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Nesting a data-driven agent-based model within a theoretical framework

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Abstract

Traditionally agent-based modeling has been a field that focuses largely on abstract models that offer insights into real world phenomena, but rarely with enough complexity to play a major role within academic or policy discussions about particular problems in particular places. In this paper we outline an approach to building country virtualization models that combines traditional micro-level interactions in an agent-based model with macro-level theory to simulate complex political systems in a range of countries in Southeast Asia. We discuss the advantages, and potential downfalls, to adding complexity into agent-based models and present results that highlight some of the analytic advantages to having multiple levels of analysis present in a model and a distribution of counterfactual model results by which we can analyze and forecast political outcomes.

1. Introduction

One of the fundamental strengths of agent-based modeling is its ability to use relatively simple rules governing agent behavior to produce complex, emergent phenomena. Theories of the dissemination of culture [1], state development [2], and tipping points [3] have all been explored using very simple agent based models while somewhat more complex models have gone on to investigate Israeli-Palestinian violence [4], insurgency in India [5], and the war in Afghanistan [6]. One of the frontiers for the development of more sophisticated agent-based models is to take advantage of interactive synergies between simple agent-level rules and higher level model functionality. In this paper we will highlight how our modeling process combines traditional agent-level interaction rules with a sophisticated theory of macro-level political organization to virtualize the political environment of a target country. Additionally we will address concerns about complex agent-based models and demonstrate the utility of a virtualization model that combines both micro and macro level social science theory and can explain political outcomes at many levels of analysis.

2. Determining the Proper Level of Analysis

Before building a model, the first question that should be asked is: What is the model for? This might seem like a trivial question, but it is often clumsily answered, delayed for later, or altogether ignored. Since all models are abstractions of varying degrees, we must first decide how abstract our model should be, keeping in mind that there is a trade-off between realism and complexity. Ideally, the level of model abstraction is determined by the types of

questions or problems the model is seeking to address. Dennett exemplifies this imperative when he observes, "If you want to know why traffic jams tend to happen at a certain hour every day, you will still be baffled after you have painstakingly reconstructed the steering, braking, and accelerating processes of the thousands of drivers whose various trajectories have summed to create those traffic jams" [7]. Unless you focus your model at an appropriate level of analysis, in this case an aggregate level above individual driving patterns, the model may fail to contribute anything to the research topics it was designed to assist. However, to continue Dennett's example, it may be possible to analyze traffic patterns by examining individual driver behaviour *and* aggregate traffic conditions. Doing so would require a more sophisticated model that takes both levels of analysis into account and addresses complicated interaction effects between the individual level and the aggregate level, but could have a great analytic payoff. In our country virtualization process we attempt to build models that can answer questions concurrently about the macro structural events involving political groups or institutions and the micro-level political events involving individual actors.

The benefit of synthesizing both micro and macro theories of political society is not only that we believe it is a more accurate reflection of the real world where agents are interacting with each other within the context of broader political norms and institutions, but also that it means that the model results can address different levels of analysis. The model can simultaneously speak to micro level behaviors such as the spread of certain identities or incidents of violence in a particular region and to macro level behaviors such as changes in political alliances, group alienation and large scale protest movements. The challenge, of course, is that adding multiple levels of analyses adds significant complexity to the model. Added complexity opens a model up to more potential areas for theoretical disagreements about the structure of the model and makes model transparency a much more difficult task, leading many agent-based modelers to focus on very simple, but unrealistic models.

3. Micro and Macro Level Theory

To build our country virtualization models, we input real-world data into a generic model to develop a virtualization, which is distinct from abstract and ensemble models because it attempts to tackle a specific set of problems in time and space [8]. We gather data from many sources including the national census, data repositories, monographs about the country, and experts on the country. There is a heavy emphasis on GIS and other geographic data in order to represent regional variation within the country. Research into the institutional and hierarchical structure of the country plays a role in developing where influential agents and groups will be placed throughout the power centers of the country. This data, combined with basic elements of constructivist identity theory form the basis for the micro level interactions within the model. Agents interact with each other, changing and trading markers for what they may "identify" with, and sometimes take action to change their neighborhood through peaceful political action or violent attacks against agents that are unlike themselves. An identity is a marker people use (ethnic, religious, political, regional) to fit themselves into an group and identify those who are not part of their group. Agents can identify with more than one group and may activate on a particular group when it is politically salient. As the model progresses, these agent-level interactions regarding identity affiliation evolve as agents share new identities and extrude old identities [9].

