Agent-Based modeling as a Strategic Geopolitical Analysis method

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ABSTRACT: The unforeseen events that occurred during the Arab spring calls for geopolitical analysis methods that are able to make forecasts in times of instability. Under the assumption that volatile regions are most accurately represented as a complex adaptive system, we have performed a literature study to identify which geopolitical analysis method is the most suitable to study volatile regions. As we expected, agent-based modeling appears to be the most suitable method. This is validated by a rich group of experts in international security and risk management, who hardly knew about the existence of agent-based modeling. Since we do expect that the suitability of the method depends largely on how volatile the region under study actually is, and which questions needs to be answered, we recommend future studies to identify with greater precision under which circumstances which method is most suitable. Finally, we would also like to recommend investigating how agent-based modeling can be introduced to actual decision- and policy making processes.

1 INTRODUCTION

The recent events of the Arab spring showed a high volatility in regions which had been previously assumed by western policy makers to be relatively stable [1, p. 102]. Many known actors dissolved and new actors emerged in a short period of time. Social media helped ordinary citizens organize themselves and get catapulted into heroes during the major uprisings [2, p. 112]. This rapid dynamic behavior can be described by analysis methods within the social constructivist paradigm of International Relations studies, but predictive methods are lacking in this field [3, p. 24]. As for the realist and liberalist paradigms, structured foresight methods exist, but as they assume top down governance in stable geopolitical systems, they are invalid in dynamic uprisings [ibid. p.18-23]. Based on a literature study, this paper will show to international relations scientists and policy makers how agent-based modeling can overcome the problems posed above.

2 AGENT-BASED MODELING

In the late 90s agent-based modeling was introduced as a new analysis method for international security sciences [4]. Its use lies in its quantitative, open-form, inductive bottom-up, modeling that is suitable for replicating actual international security problems. Agent-based modeling is based on the complex adaptive systems paradigm and assumes, similar to social constructivism, that any structure is meta-stable and emerges from low level interactions [ibid. p.53]. Hence such predictions would not only assist policy makers to understand what to expect in times of political instability, but also what meta-stable structure to expect after times of instability. Such analyses are especially relevant in the current era of international security.

In the post-9/11 era, state-to-state international studies have shifted from state-to-state war, to studying geopolitical dynamics that makes a certain region stable or not. For example, think of how internal struggles in Libya managed to destabilize Mali [5, pp. 137–139], or how the civil war in Syria has affected the entire Middle East [6, p. 4].

Under the assumption that the complex adaptive systems paradigm is indeed a valid way of perceiving volatile regions, this paper demonstrates why and how agent-based modeling is suitable for strategic geopolitical analyses of volatile regions.

3 AGENT-BASED MODELING IN GEOPOLITICAL ANALYSES

It should be noted that Agent-based modeling may not be useful for all geopolitical analyses. This paragraph shows where this tool should be used in the broader scope of analysis techniques. Figure 1 shows how the properties of agent-based modeling relate to properties of other analysis methods. Each node represents a split in analysis methods and is described in the next few paragraphs.

