An Agent-Based Model Approach to Understanding Complexity in International Relations

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ABSTRACT

There is a significant difference between a complex system and a complicated one yet most approaches to understanding the global or regional political landscape have been aimed at understanding specific aspects of a complicated problem, instead of viewing its complexity. These approaches usually involve various frameworks for understanding specific aspects of complex environments, but most come with one of two limitations: they either are most instructive for a single state vs. another state or one group of allied states vs another, or they are so general as to be almost entirely theoretical. This paper addresses the issue of understanding strategic complexity by examining multiple states and their interactions from a high-level, through use of an agent-based model (ABM).

Methodology and Scope: In this ABM, the agents interact with each other based on their specific goals and relative strengths. Strengths are expressed as two-dimensional vector quantities, rather than the one-dimensional scalar values typically employed in quantitative models. These two-dimensional interactions are then compared with how the actors would have behaved in a one-dimensional framework, providing a clear illustration of their differences. The model uses 20 agents, which is the number of countries one would see when examining a region of the world.

Conclusion: An ABM provides a useful tool for examining interactions between states, and shows not only how they compare in a snapshot of time, but how their interactions change and evolve over time.

ABOUT THE AUTHORS

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BACKGROUND

Although not originated by them, the idea of using multiple variables to calculate relative national power was refined in the landmark work by Alcock and Newcombe (Alcock and Newcombe, 1970), where they discuss 54 political and social indicators to rank-order over 120 countries. These factors included economic development, or GNP; population size; population density; culture; and military expenditures. Hall and Citrenbaum provide insight into understanding complex environments with two of their works, which provide a workable framework for examining complex environments (Hall and Citrenbaum, 2010), (Hall and Citrenbaum, 2012). Their framework is a simplified version of Alcock and Newcombe's work, as it only has 14 functions, which, taken together, comprise advanced analysis. Although still highly detailed, this framework has its limitations—it is targeted largely at the operational and tactical levels, is designed primarily for force-on-force, and is most instructive for a single state vs. another state, or one state vs an allied force. It does, however, sidestep one of the hidden flaws in traditional analysis: it functions equally well against non-bureaucratic foes as against bureaucracy-driven one. In this regard, it is a significant improvement over other, similar methods of analytic frameworks, such as DIMEFIL aka MIDLIFE,[1] as discussed by Worley (Worley, 2015). While useful for understanding state-on-state actions, and fulfilling Sun-Tzu's dictum to know oneself and one's enemy (Sawyer, 1994), these framework approaches fall short in three areas. First, it does not account for the unpredictable actions of small, independent actors, who have only limited ties to a central leadership cadre, as found in terrorist cells. Second, it does not account for unpredictable behaviors, even by leaders of bureaucracies. Thus, this approach would fail to predict the use of IEDs in Iraq and Afghanistan, the D-Day landings, and the Incheon Incursion, as these fall outside the traditional actions of the military commanders in charge. Third, this approach is primarily applicable to the actions of a single state, usually in opposition to the observer; while useful, this does not address the interaction of multiple states with each other. With multiple states interacting, a different approach is needed. While a systems dynamics approach may work for a single state (especially a bureaucratic one), the higher-level view required for a strategic overview, with multiple states, necessitates an approach dealing explicitly with multiple states, where the states are free to act outside of the confines of predefined equations.

One significant challenge in applying these types of models to the real world of decision makers is in the application of national power itself. Stoessinger (Stoessinger, 1968) notes that in applying national power, the classic problem is to neither overdo it, nor underdo it, but to use it optimally. Raphael (Raphael, 1982) examines the decision maker by using a mathematical model to test the idea of cognitive complexity as a way to predict crises between countries, but found the correlation to be "not statistically significant." Cartwright (Cartwright, 2015) mentions four challenges in formulating military advice for national security policy makers, two of which are closely related and demonstrate some of the shortfalls in military planning that a more robust understanding of all the elements of national power might mitigate. These two are recommending military plans that do not account for the role of other agencies, and deciding on a military objective without sufficient study of the overall national security objectives.