However, if the goal is to simulate a complex political system, it is important to recognize that agents are not just operating under information they gain from their micro level interactions with other agents. Indeed, political agents are aware, to varying degrees, of the institutional structure in which they are operating and how that structure is changing. To try and capture this macro-level awareness we have developed the Dynamic Political Hierarchy (DPH), which is a fusion of three theoretical traditions in political science: nested institutions, cross-cutting cleavages, and dynamic loyalties [10]. These theories work at different levels (institutions, groups, and individuals), but they fit well into our larger model framework which also considers more than one level of analysis. Every time step, macro-level measurements of the agents are collected and reinterpreted in the light of the DPH framework. This data is then input back into the model and agent behavior changes as a direct consequence. This means that agents can simultaneously poll their local and global circumstance, acting in a coordinated fashion more congruent to the way real-world institutions tend to behave.

More specifically, the Dynamic Political Hierarchy creates five levels of a societal hierarchy including the dominant, incumbent, regime, system, and non-system levels. The dominant group is the largest, most influential set of agents during a given time step, while the incumbent group is made up of the strongest supporters (but not members) of the dominant identity. The regime, system, and non-system levels each descend slightly farther from the center of political power. Those groups that find themselves at the top of the political hierarchy will lobby

peacefully whereas those that are severely isolated will have the potential to become violent against the ruling classes. Some agents that identity at the middle regime level will protest semi-legally and can cause massive destabilization of the political system. This hierarchy is recalculated every time step and the position of different identities can change over time.

4. Experimentation and Analysis

Once the theoretical and data inputs into the model are complete, we then run 1,000 separate iterations of the model with small, random perturbations ensuring that each iteration is unique. Each "future" of the model (if we are thinking predictively) is then compiled into a cross-sectional time-series data set. Assuming that our sample size if reasonable, these runs comprise the set possible outcomes for the model, given our specific set of inputs. The set of possible outcomes can be further divided into plausible outcomes, those events that occur with relative frequency within the distribution, and probable outcomes, events that happen with the highest frequency. When changes are made to the parameters, theories, or data in the model, we then may see changes in the realm of what is possible, plausible, or probable in the set of futures. This technique of generating a distribution of possible outcomes requires model users to think counterfactually about future outcomes [11]. While ultimately only one future will exist for a given country, it is problematic to think that it was inevitable or even likely. Instead, our model pushes users to think about the future as one of many possible outcomes and to explore the probability of each and the reasons for divergences and convergences, similarities and differences.

Having micro and macro level theories operating within the model and a distribution of 1,000 futures to analyze allows for very flexible exploration of model results. For example, we may want to investigate specific agents or an important region of the country by calculating how much violence or protest occurred on average over 1,000 runs. We may also want to look into which groups were isolated from the ruling center in the system level of the DPH and how often they moved from that isolation to a more inclusive space in the hierarchy. If something surprising or interesting occurs in a specific run, we may want to investigate the entire run and pinpoint specific processes that caused destabilizing events. At the distributional level, a user may want to know how often a crisis occurred or what patterns emerge over 1,000 runs that can lead to discussion of what the common thread among all of the runs with a crisis may be. The breadth of results in this modeling program is an asset because it provides flexibility to an interested user to answer a wide variety of questions, but from an analytic perspective it is challenging to convincingly and intuitively provide a framework for a user to navigate the complex model results.

5. Addressing The Challenge of Complexity

Some may argue that a model with such complexity at so many levels of analysis is too complicated to understand the very low-level causal relationships between agents or that too many theories and assumptions are required for the model to accurately reflect the real world. However, one of the virtues of computer modeling is that the model mechanisms, data inputs, and theoretical foundations can all be identified, critiqued and either accepted or rejected. Furthermore, as George E.P. Box stated, "Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful [12]." Inevitably, the theoretical foundations of a model will be challenged, the data used will be incomplete, or the assumptions made will be incorrect. However, instead of treating the model as a mirror of the world, we treat it as a tool that can be used to supply a research topic with evidence and ideas. In the same way, experts can help illuminate a particular topic even though it is impossible to know how the person's mind works and can recognize that their knowledge is imperfect. Steven Bankes uses the term "exploratory modeling" to refer to the technique of using agent-based models as "laboratory equipment" rather than a realistic depiction of the world. According to Bankes, "When building laboratory equipment... adding additional knobs and switches serves to increase the utility of the instrument. And it can be observed that inside an exploratory modeling context, model builders tend to declare a larger number of dimensions of uncertainty, as this gives their products more rather than less potential value." [14] This is not to discourage critical reviews of model assumptions, inputs, and theoretical foundations but instead to recognize that adding complexity, in and of itself, is not something to fear in modeling because the purpose of modeling is not to simulate the world perfectly but to contribute to ongoing research projects.

