

GROWLab: A Toolbox for Social Simulation

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Abstract: GROWLab (Geographic Research on War Laboratory) is a software toolbox to facilitate the modeling, simulation, analysis, and validation of complex social processes, with a special focus on geographic conflict research. GROWLab is designed as a collection of independent software components, which is intended to bring the development of agent-based simulations to the next level of complexity and realism. In this paper, we present our motivation guiding the design of GROWLab and the toolkit's key features. GROWLab is still at an early stage of development, but has already been used for various applications. We exemplify the use of GROWLab with some well-known models from the social sciences.

GROWLab is available on our website: <http://www.icr.ethz.ch/research/growlab>

1 Motivation

Computer simulation in the field of geopolitics has successfully been applied to various applications such as state formation (Cederman 1997; Cederman 2002), war sizes (Cederman 2003), nationalist conflict (Cederman forthcoming), and the strategic behavior of states (Weidmann and Cederman 2005). However, over the course of our group's modeling activities, we found that our modeling projects had specific requirements which were sometimes hard to resolve using existing agent-based toolkits. Typically, the models we created had the following properties in common:

1. *Importance of space:* agents live in a discrete space and use the spatial context to make their decisions. For example, states in the GeoContest system can engage in conflict with their neighbors, and the decision to do so is based on a state's geographic neighborhood.
2. *Hierarchical:* agents are organized in layers of different aggregation levels. GeoSim (Cederman 1997) for example has a two-level architecture where sovereign states are again composed of provinces. The "Growing sovereignty" model (Cederman and Girardin 2005b) features even more than two levels.
3. *Relational:* agents at each layer of the hierarchy need to get information about their neighbors, or about their correspondents at other levels of the hierarchy. For example, in GeoSim states pick one of their provinces to oppose another threatening state in a battle.
4. *Empirical calibration and validation:* our models require calibration with empirical facts to reach an appropriate level of realism. Given the importance of space for our models, we have to rely on geographic data collected with Geographic Information Systems (GIS). We therefore have to enable our models to process GIS data and run simulations in a data structure compatible to GIS.
5. *Computationally intense:* large numbers of runs are sometimes needed to conduct sensitivity analysis as well as to validate the model.

Given the technical requirements we have for our geopolitical models, there are two options. (1) One could take an existing modeling toolkit and extend it, or (2) one could start with a new one from scratch. In our case, we opted for the latter because we wanted to have a fresh look at the problem. However, the design of GROWLab as a set of largely independent components makes it compatible with other Java-based systems, and the development of models making use of GROWLab and other toolkits at the same time is well possible.

As the name suggests, GROWLab is in the first instance designed to fit our needs of geopolitical and conflict modeling. However, we believe that some of the key features of GROWLab like the support for agent hierarchies and GIS data structures could make it an interesting option for modelers from other fields too, especially because it can be used in combination with other systems as mentioned above.

2 GROWLab Design and Features

Like other well-known modeling toolkits such as RePast (Collier, Howe, and North 2003), MASON (Luke et al. 2004), JAS (Sonnessa 2004), or Ascape (Parker 2001), GROWLab is implemented as a Java class library. At present, the library features classes supporting agent hierarchies and GIS data as well as their corresponding visualization components.

2.1 Data Structures

Configurations

At the core of GROWLab's support for hierarchies and relations is the Configuration. A Configuration essentially links two model elements of an arbitrary type and provides an efficient way to retrieve the elements an object is linked to. GROWLab provides different types of configurations which impose certain constraints on the number of elements on either side of the relation.

The most general type is the ManyToManyConfiguration. Here, a "parent" element can be linked to many "child" elements, and each child can in turn be linked to more than one parent element. Figure 1 gives an example of a ManyToManyConfiguration linking countries to ethnic groups living in that country. However, an ethnic group can occur in more than one country, so each child element can have more than one parent.

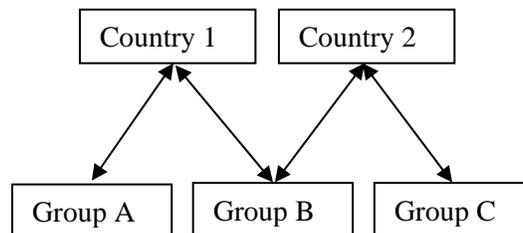


Figure 1: A ManyToManyConfiguration where ethnic groups are linked to the states they live in.