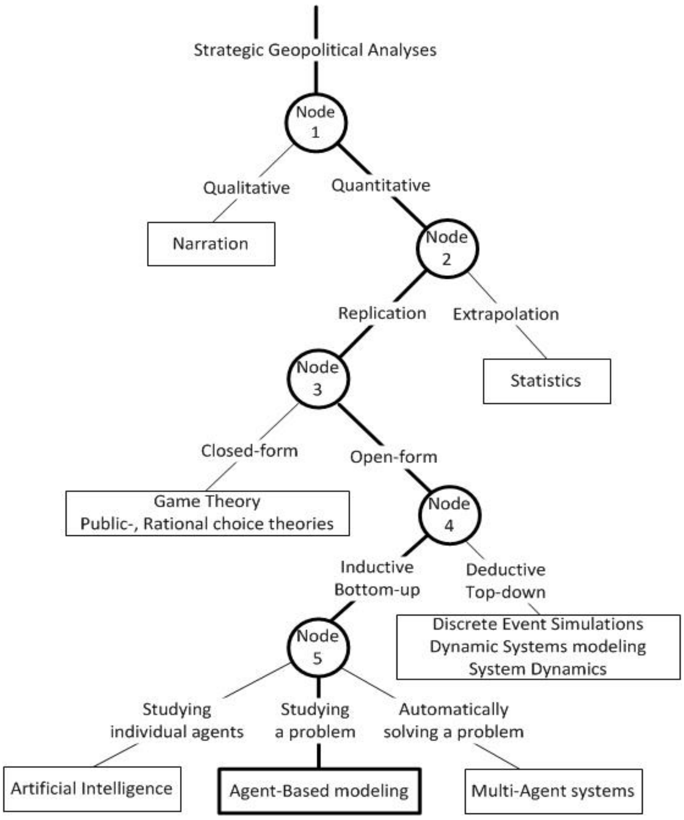

Figure 1: Positioning of agent-based modeling

3.1 *Node 1: Qualitative versus Quantitative*

Qualitative methods are very flexible and do not force the analyst to look for equilibria or consider actors to be fixed and given with common and complete knowledge. This is useful for people who, like us, consider geopolitical systems to be a complex adaptive system. However, ironically, reasoning from the complex adaptive systems paradigm especially requires a quantitative methodology. This is due to the inherent complexity and context dependence of complex adaptive systems. The logic and strict reasoning required for quantitative analyses helps analysts to maintain coherence and consistency in the analysis of a complex adaptive system [4, p. 30], or limit the negative effects of psychological phenomena like *groupthink*. Furthermore a quantitative study can help the analyst to explicitly formulate the used line of reasoning and produce precise and testable theories [ibid.]. Quantitative analysis on computers, also has an advantage when a high number of interrelations are present or when a high number of scenarios are analyzed in complex adaptive systems [7], [8, pp. 176–177].

3.2 *Node 2: Replication versus Extrapolation*

There are two types of quantitative forecasting approaches. Either the analyst forecasts based on replication or on extrapolation [8, pp. 123–151]. One can extrapolate based on past events in the case of interest or one can extrapolate between multiple similar cases. This way of forecasting is based on the assumption that events occurred in the past or occur in other cases, will likely occur again if the situation is similar. Although these trends prove to be quite reliable in practice [9, pp. 100–130], an analyst will never be able to identify possible future types of emergent events that have yet to never occurred yet in history. This does not reflect the complex nature of uprisings and is therefore, in itself, not sufficient to be used for strategic geopolitical analyses of volatile regions.

Replication overcomes this problem because it can be used to model the problem under study in its present state and allows for the introduction of future trends. Furthermore, replication also allows an analyst to compare, within a fully controlled environment; different scenarios, new parameters and varying starting situations. The analyst can also determine the likelihood and impact of generated future scenarios. The validity of such forecasts is coupled to the accuracy of the information used to determine the parameters settings. To determine accurate parameter settings one usually depends on quantitative and qualitative extrapolation analyses. Another additional method to determine likely parameter settings is to create serious games out of replicative models [10, pp. 219–220]. This is useful for incorporating human behaviors directly in the model, with the additional benefit of conveying insights of the study better towards non-experts [ibid.].

3.3 *Node 3: Closed-form versus open-form*

When modeling a part of the real world, a modeler has to decide what dynamics are inside the system and what dynamics are the environment of the system. Closed-form models aim to model all significant dynamics that influence a system. Conversely, open-form models attempt only to model the dominant dynamics, and uses input variables to replicate the effects of the environment of the system [11, p. 20]. Thus the input variables are types of parameters that in the experimental set-up represent the external dynamics onto the system. The domains of all variables used to replicate the environment can have practically unlimited different values since the environment around the system under study can develop in practically unlimited ways[1]. This means open-form models can generate unlimited possible futures, as

[1] Under the assumption there are finite elements in the world, every possible future can be simulated. However the large amount of elements and possible combination make such an analysis intractable. Which means that there is no computational device in the world that can provide an outcome before the outcome itself occurred in the real world [12, p. 3].

opposed to closed-form models that do not take into account practically unlimited parameter domains to represent effects from the environment.