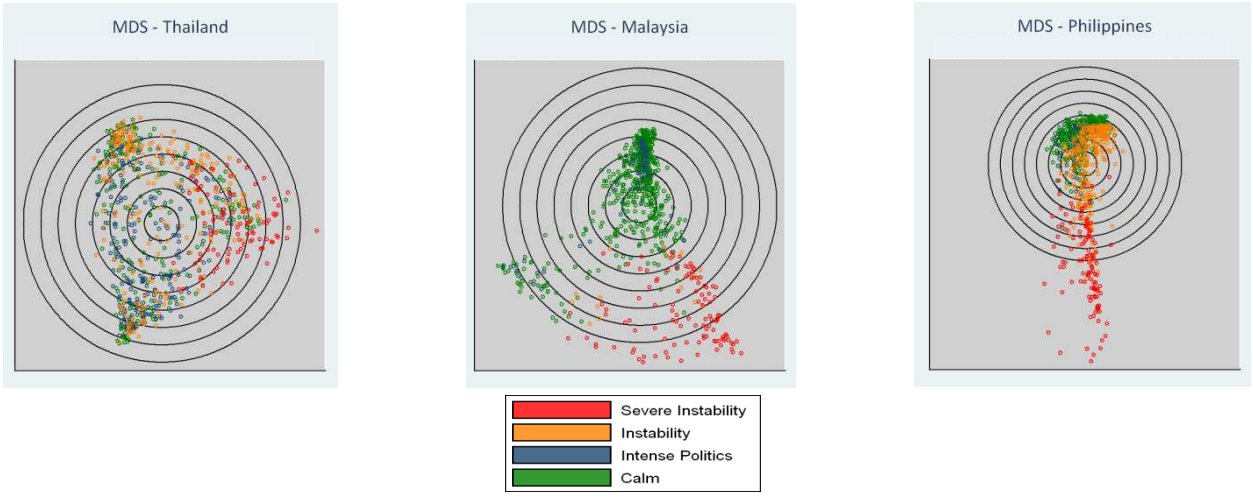
6. Visualization

Using a complex agent-based model that incorporates multiple levels of political analysis and generates a distribution of 1000 counterfactual futures creates major challenges in terms of identifying and displaying model results. As mentioned previously, users may be interested in looking at the results of the entire distribution, a subset of the distribution, or one specific run and they may be interested in macro level variables, such as the DPH, or micro level variables such as violence or identity growth. As a result, we have adopted an approach to visualization that presents a user with a suite of possible visualization options that they can use to compare high-level results across countries before drilling into a specific country, where more visualizations are available, to gain an understanding of specific questions.

6.1. Multi-dimensional Scaling

One method to explore our hyper-dimensional distributional data set is through the use of multi-dimensional scaling (MDS). MDS takes each of the 1000 futures generated by a country model and plots them as points in space based on how similar or different they are. Points that are closer together represent futures that are similar to each other while points that are further apart represent futures that are different. A unique distance function weights each run on a very wide range of variables to determine the level of similarity between two futures.