A OneToManyConfiguration imposes the constraint that each child element can only have one parent. This is useful when representing for example countries as sets of elementary provinces like in the GeoSim model (see Figure 2). Here, a state occupies a contiguous set of provinces, but a province can only belong to one state at a time. Whenever a province is transferred from one state to another, the OneToManyConfiguration automatically unlinks the province from the former state before linking it to the new one.

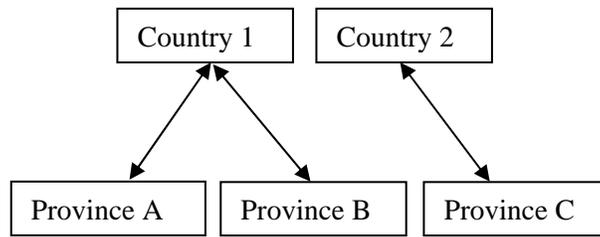


Figure 2: A OneToManyConfiguration with countries linked to the provinces they occupy.

Another type of configuration is the OneToOneConfiguration, where a parent element can only be linked to exactly one child. An application for this type of Configuration can again be found in the GeoSim model. In GeoSim, each state has exactly one capital, so this relation can be stored in a OneToOneConfiguration as shown in Figure 3.

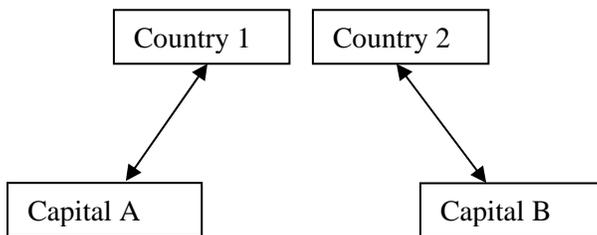


Figure 3: A OneToOneConfiguration with states linked to their capitals.

Spaces and SpatialConfigurations

Unlike in other toolkits, Spaces in GROWLab are not containers of agents or other elements. GROWLab Spaces only define a set of locations and the neighborhood relations between them, whereas the mapping from model elements such as agents to their locations in a Space is done using a SpatialConfiguration (see below). The separation of Spaces and SpatialConfigurations allows us to link different types of model elements to the same space without having to create a separate space for each of them.

SpatialConfigurations are essentially Configurations as described above, with the only constraint that they link parent elements not to an arbitrary type of child element but to one or more locations. In addition to the basic operations such as relation creation and element retrieval, SpatialConfigurations provide methods for simple topological queries. Consider the example of two states, each of which is linked to a contiguous set of locations in a space using a OneToManySpatialConfiguration. This SpatialConfiguration offers methods to test for example if the two states are neighbors of each other, or where the borders of a given state are located.

2.2 GUI Features

During the development of GROWLab, special emphasis was put on the design of the graphical user interface. Our general approach is to have a GUI where multiple views on different aspect of the simulation are closely linked together. Following Brodbeck and Girardin (2003), the main guidelines we used to design our GUI were

- *integrated systems*: the system should provide all the essential tools and views in a single integrated frame to preserve spatial continuity;

- *high interactivity*: the system should provide immediate feedback for all actions to preserve temporal continuity and to encourage exploration;
- *different views*: the system should provide different views onto the same data to emphasize different aspects and perspectives;
- *tightly linked views*: the views should be tightly coupled so that changes in one view are reflected in the others.

At the present stage, the GROWLab GUI features a set of interconnected views on the simulation, such as

1. a *spatial view* which displays the simulation space,
2. a *configuration view* which allows for agent hierarchies to be displayed, and
3. a *process view* tracing the actions performed and the results produced in the model over time.

The views are interconnected in such a way that selecting an agent in one view causes this agent to be displayed in an other view (see examples below).

2.3 Other Features

GROWLab offers more features in the following areas. However, at the present stage of development only some of the listed features have been implemented, so the given list should be considered as a roadmap of development.

Data loading: GROWLab is able to load and display GIS raster data. GROWLab Spaces can be linked to GIS raster datasets and directly be used as a simulation space.

Actions and simulation control: Actions in GROWLab can be encapsulated. The toolkit offers functionality to "rewind" a simulation by undoing the actions performed up to that time.