Slaughter (Slaughter 2017) proposes a different perspective, that of a networked world. This approach is valuable, as it accurately points out that underlying connections and networks play a significant role in the modern world. It also makes the case for social network analysis (SNA) as a useful tool for examining the global society, and

[1] DIMEFIL stands for Diplomatic, Information, Military, Economic, Financial, Intelligence, and Law Enforcement, which are elements of national power. MIDLIFE is the same elements, but in a different order

addressing critical issues. Ironically, however, the sheer number and type of observed connections renders understanding the international system virtually impossible, as the level of complexity has been raised exponentially. Instead of Hall and Citrenbaum's finite number of mathematically definable variables, this approach adopts virtually any number of variables, including actors, few of which can be readily quantified or otherwise measured, merely stated to exist. As such, a working, understandable analytic model is moved far out of reach. Kim (Kim, 2010) provides a more measurable method for using SNA, based on the degree of centrality of individual states, as measured using various communication patterns and the flow of resources. However, while this method provides numerical scores individual countries, it does not present a way to determine their relative strength in time of conflict or crisis, limiting its utility as a predictive tool for national policy makers.

Instead of adopting an entirely mathematical model, or a completely SNA driven one, a more middle-ground approach is warranted. While many possible models exist, very few types of models are able to address complexity without becoming too complex themselves. For example, Dyer and Dyer (Dyer and Dyer, 1960) proposed a series of gaming or status boards as a way to evaluate national power and test proposed policies in advance; although the proposed mechanism would be considered crude and overly complicated by today's standards, it does show a serious attempt to measure factors affecting national power, and provides a comparison between countries. As such, it can be considered a precursor to current models; if its proposed series of five game boards with multi-colored lights were replaced by a computer screen, it would not be out of place today. Even the factors used (geographic, demographic, political, foreign affairs, economic, industry, transportation and communication, scientific, armed forces, and biographic) are remarkably similar to those in current use today, as in DIMEFIL.

Yetiv (Yetiv, 2011) urges the use of interdisciplinary analysis, and touches on elements complexity theory, but does not go as far as Scartozzi in embracing these ideas. Scartozzi (Scartozzi, 2018) posits the idea that the international political system is a complex adaptive system, which needs to be understood with a multidisciplinary approach, with methodologies from complexity science, and notes that very few International Relations (IR) scholars use complexity theory, or its modeling techniques to study the international system. Complex systems should not be confused with complicated ones. As noted by Harrison, Massey, and Richards (Harrison, Massey, and Richards, 2006), while local behavior in a complex system may be unpredictable, the behavior of the system as a whole is "surprisingly simple". Along with Miller and Page (Miller and Page, 2007), Rosenau (Rosenau , 1996), and the ground-breaking work by Simon (Simon, 1996), they provide several characteristics of a complex system, including: many interactions between many simple components; highly structured component inter-relationships; the system changes through time; ill-defined boundaries; emergence; non-linear behavior (or path dependency); sensitivity to initial conditions. Pippenger (Pippenger, 1978) notes that complexity emerges not from the individual components, which are often very simple, but from the intricacies of their interactions. Radford (Radford, 2008) concurs with the ideas of Geller (Geller, 2011) when he explains in more detail that emergence is the "interactions of new variables that could not have been predicted from circumstances prior to the interaction." This last characteristic highlights one of the key problems in working with mathematical models of complex systems: not all the variables can be known or calculated in advance; as such, a different approach to complex systems may yield the desired insight, especially if it examines the system as a whole. This characteristic is one further explanation for the real-world shortcomings of the complicated models discussed previously—one can not account for variables one can not be aware of.