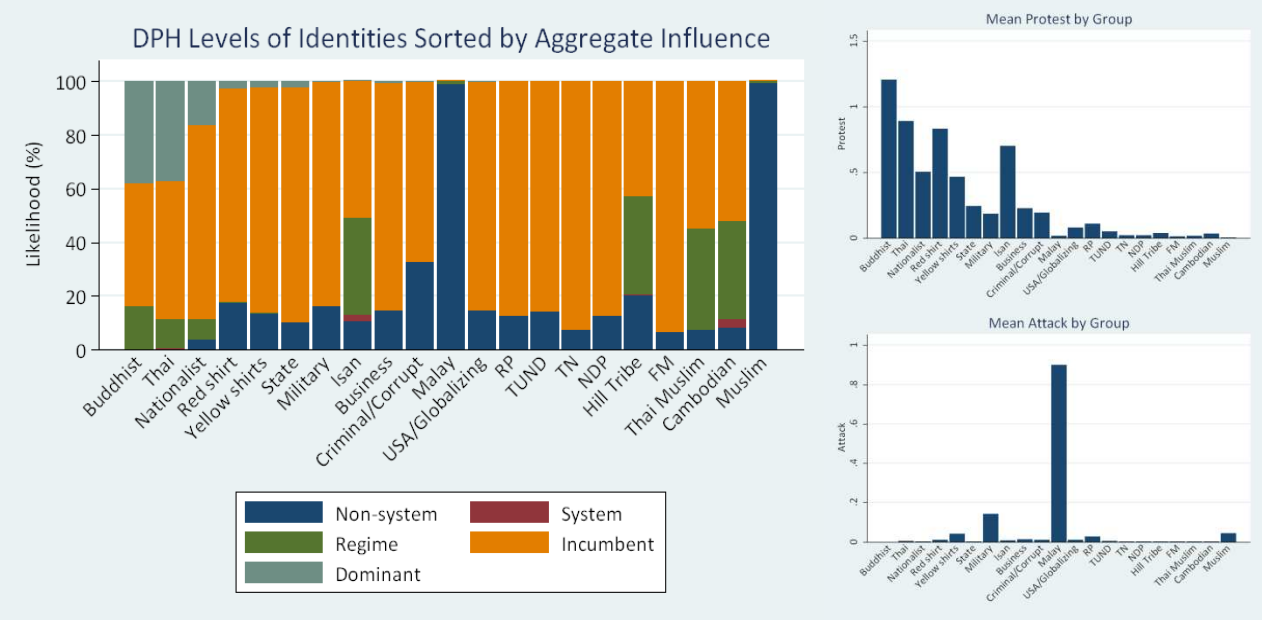
MDS allows for a very rapid assessment of the state space of futures for a given country and works particularly well when comparing across countries. Below we have MDS results from three country models: Thailand, Malaysia, and the Philippines. In addition to the MDS array that provides information about the similarity and dissimilarity between futures, we have also colored each future based on the most common stability pattern observed in the run. Calm futures are characterized by very little protest and violence and as protests and/or violence increase the stability patterns change to intense politics, instability, and severe instability.



By comparing these three countries at the distributional level, we can quickly draw conclusions about the political futures for each country. Thailand and Malaysia both have a wide area in which their futures lie, indicating a wide range of possible political outcomes and a high number of futures that are relatively unique within the distribution. Malaysia does appear to have a more dense concentration of similar futures than Thailand does, but not as dense as the Philippines where a very high number of futures are concentrated in the center of the MDS display. However, this dense cluster of similar futures in the Philippines is divided between runs coded as “calm” and runs coded as “instability.” This suggests that there is a very fine line between politically stable futures and politically unstable runs in the Philippines. Two futures could be very similar on a wide range of variables, but still diverge significantly when it comes to political stability. In Malaysia on the other hand, the unstable political futures are very distinct from the calm runs according to the MDS. The MDS display for Thailand highlights the uncertainty of the political future, with a wide range of stability outcomes scattered across the entire MDS display.

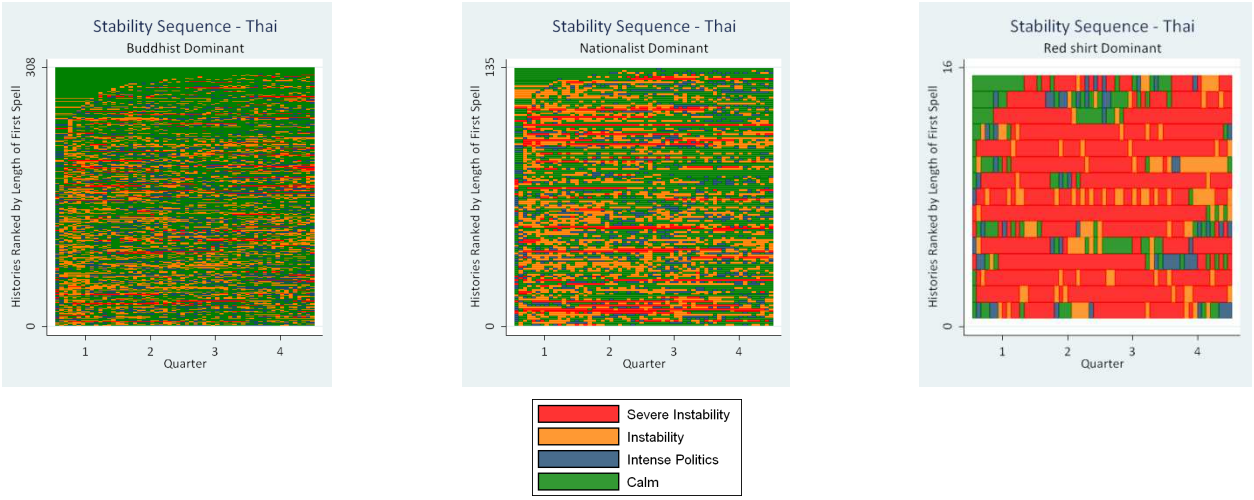
6.2. Country Dashboard

After comparing across countries, our visualization platform allows a user to drill more deeply into one particular country of interest to gain information on the strength of particular groups, levels of protest and violence, and other variables of interest. Below we have a sample section of the visualization dashboard for the Thailand model highlighting the political strength, tendency to protest and tendency to mount violent attacks of major groups in Thailand across the entire distribution.