Graphical display of spaces: Spaces in GROWLab can be visualized using a multi-layered display. This way, the user can select the layer to be displayed and thus examine multiple views on the same space at a time.

Output: GROWLab model output can be saved in various file formats, making it possible to directly analyze the output in statistics packages such as Stata.

3 Examples of GROWLab Models

(see end of paper for screenshots)

3.1 Schelling's Segregation Model

Schelling's famous model of segregation (Schelling 1978) is a prominent example of a agent-based model. We implemented the segregation model using GROWLab. Figure 4 shows a screenshot of the simulation. In the configuration view on the left a list of agents is given, ordered by color. The space view displays the current configuration of the simulation, with "unhappy" agents marked by a dot. Clicking on a agent in the space view lets the configuration view scroll to the line of the respective agent. In the process view at the bottom the basic actions of the model (i.e. agent moves) are displayed.

3.2 The Iterated Prisoners Dilemma (IPD)

The model presented here is an implementation of an Iterated Prisoners Dilemma game as described in (Cohen, Riolo, and Axelrod 1998). A Genetic Algorithm is applied to adapt the players' strategies (Axelrod 1987). Figure 5 shows a screenshot of the model implemented in GROWLab. The configuration

view on the left shows a list of the genetic strings of the strategies present in the simulation, as well as the locations of the players using that strategy and the payoff the strategy has accumulated in the present run. The space view displays the players, where the background shading varies with the payoff of the respective player. In the process view, average levels of payoff and cooperation are given for each time step.

3.3 GeoContest

GeoContest (Weidmann and Cederman 2005) is framework for modeling strategic behavior in geopolitical systems. The GROWLab implementation of it (see Figure 6) shows the different states in the abstract space, where colors refer to the different strategies used by states. Clicking on a location in the space view lets the configuration view scroll to the respective state the location belongs to.

3.4 The Spatial N* Model

The model is a spatial version of the N* conflict model (Cederman and Girardin 2005a) and illustrates the use of GROWLab with GIS data (see Figure 7). A list of countries is provided, along with the ethnic groups living in the respective country. Based on empirical findings the model initiates a conflict between a government and a peripheral ethnic group (groups in conflict are highlighted in red). Again, clicking on a country causes the list to scroll to display the respective information.

4 Summary

We have presented an overview of our GROWLab toolkit for social simulation. GROWLab is especially designed to support geographic conflict research, but might be useful for applications from other fields too. Among the core features of GROWLab is an extensive support for agent hierarchies and relations, an integrated GUI allowing for different views on the simulation, and the support for GIS raster data. We briefly introduced four models which were implemented using GROWLab.

Acknowledgments

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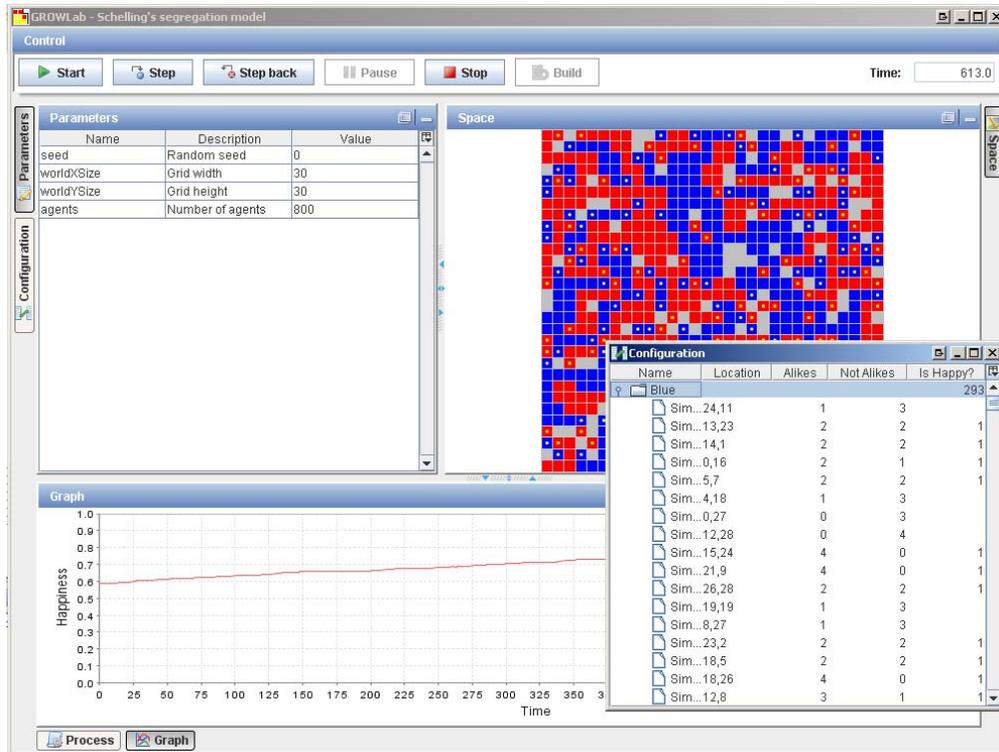