One type of model that embraces complexity while remaining understandable is the agent-based model. Andrei and Kennedy (Andrei and Kennedy, 2013) demonstrate how agent-based models are a useful tool for analyzing complexity, while Gilbert and Troitzsch (Gilbert and Troitzsch, 2005) explain their utility in policy making. Due to their utility in facilitating understanding complex systems, I used an agent-based model to simulate a group of nations working for or against a common objective, and compared that with the results one would reasonably expect if the same inputs were applied to MIDLIFE or a similar framework. Although there are many suitable programming languages and tools for using ABMs, NetLogo is sufficiently robust, and adequate for this model. This model was built using NetLogo 6.0.4 (Wilensky 1999), and utilizes some of the inherent characteristics of NetLogo in driving interpretation of the model, such as color, shape, and movement of agents.

MODEL DESCRIPTION

The model works by simulating two different scenarios simultaneously, each of which involves a directional number of forces trying to move an object in their desired direction. The difference between the two scenarios is that one object is affected by scalar forces, in one dimension (the y-axis), while the other object is affected by vector forces, in two dimensions (x-axis and y-axis). The scalar object represents traditional means of assessing national power, while the vector object represents a different approach, which illustrates the complexities of the international system. The forces could be considered allies working together, but with their own overall objective. The spatial difference between the vector and the scalar object illustrates how each force having their own objectives versus having the same objective affects the overall system.

At setup, the user selects how many forces will act on an objective (from 2-30), and selects which, if any, of the following three options will be applied: *Momentum*, *Weak Effort*, and *Short Duration*. Once the initial conditions are set, the model creates half of the number of forces, and assigns them to the Scalar object, with the objective of moving the object upwards. Next, these forces are duplicated in magnitude, and assigned to the Vector. Additionally, each force is given a vector, or angle through which the magnitude of the force will act. Next, the other half of the forces are created, and assigned to the Scalar object; each of these has the objective of moving the object downwards. These forces are then duplicated and assigned to the Vector object, with the same magnitude as the original forces, but with a vector. Finally, if any of the options for *Momentum*, *Weak Effort*, or *Short Duration* have been selected, the affected forces are assigned here; each vector force (or agent) has a 20% chance of being affected by the selected options. Forces affected by *Weak Effort* have their magnitude reduced by half, while those affected by *Short Duration* and *Momentum* will be affected at certain times as the model runs. A flowchart showing the logic flow of the model is found in Figure 1, Model Internal Logic.