Closed-form models are preferred over open-form models as they generate findings that are verifiable for the entire parameter space with their limited parameter settings and limited outcomes [4, pp. 62–63]. However such models, adequately representing a complex adaptive system like a volatile region, do not exist [ibid. p.64]. That is not to say that there are no useful closed-form models of geopolitical systems. On the contrary, Game-theory models by RAND helped to develop the Mutual-Assured-Destruction doctrine that probably prevented a nuclear holocaust during the Cold War [13]. However in the post-Cold War era, three major assumptions that closed-form geopolitical modeling methods require became less valid. Because closed-form models exclude external effects from the environment onto the system under study, such models assume *fixed and given Actors* and *common and complete knowledge* [4, pp. 32–36]. Under these assumptions;

- Actors do not change their preferences or identity through time;
- Actors are fully rational; and
- Actors know everything on the identity, preferences, and resources of all the other actors.

This is especially unrealistic when considering volatile regions; where changing preferences of actors can emerge into new aggregate actors who, through revolution, can even replace an actor. Another problem of closed-form games is that they often attempt to identify equilibria in the system under study. However in that case an analyst assumes that equilibria exist at all in a system, and even when an equilibrium does exist then the historical processes should be fast enough to reach that equilibrium before its environment changes and the equilibrium itself will be changed [ibid.]. These unrealistic assumptions required for closed-form modeling force the analyst to use open-form modeling, unless one wants to ignore the high complexity in strategic geopolitical systems and escape to extrapolation or qualitative methods.

3.4 *Node 4: Deductive (top-down) approach versus Inductive (bottom-up) approach*

From a top-down approach, one studies the real world system and deduces all perceived patterns and regularities into a model. There are two troubling assumptions with this approach:

- The analyst knows how the system behaves; and
- The system structure is static.

From a deductive approach it is necessary for the analyst to be able to identify the presence of all the structures in a system under study. However this requires the analyst to have extensive knowledge on the system structure even before modeling. Furthermore, the structures that an analyst can identify from the real world are usually metastable and may dissolve suddenly [ibid. p.53]. These metastable structures are assumed to be static in deductive models, which means that these models are only valid as long as the structure of the system remains the same. This limited validity significantly impairs the utility of such a model on geopolitical systems where some structures, that in the future will/can dominate the system, do not exist yet at the time of study (e.g. emerging strategic alliances).

At the cost of significant more computation power[2] and losing mathematical descriptions[3], the presented problems can be overcome when using an inductive approach [ibid.], [15, p. 368], [16, p. 4], [17]. By focusing on the low level interactions that causes patterns and regularities to emerge, the analyst uses generative science to model his perspective on the real world by letting the model grow. This means one does not have to identify or understand the global interdependencies in the system to be able to grow a model that exhibits the effects of global interdependencies [18, p. 7]. Growing a model provides the analyst with better understanding of the system under study [19, p. 51]. Furthermore the grown model also includes critical paths and history that affect future dynamics. This adds to the realism of the model and if input data with a relatively high level of accuracy is available; the model can be used to identify possible paths that lead to a certain emergent event [10, p. 55]. This is useful for both the *ex ante* analysis of what has to happen to lead up to a certain future event, and for the *ex post* analysis to discover what likely happened in the past that created the current situation.

3.5 *Node 5: Solving a problem versus Studying a problem versus Studying individual agents*

At this level of the taxonomy of analysis methods only three tools remain. These tools are theoretically distinctive from each other (primarily in their objec-

[2] Due to the high number of interactions and the extra simulations required to handle parallelism in inductive models, these models require significant more computer power than deductive methods.

[3] Since inductive models are programmed based on micro-interactions, the model will not produce a mathematical description of any behavior that is analytically [14, pp. 5–6]. Therefore no existing mathematical analytical methods that require such expressions, like comparative statistics [4, pp. 62–63], can be used.

tives) but in practice show significant overlap, resulting in confusion both in science as well as in practice [10, p. 56], [20]. Following our arguments presented in this thesis, the aim of the tool we are looking for is one that helps an intelligence service understand the complex dynamics in volatile regions better. Therefore the most suitable tool appears to be an agent-based model, as an agent-based model attempts to model, in silico, the real world system under study in order to try to understand that real world better [10, p. 55].

This is an essential difference with a *multi-agent system* that attempts to make predictions on emergence in a system based on real-time data, and automatically act to control that emergence in the system [ibid. p.56]. Multi-agent systems are already successfully applied in practice for gathering information for strategic geopolitical analyses though [21], [22], but these systems are not used to understand and identify regularities and patterns that emerge in a real world system under study.