Figure 4: Screenshot of Schelling's segregation model implemented in GROWLab.

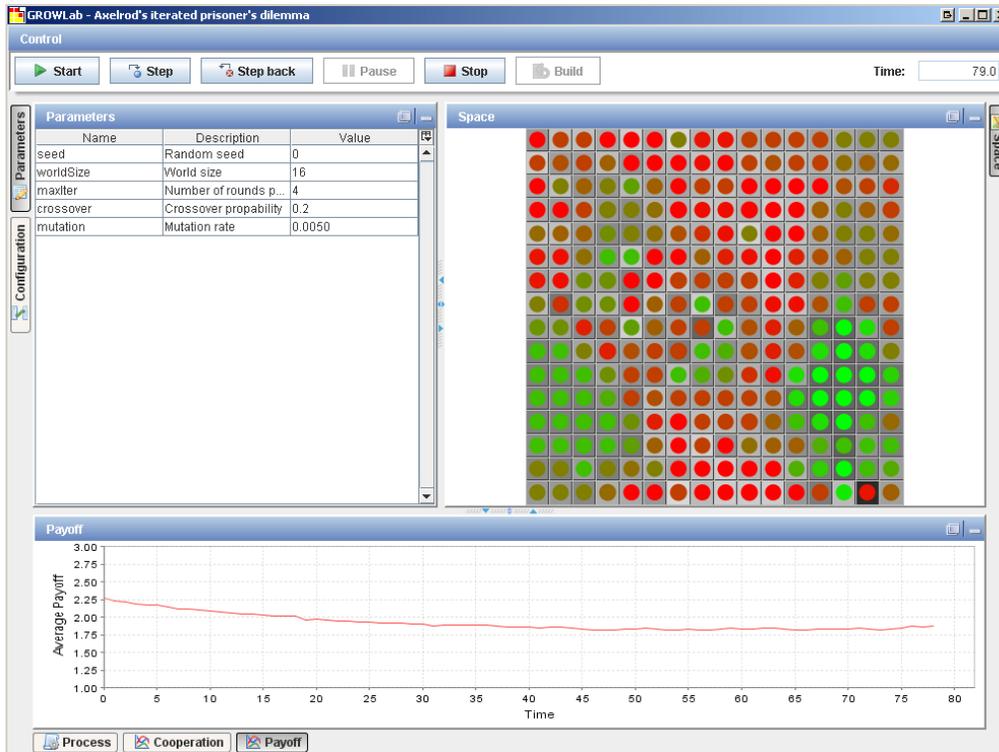


Figure 5: Screenshot of the IPD model implemented in GROWLab.