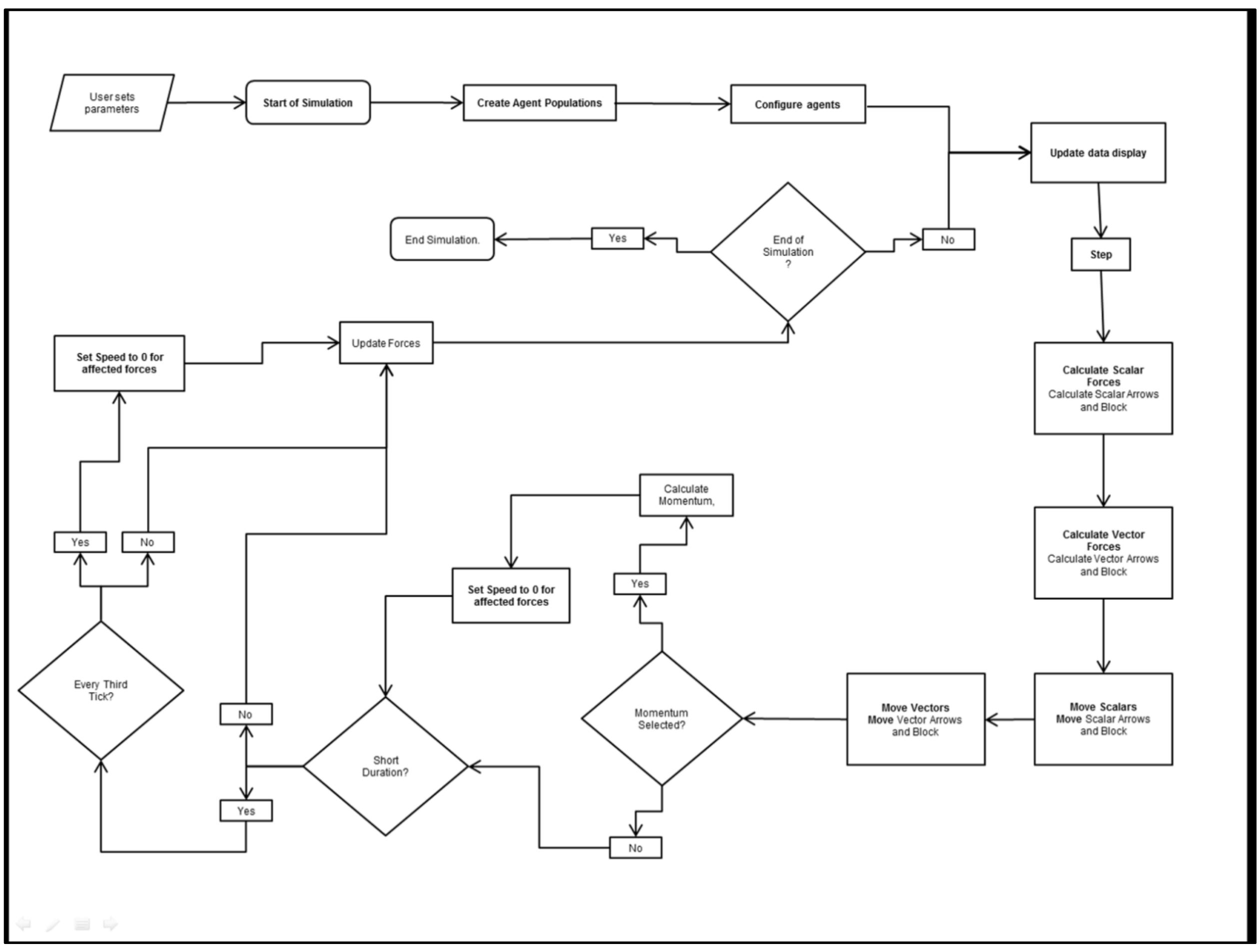

Figure 1. Model Internal Logic

With the agents created, setup is complete, and the model runs. For each tick of the clock, the model calculates the sum of the scalar forces on both sides of the object, and prepares the object to move either up or down, depending on which direction has the greatest total force. For the vector object, forces are summed in both the x-axis and y-axis, using sine and cosine functions of the angle and the magnitude of the vector to decompose the vector forces to their x- and y-axis component parts. Then, an angle of movement is calculated, and the block is ready to move in this direction. The next step is to move the scalar object and its accompanying forces, and then to move the vector object with its forces. If *Momentum* is active, it applies to the last three movement angles of the vector object; if these are more than +/- 90 degrees from the affected forces' desired direction of movement, the magnitude of the force is set to zero, and it ceases to be an active participant. If *Short Duration* is active, it is factored next. This applies on every third tick; affected forces have a 50/50 chance of either dropping out of the effort, or continuing. Finally, each element in the simulation is updated, and prepared for the next tick of the clock. The simulation runs until it is stopped by the observer, which is when either of the objectives reaches one of the edges of the screen. Then, the observer can see the final x and y values of the vector object, and the y value of the scalar object. This enables the observer to calculate the spatial difference, and mathematically show how different the results are when using two-dimensional vectors instead of one-dimensional scalars, to calculate the results of an international policy.

As noted by Geller, two important aspects of using ABMs are validation and verification (Geller, 2011). Verification is confirming that the model is coded properly, and running free of logical errors. Validation is that the results are consistent, and as intended, even if not always as expected. This model ran properly, and produced consistent results, and thus meets Geller's requirements.