Then there is *artificial intelligence* that focuses on the individual agents and attempts to replicate their; learning processes, decision making, etc. [10, p. 56]. Although quite distinctive from agent-based modeling and multi-agent systems, the differences blur when artificial intelligence models have multiple agents that can respond to each other his actions [ibid.]. However the aim in artificial intelligence is to understand the individual agents, rather than understanding the emerging dynamics between agents like an agent-based modeling study does.

4 VALIDITY OF ARGUMENTS

In order to validate the statements made in the previous section, we surveyed relevant experts whether they agreed with the above statements. The selected experts were approached because of their research experience in intelligence services, international relations or risk management. The main arguments used throughout the previous paragraphs were presented to these experts in an online survey and they were asked whether they agreed or disagreed with the statements[4]. All our main arguments were considered valid by significant majorities of respondents [23, pp. 25–30][5].

5 DISCUSSION

Section 3 indicates that agent-based modeling is the only method suitable to study volatile regions assuming the complex adaptive systems paradigm. Although technically narration also has the flexibility to reason from the complex adaptive systems paradigm, practically this qualitative method is not able to do so without oversimplifying the system under study. Besides the ability of studying in the complex adaptive systems paradigm, agent-based modeling has additional benefits which it shares with other methods. These are per property of the method, listed below:

Quantitative method;

- Forces analyst to be explicit about all his research decisions.

Replicative (modeling) method:

- Allows serious gaming to directly adopt human behavior into study and improve the understanding of the study more to the user.

Open-form modeling method:

- A large number of computations can be performed to explore various environments of the system under study.
- Sensitivity analyses can be used to evaluate input data and its effects on the results as well as to identify the bandwidth under which certain conclusions are true.

Bottom-up (inductive) modeling method:

- The modeler will gain a better understanding of the system under study due to the way bottom-up (inductive) models are developed.

Based on the above identified benefits we would strongly recommend policy analysts/makers to consider agent-based modeling as their geopolitical analysis tool in the future. Especially due to the ability of agent-based modeling to explore futures across times of instability, this method has the potential to significantly change the foreign policy of its user. Specifically by being able to evaluate futures across instability, decision makers can make multi-criteria decision analyses before they decide whether is wise to force stability, remain passive or to instigate instability in a certain region. The open-form nature of agent-based modeling also enables deduction of adaptive policies from the model [24]. Such adaptive policies would then indicate in which possible futures, which particular policy is most the suitable [ibid.]. This is especially useful as it relates to policy making concerning volatile regions, where it is very uncertain what the most likely future will be.

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[4] In order to make sure that the expert would make his judgements as objective as possible, we also used opposite statements and checked whether they would disagree with them. Furthermore we have left out respondents who considered themselves experts on Agent-Based modeling, to prevent biases.

[5] For the raw results of this survey go to: https://qtrial.qualtrics.com/WRReport/?RPID=RP2_3aSKcmZoBsKM8wl&P=CP with the case sensitive password: “TUDelft”.

6 CONCLUSION

The results from the literature study and the survey indicate that agent-based modeling is the most suitable method to study volatile regions. The bottom-up approach signifies agent-based modeling from other, more conventional, methods. However, our findings are subject to the assumption that volatile regions are best represented as complex adaptive systems. The suitability of such an assumption depends on the volatility of the system under study and the questions the analyst wants to have answered. The arguments in section 3 should help the analyst to choose the most suitable method based on the situation, which for genuine volatile regions is most likely agent-based modeling.

7 RECOMMENDATIONS

In order to increase the validity of this article we would recommend consulting more (varied) experts on agent-based modeling, international security and intelligence practices. Preferably also consult experts with knowledge and experience across all three domains. Consulting such experts should prove useful in helping assessing the assumption of complex adaptive systems for strategic geopolitical analyses and consider its validity for different types of geopolitical systems. We recommend utilizing such a study also to identify under what conditions which type of geopolitical analysis tool is the most suitable to use. Finally, we would also like to recommend examining how agent-based modeling, as a geopolitical analysis tool, can be integrated in decision- and policy making processes.

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