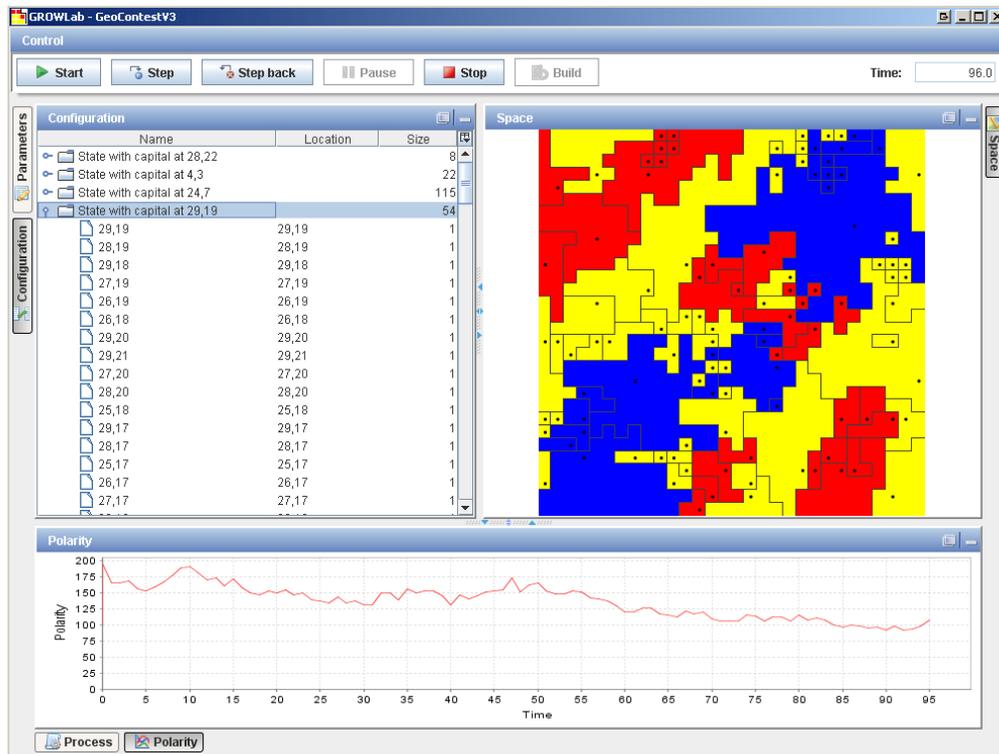


Figure 6: GeoContest implemented in GROWLab.

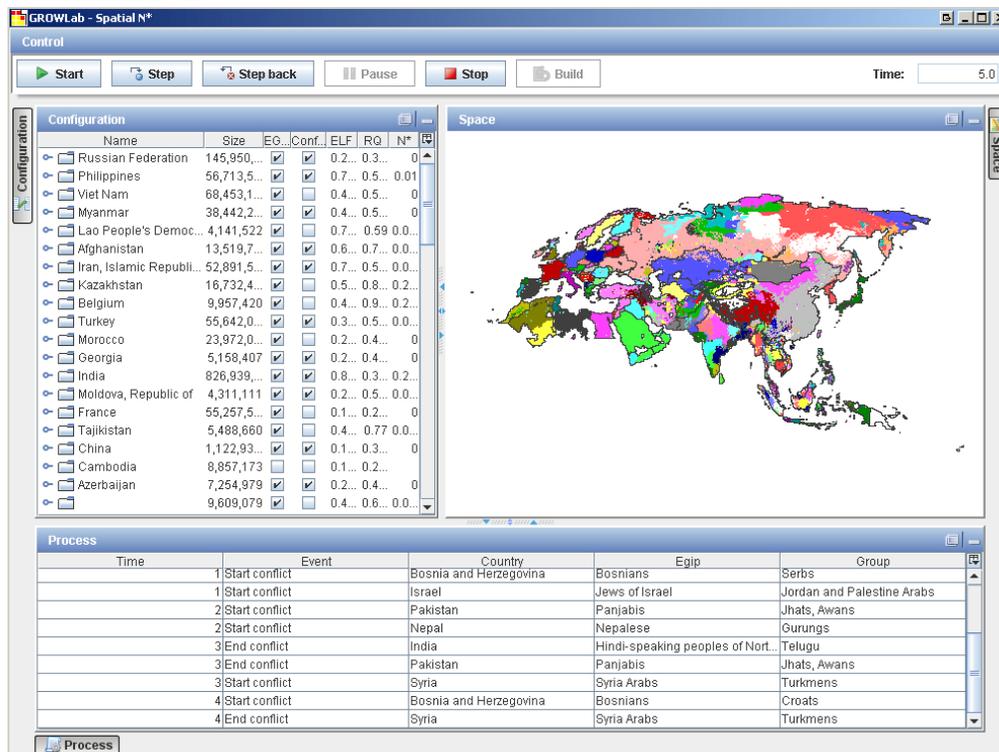


Figure 7: A spatial N* model, illustrating the use of GROWLab with GIS data.