RESULTS

As noted in the model description section above, this model accepts any number of agents between 2 and 30; for the data gathering phase, this number was set to 20, because that is the approximate number of states one sees in a region of the world. A larger number of possible agents could be built into the model, but a simulation of the entire world would require additional rules governing the interactions between agents, and it seemed prudent to have a model work at a regional level prior to scaling it up to the global level. Instead of varying the number of countries, the model was run with different settings for *Momentum, Weak Effort,* and *Short Duration*. With three binary choices (Off/On), this presents eight possible conditions; the model was run 10 times under each condition, with the results for the series of run for each condition averaged together, as shown in Table 1, Table of Default Results.

Table 1. Table of Default Results

Momentum	Weak Effort	Short Duration	Average delta x	Average delta y	Average distance
Off	**Off**	**Off**	20.47	18.19	29.09
ON	**Off**	**Off**	19.77	25.70	33.93
Off	**ON**	**Off**	14.92	18.75	27.58
Off	**Off**	**ON**	19.58	23.71	33.05
ON	**ON**	**Off**	16.15	7.43	18.47
ON	**Off**	**On**	22.04	16.95	28.64
Off	**ON**	**ON**	23.73	22.44	34.18
ON	**ON**	**ON**	22.49	26.35	35.64

Delta y values were calculated by finding the difference between the y-axis values of the vector object and the scalar object. Results for delta x were obtained by subtracting the final x-axis value of the vector object from its original position; as the scalar object does not move in the x-axis, any variation in x-axis value would be due to the two-dimensional nature of the vector object. As on a Cartesian coordinate system, distance was calculated as shown in equation 1, where d is distance, and x and y are the values for delta x and delta y, respectively. Average distance, as

$$d = \sqrt{x^2 + y^2} \qquad (1)$$

shown in Table 1, is the average of the distance calculated for each run in a series; it may be noted that this number is a slightly higher than if it were computed based on the average values for delta x and delta y. Average distance demonstrates how much the results of a complex system would vary compared with a more traditional model that ignores the complexity of the international system, and attempts to reduce it to a series of mathematical equations. For example, if the United States were to implement sanctions on country (e.g. Iran), traditional theory would indicate that to calculate whether this action would be effective, it is only necessary to calculate the relative power values of both countries, plus allies for both; whichever side has the larger value is more likely to prevail. However, the ABM takes into account the fact that different countries may have different objectives, or maybe not be willing to exert the full measure of their power (*Weak Effect*, in the model), or may only be willing to exert pressure for a limited time (*Short Duration*, in the model), or may only exert pressure if things are going their way (*Momentum*, in the model). The drastic difference between what is expected in the standard model, and the actual results, can be observed in Figure 2, Typical Results. In this figure, the blue block represents the traditional, one-dimension model, with forces pushing it from above and below. The trailing line shows its initial position, and how it arrived at its goal. The red block represents a two-dimension model, with forces acting as vectors i.e. multiple goals, which mostly align with the overall objective. Again, the trailing line shows where it started, and where it ended up. The fact that the red block has moved in a completely different direction than the blue block is an example of how drastically actual results can vary from standard model predictions.

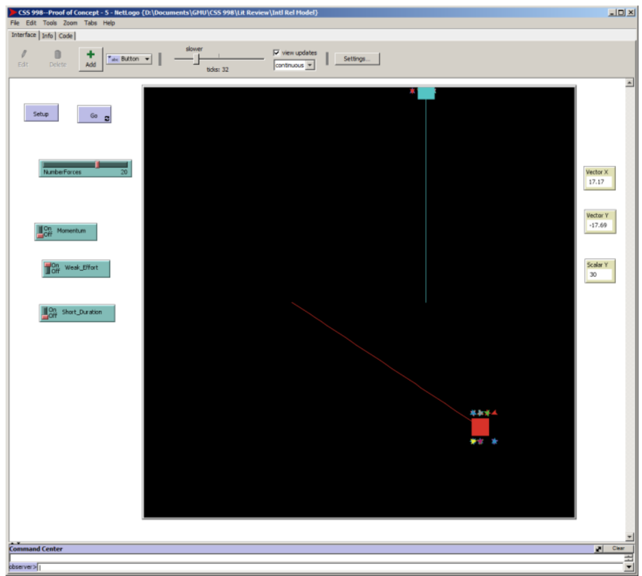

Figure 2. Typical Results

This is not to say that every run of the model resulted in such drastic differences; there were, in fact, a number of instances where the red block ended up at least heading in largely the same direction as the blue block, indicating that the traditional model possesses a certain level of accuracy. Of course, if the traditional model was never right, it would be discarded, so this is hardly unexpected. However, while such runs occurred, they were not very common.

