Guf is removed from the simulation.

To enable suspension of agents, SCAMP supports pseudo-events of the form L*nnn* (for "Limbo"). If a rule moves an agent from a CEG node to a Limbo node, the agent ceases to participate in the simulation until execution of another rule moves it from the Limbo node back to some CEG node.

8 SCAMP's Data

SCAMP uses Repast's user interface to display the total presence pheromone on each CEG node and geospatial hex and the satisfaction on each HGN goal in real time, but it also generates several logs that can be analyzed after a run and compared across different parameter settings. These include:

- *Agent state* over time, including event participation, group affiliations, physical location, preference vector, meetings with other agents, group membership and location changes, and emergent social networks
- The number and total length of agents' *pairwise meetings* on events and in geospace
- Presence pheromone *entropy* over events, by group and total, over time
- The *strength of influence edges* over time

- The *satisfaction level* at the root of each group's HGN over time.

From these logs, we can construct answers to many questions that an interviewer might ask research subjects in a real scenario. Here are some examples that we answered.

- What were you doing on a given date?
- What was the last thing you were doing before your present activity?
- What other options did you consider at that time?
- What influenced your choice of this option?
- What options are you considering next, and how would you prioritize them?
- Whom have you met recently?
- How strong is your relation to those people?
- How satisfied are you with your achievement of your objectives?
- How happy are you about your current economic, physical, psychological state?
- How sympathetic are you to a specific group (e.g., the government)?

Additional logs of internal SCAMP variables can easily be added.

The full conflict model has a CEG with 467 event types involving six groups (Fig. 4). The HGNs for these groups have a total of 77 goals and subgoals, zipped to 253 events (of which 177 are distinct). Fig. 5 shows geospace, which includes four countries and their borders, numerous cities, and diverse terrain. Our forthcoming *CMOT* paper [26] reports on results generated by this model, including variations in group satisfaction as the scenario evolves, maps showing the interactions of agents in geospace, and population changes over time, in addition to results of the experiments with the social science teams in the program.

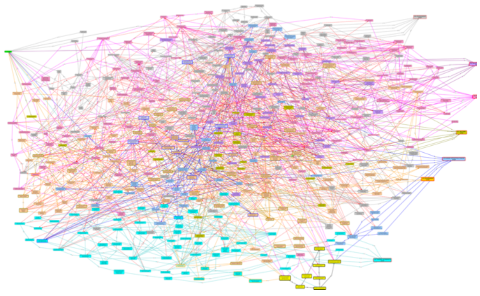

Fig. 4. CEG for conflict model. Node colors show which groups have agency for each event type.

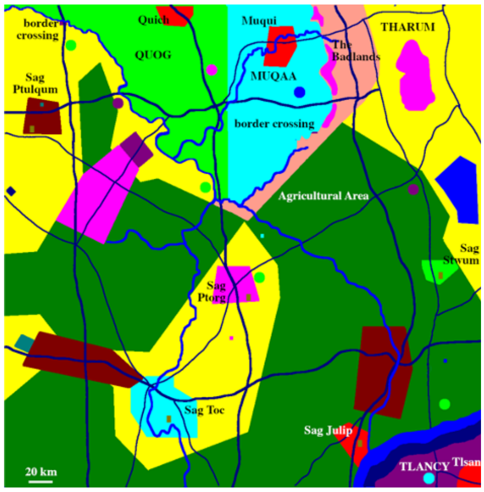

Fig. 5. Geospace for conflict model

9 Discussion and Next Steps

The capabilities described in this report evolved during the 30 months of the Ground Truth program, driven both by the needs of modelers to capture the social dynamics of a complex scenario and by the information requests posed by the social scientists. By the end of the program, SCAMP had matured into a robust, flexible system. Parsing the wide range of data that modelers can define externally necessarily results in a complex code base, but it is supported with thorough unit tests and commented to trace its behavior to the underlying causal metamodel of the system. Our experience with two different teams of modelers without programming experience shows that non-hackers can indeed construct complex models in SCAMP. The largest drawback is the large number of parameters that they must specify, though a system of defaults can reduce this considerably. The model graphs and spreadsheet can have bugs, just as code can (e.g., undefined locations, dead-ends in the CEG), but every time a model revision encountered a new bug, we added tests for it in the code, so that SCAMP itself now flags a wide range of possible model flaws.

A number of future directions for SCAMP are possible.

- Our success in representing a complex social situation in the Ground Truth program suggests that the system will be useful in providing decision-makers with planning insight in other domains. We are exploring opportunities, and welcome opportunities to collaborate with other researchers.
- Currently, models are constructed manually. We are exploring techniques that would automate the partial construction of models (for example, the basic structure of the CEG) from archival materials that describe a domain of interest.
- Like any agent-based model that can capture human cognition, SCAMP runs much more slowly (on a per-agent basis) than an equation-based model. We are exploring a number of techniques to address this challenge, including hybrid models that either alternate or integrate an equation-based model with SCAMP, and a renormalization approach inspired by theoretical physics.
- SCAMP includes some execution parameters (e.g., pheromone deposit and evaporation rates) that in their present form are not meaningful to modelers and must be set by developers. If we can map these to variables that are psychologically and socially meaningful, we can reduce the involvement of programmers even further.

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