By moving into more detailed, country-specific data visualizations for Thailand, we are able to learn from the left-most chart that the political groups that are most likely to dominate the political landscape, according to the theory of the Dynamic Political Hierarchy, are Buddhists, Ethnic Thais, and Nationalists followed by the Red Shirts, Yellow Shirts, and State Bureaucrats. The groups that are most likely to found in the regime level, and therefore be a source of protest, are the Isan, a prominent ethnic group in the Northeast of Thailand, various hill tribes, Thai muslims, and Cambodians, of which only the Isan comprise a significant portion of Thailand's population. The Malay-Muslims are by far the most likely group to fall into the non-system level of the DPH and, as we can see in "Mean Attack by Group" bar chart, they account for the huge majority of violent attacks in Thailand followed in a distant second by the military.

While the country dashboard still looks at the entire distribution of political futures for Thailand, we can break that distribution into subsets to explore the data even further. The three sequence plots below focus only on the subsets of the distribution where Buddhists, Nationalists, and Red Shirts are dominant respectively. In these sequence plots each line along the y-axis represents one individual future as it moves through time (x-axis). Each unit along the x-axis, represents approximately one week in the real world and is colored by the level of political instability at that moment in time.



As you move from left to right across the three sequence plots above, there is a noticeable increase in the likelihood, severity, and duration of political instability. The Buddhist dominant futures are characterized mostly by a calm political landscape, with some futures displaying uninterrupted calm for the whole year. When instability does occur, it tends not to be severe and to be very brief. In the subset of futures where Nationalists are dominant, we see more varied political outcomes. While there are still long periods of calm in some futures, there are also many more futures that feature instability and severe instability, sometimes for an extended period of time. Finally, the Red Shirt dominant futures all display very high levels of instability, mostly severe. Periods of calm and intense politics are few and far between. It is important to note that while the Red Shirt dominant futures are certainly the most unstable of these three subsets of the distribution, they are also the rarest. Relatively few runs are characterized by Red Shirt dominance compared to Nationalist dominance or Buddhist dominance. However, in the field of political forecasting and analysis it is a noteworthy strength of a model when it is able to not only comment on the most likely outcomes but also on rare, but significant events, or "black swans" [14]. It is often these rare events that are most impactful, and least expected, so identifying and describing them is a crucial element to comprehensive political analysis.

7. Conclusion

Agent-based modeling is still very much a field in its infancy, its application to political forecasting and analysis even more so. With the ever increasing number of available data sources, the well-corroborated social science theory in a range of fields, and the computational power available today there are huge opportunities to utilize and expand agent based modeling. One thing holding back this development is a general reluctance to build complex models that attempt to simulate the real world and answer relevant questions within academia and policy-making circles.

One of the major benefits of computer-assisted agent-based modeling is that the entire modeling process, inputs, outputs, and analysis can be rendered completely transparent to an end user. This has major benefits because it allows a model to be understood, analyzed, and reproduced with ease. However, it may also contribute to the difficulty agent-based modeling has had in moving towards more complex models. With added complexity comes added uncertainty and increased opportunities for disagreement. Questions about how a particular theory was operationalized or why an input was set at a particular value are worthy discussions but can also disrupt important conversations about the overall model, what it was designed to do, and whether or not it was effective in accomplishing that goal. Bankes' idea of exploratory modeling tries to overcome this hurdle by framing computational social science models as tools that are used, despite having inevitable flaws, to advance discussions, encourage debates, and build upon research projects.

It is within this context that we have developed country virtualization models that are designed to simulate the dynamic political system of various countries in Southeast Asia with the goal of contributing to political forecasts and analysis of the micro and macro level events in this region. The combination of data, theory, and

assumptions that build these models are flawed. The data is at times incomplete, the theories, while having proponents, also have opponents who would disagree with some or all of our operationalizations, and assumptions made by the modelers about model settings, such as thresholds, could certainly be altered. However the end product, a complex, agent-based model that captures powerful elements of political society at both the micro and macro level in a broad range of countries, pushes users to think counterfactually about possible, plausible, and probable political futures for a country, draws relevant conclusions, and provides insights at various levels of analysis that might not otherwise be possible is an incredibly useful tool, despite its inevitable flaws.

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