A more dramatic result is shown in Figure 3, Things Take a Sudden Turn. In this example (which is larger than Figure 2 to clarify the details), the red block starts to move in almost exactly the same direction as the blue one, indicating that the countries on each side of the issue are in agreement with how things are working, and things are going as predicted. However, just as happens from time to time in the real world, something unexpected happened. In this case, both *Momentum* and *Short Duration* are turned on, so it is not clear which had the greater effect, but the end result is that, after a short time, one or more countries ceased to be an active participant in the effort, and things went dramatically different than they had been. The red block does not reverse course, but it ceases to make significant upward progress, and ends up with a completely unexpected result.

Expecting The Unexpected

As this example illustrates, unexpected actions by individual actors can have dramatic results; however, this type of action is not accounted for in traditional models. Not only are participants in traditional models acting with the same purpose, or toward the same objective, they continue to use all the full measure of their power, and do not change their mind. Of course, we know that state actors often change their minds, due to a variety of reasons, or say they are supporting an objective, while exerting only partial (if any) effort. These possibilities were captured with *Momentum*, *Weak Effort*, and *Short Duration*; what is instructive is the effect each one of these variables has on the system as a whole, and in conjunction with each other. As can be observed from Table 1, the greatest effect of these three variables was found when all three were active; this should hardly be surprising, as they all have the potential

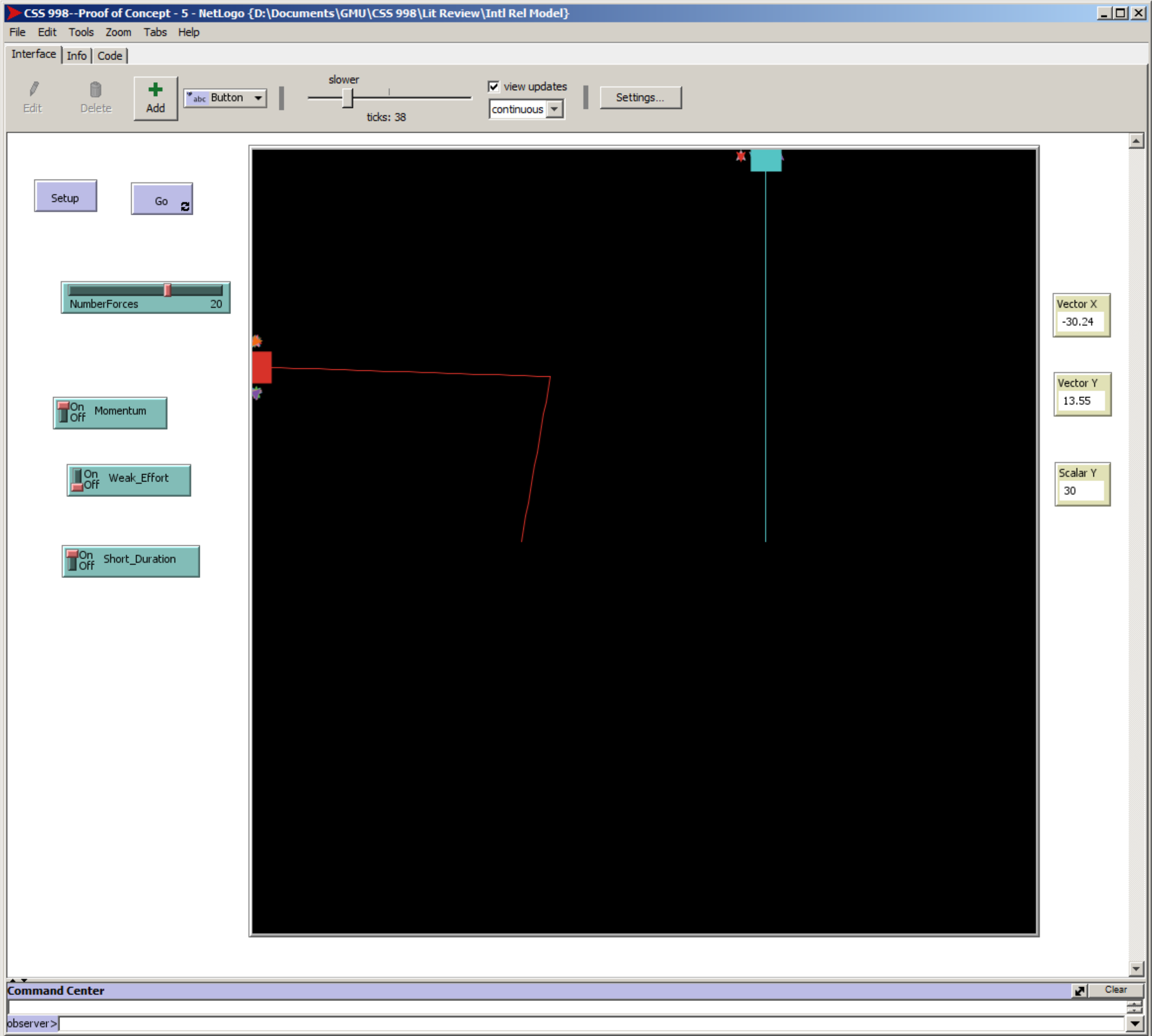

Figure 3. Things Take a Sudden Turn

to dramatically affect the outcome. What is perhaps surprising is the combination that had the least effect, namely, *Momentum* and *Weak Effort* set to ON, with *Short Duration* Off. However, an examination of the overall data provides an explanation. *Weak Effort* has the lowest individual effect of the three variables; however, it also has two of the three highest values for delta-y for individual runs. This demonstrates that it has the most extreme effect on the system. This can be explained because of the duration for which each individual variable affects the system: *Weak Effort* acts on the affected force throughout the entirety of its run, while *Momentum* and *Short Duration* only apply after at least three cycles/ticks have elapsed, so neither can act for the entirety of the individual run. In this way, *Weak Effort* represents an actor who agrees with and commits to a proposed course of action on the international stage, but then fails to follow through on that commitment.

CONCLUSION

Theoretical frameworks in IR and national security work because they help make sense of the world around us, and help explain the actions of actors in the international arena. Their primary strength is that they can be easily taught and understood, and the mathematical parts of them can be readily quantified or calculated, even by non-experts.

This makes them approachable to a wide audience, potentially leading to many people working together on and dealing with a single issue, which is particularly important during times of crisis. They also possess sufficient accuracy to continue to be used, but they do have their limitations, particularly in addressing sudden changes, unexpected actions, and dealing with multiple objectives from individual actors. In an ever-changing world with rapidly increasing complexity, a different approach that embraces that complexity may provide better insight to decision makers. ABMs are one of the best tools to address complexity, as they account for emergent behavior, which no mathematical model or theoretical framework can. They can also deal with multiple objectives held by different actors, and can treat actors in two, three, or even more dimensions, rather than just one. Instead of calculating a sea of variables for each actor, ABMs work by working with the entirety of an actor instead of that sea of variables, requiring only that the total effect be known, rather than the individual components account for, addressed, and calculated. They also show how interactions may change over time, rather than just one snapshot, as in static, one-dimensional models. Finally, as computer models, they can be run multiple times, which allows the effect of different policies or actions to be predicted, especially unexpected results. Where a traditional model does not deal with the unexpected, an ABM does, and can show a result that not only was unexpected, but hadn't even been anticipated as a possible result.

While far from perfect, the model used in this paper provides a readily understood look at complexity in IR, and demonstrates the potential of ABMs for greater insight than that provided by traditional models.

REFERENCES

Alcock, N.Z., & Newcombe, A.G. (1970). The Perception of National Power. *The Journal of Conflict Resolution, 14*, 335-343.

Andrei, A.L.,& Kennedy, W.G. (2013). Agent-Based Models And Ethnography: Combining Qualitative And Computational Techniques With Complexity Theory. *Practicing Anthropology, 35*, 29-33.

Cartwright, J.E. (2015). Best Military Advice. *Strategic Studies Quarterly, 9*, 13-17.

Dyer, C. & Dyer, G. (1960). Estimating National Power and Intentions. *The Annals of the American Academy of Political and Social Science, 330*, 145-155.

Geller, A. (2011). The Use Of Complexity-Based Models In International Relations: A Technical Overview And Discussion Of Prospects And Challenges. *Cambridge Review of International Affairs, 24*, 63-80.

Gilbert, N. & Troitzsch, K. (2005). *Simulation for the Social Scientist. 2nd ed*. New York: Open University Press.

Hall, W.M., & Citrenbaum, G. (2010). *Intelligence Analysis: How to Think in Complex Environments*, Santa Barbara, California, Denver, Colorado, Oxford, England: Praeger Security International/ABC-CLI, LLC.

Hall, W.M., & Citrenbaum, G. (2012). *Intelligence Collection: How to How to Plan and Execute Intelligence Collection in Complex Environments*, Santa Barbara, California, Denver, Colorado, Oxford, England: Praeger Security International/ABC-CLI, LLC.

Harrison, S., Massey, D., & Richards, K. (2006). Complexity and Emergence (Another Conversation). *Area, 38*, 465-471.

Kim, H.M. (2010). Comparing Measures of National Power. *International Political Science Review, 31*, 405-427.

Miller, J., & Page, S. (2007). *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton, N.J.: Princeton University Press

Pippenger, N. (1978). Complexity Theory. *Scientific American, 238*, 114-125.

Radford, M. (2008). Prediction, Control and the Challenge to Complexity. *Oxford Review of Education, 34*, 505-520.

Raphael, T.D. (1982). Integrative Complexity Theory and Forecasting International Crises: Berlin 1946-1962. *The Journal of Conflict Resolution, 26*, 423-450.

Rosenau, J.N. (1999). Many Damn Things Simultaneously — at Least for Awhile: Complexity Theory and World Affairs. *Theoria: A Journal of Social and Political Theory, No. 94, Governance and Globalisation*, 48-66.

Sawyer, R.D. (1994). *Sun-Tzu: The Art of War. Translated, With Introduction and Commentary by Ralph D. Sawyer.* New York: Barnes & Noble Books

Scartozzi, C. (2018). A New Taxonomy for International Relations: Rethinking the International System as a Complex Adaptive System. *Journal on Policy and Complex Systems, 4*, 109-133

Simon, H. (1996). *The Sciences of the Artificial (3rd ed).* Cambridge, Mass.: The MIT Press.

Slaughter, A. (2017). *The Chessboard & the Web: Strategies of Connection in a Networked World*, New Haven and London: Yale University Press.

Stoessinger, J.G. (1968). Power And Elements Of National Power. *Naval War College Review, 20*, 11-27.
Wilensky, U. (1999). *NetLogo*. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL
Worley, D.R. (2015). *Orchestrating the Instruments of Power: A Critical Examination of the U.S. National Security System*, Lincoln, Nebraska: University of Nebraska Press, Potomac Books.
Yetiv, S. (2011). History, International Relations, and Integrated Approaches: Thinking about Greater Interdisciplinarity. *International Studies Perspectives*, *12*, 94–118.